A Nuclear-Powered Green New Deal: an ex-insider's explanation of why the USA sorely needs but hasn't implemented one*

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Introduction

I'm a retired 77-year-old, US National Laboratory "Consulting Scientist" (chemist, chemical engineer, and finally, self-taught radwaste materials expert) who spent much of his last ten years at Idaho's National Engineering Laboratory trying to "whistle blow" about how the USA's radwaste management programs were and apparently still are being mismanaged (see several of this book's APPENDICES). This book is a much-expanded revision of 2019's "Nuclear Power: Policies, Practices, and the Future" (Wiley-Scriveners) describing the whys of powering the world with a sustainable nuclear fuel cycle, what accomplishing that would entail, & the reasons why it hasn't already happened. Since then, almost three years' worth of constructive interactions with Dr. Alex Pavlak 's little group of mostly also-retired professional engineers (*www.futureofenergyinitiative.org*) has taught me much more about the energy business. "Nuke-world" itself has also undergone enough changes to justify a redo. Another difference is that it's now "too big" (~280,000 words, profusely illustrated - 93 figures , 20 tables, and 53 APPENDICES), contains lots more footnotes & worked-out examples, and "homework" problems[1]. It's also politically incorrect, names names, & punctures balloons.

What are the consequences of what's been going on? Because we didn't nuclearize our energy supplies when we could have readily done so, today's (September 2022) war between the "West" and Asia's predominant petrostate, worldwide "food insecurities", more and bigger hurricanes, and widespread droughts, our leaders' choice isn't between gas or rewewables – it's between gas or coal. A just released international State of Climate Action 2022 Study concludes if we are to avoid the most catastrophic effects of the climate crisis, the developed world's consumption of meat should be reduced to the equivalent of around two burgers a week, and fossil gas must be replaced rather than continue to rationalize the growth of today's renewable energy. Industry. That report also recommended expanding public transport and phasing out coal six times faster than is currently happening. rates.

Researchers found over half of the indicators key to halving global greenhouse gas emissions by 2030 were not making the necessary progress.

One of the scientists behind the report said: "."Our civilization's eminently predictable energy-related emergencies are greasing the wheels for further growth of the LNG industry. Unfortunately, a 2020 analysis by the Natural Resources Defense Council (NRDC) concluded that the extraction, transportation and liquefaction required to export LNG creates almost as much greenhouse gas (GHG) emissions as does burning it. In other words, LNG's greenhouse

[1]It's already been used as a textbook by one of my Idaho National Lab ex -bosses who went on to become GE Hitachi's stateside technical lead and President of the American Nuclear Society, He also teaches nuclear engineering while "resting" after work.

gas impact is only modestly smaller than that of other fossil fuels. A key problem is that gas drilling, transport, and liquification both requires and leaks vast amounts of a greenhouse gas far more effective at trapping heat than is carbon dioxide with the latest incident involving two Russian gas pipelines under the Baltic Sea at the heart of the much-exacerbated energy crisis caused by Putin's Russia invading the Ukraine.

Climate campaigners are continuing to argue that the US and Europe should invest heavily instead in renewable energy such as solar and wind, to help negate future price shocks as well as slash emissions. What almost all of them refuse to either mention or admit is that their own multidecade-long campaign against nuclear power is responsible for the situation that we find ourselves in.

What's really happening is that an already rich petrogas industry is seizing the moment to force the world's decision makers to double down on the same mistakes that have led both them and us to this situation [How the gas industry capitalized on the Ukraine war to change Biden policy | Gas | The Guardian] .

It was inspired by the fact that I've always questioned anything that sounded "fishy" to me which attitude eventually led to the employer backlash/retribution that finally persuaded me to retire early (at 62)[2]. I am aware of the fact that some of the things that I've done, said, and written raise peoples' hackles. I'm also aware of the fact that most of the USA's "technical people" including its "public servants", don't question anything fishy-sounding while they are still working. They/we are/were supposed to be nonjudgmental idiot savants, never volunteering opinions, or poking our noses into more "important" people's business[3]. In particular, anyone wishing to be successful within the DOE complex never associates him/herself in a traceable fashion with troublemakers like I eventually became. I've come to understand the reasons for that & don't even mind it too much anymore (see APPENDIX XXXV).

"If you're going to sin, sin against God, not the bureaucracy; God will forgive you, but the bureaucracy won't."

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[2] Because of my whistleblowing, the Idaho then new management and operations (M&O) contractor took away "my" lab and wouldn't let me do any real work anywhere else either. That lab and everything in it was then destroyed (returned to "greenfield status") by INL's then also-new "clean up" contractor on a $/m^2 basis (DOE's managers like to measure their contractors' progress in terms of easy-to-visualize metrics like weights, heights (low, high, intermediate, etc) , areas, and volumes.)

[3]] Unlike most animals, we humans live in a world of our own "feelings" which in turn are mostly determined by what we already believe, i.e., "faith". That faith may be in a principle, e.g., "greed is good", "my boss is always right", our interpretation of "God's wishes", our political tribe's talking points, or anecdotal experiences. That's why we often seem to be oblivious to things that are immediately obvious to "dumb" creatures like dogs, cats, and people who aren't "good team players". The latter is what I've always seemed to have been - the little gunboat that sails up between two armadas and starts to blast away in both directions.

Hyman Rickover

This book isn't just another review of nuclear power's history or summary of other people's opinions about what's currently going on. For the most part, those efforts/opinions will be summarized, and "open access" references given so my readers can read them themselves which I strongly encourage. It is also autobiographical, somewhat rambling, sometimes funny, occasionally profane, and everywhere seeks to encourage its readers to do the same thing that has guided its author throughout his life: "*think for yourself and do it with numbers*"[4]. The biggest difference between this book and those written by others sharing my enthusiasm for nuclear power (e.g., Angwin 2020, Rhodes 1993, Cravens 2007, Moore 2011, Till 2011, Bryce 2010, Bryce 2013, Bryce 2010, Beckers 2016, Beckers 2017, Crane 2010, Erickson 2019 & Goldstein 2019), is that I'm a technical "insider" who has managed to retain his sense of humor while becoming aware of that industry's foibles as well as its strengths.

While I will be identifying the reasons why a properly implemented nuclear renaissance could address what's shaping up to become a dismal future's technical issues better than could any combination of currently politically correct renewable energy sources and imaginary "batteries", it won't dwell exclusively upon the downsides of those alternatives – it'll be pro nuke (not pro nuke ***industry***), not anti-anything other than the cultural pathologies rendering significant progress on solving any "controversial" technical issue almost impossible here in the USA. I don't "hate" renewables[5] – I do hate foot-dragging, liars, cheats, crooks, and hypocrites.

My goals include:

Showing readers, hopefully including some bright, still both willing & able-to-learn, young people[6] what really needs to happen via lots of accessible references, worked-out examples, and homework problems.

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[4] The reason for this is that many ideas/claims that initially appear to be perfectly reasonable prove to be unreasonable when examined quantitatively- in the real world, size matters. Most advertising – one of the especially lucrative white collar service industries that replaced many of the USA's manufacturing jobs - relies upon most peoples' reluctance to GOOGLE–up facts and do their own thinking & ballpark calculations. "*Calculate before you decide, GOOGLE before you calculate, & think before you GOOGLE"* (me).

[5] I can understand how solar panels make sense for some rich peoples' homes, people living in RVs, or anyone temporarily camping out in the wilderness. The real problem has to do with addressing all – not just a part - of everyone's energy issues indefinitely in a way that could work - not championing technologies capable of dealing only with "special", "small", "micro", or convenient problems. That's my primary bitch about how US DOE has focused its/our resources.

[6] This book's last APPENDIX is Greta Thunberg's message to the folks attending this year's international "Conference of the Parties" (COP 26).

- Try to convince my ex-colleagues at the USA's national laboratories that they must "get serious" about rendering nuclear power "renewable" (sustainable).
- Remind them that there's a pretty good chance of succeeding if they screw up enough resolve to pull their heads up out of their leaderships' drawers.
- Explain why the US federal government's nuclear engineering (NE) experts have not yet done "the right thing" with respect to developing practical solutions to the world's nuclear energy conundrum.

To support my often-controversial contentions I will present examples of my and other peoples' experiences with some of the USA's (DOE's) nuclear-related projects because specific numerical examples, not arm-waving generalities or anecdotes, support "technical" contentions. Like those in David Mackay's iconic book "*Sustainable Energy: Without the Hot Air*" (Mackay 2009), my examples will be numeric (quantitative) and based upon reasonable assumptions and readily obtained (GOOGLEable) data, not sweeping generalizations, oversimplifications, or the sorts of wishful/magical thinking often reflected in disquisitions invoking renewables powered utopias. I will also be putting the results of my examples into perspective: "naked" numbers – especially, very large or very small numbers often accompanied with unfamiliar units – often confuse even experienced scientists and engineers. Doing so will undoubtedly offend many of my pro-nuclear colleagues because most of the "advanced" reactor concepts they are currently championing are far less "equal" than others (Orwell 1945).

The discovery of nuclear energy represents one of humanity's greatest technological leaps equaled only by the invention of flint-chipping, fire, steel, concrete, electricity, and heat engines. Those breakthroughs were not just new tools or another way of doing the same thing. They rewrote the rules and couldn't be understood using the same terms extant before their invention. Collectively they rendered today's civilization, industrialization, and mechanized transport possible. Replacing fossil-fueled electrical power plants with "sustainable" nuclear power would eliminate about one third of the USA's greenhouse gas (GHG) emissions. Switching to battery-powered electric vehicles charged with more nuclear power would eliminate another third. Finally, supplying most of the entire world's residential, commercial, and industrial heat demand with nuclear-generated waste heat, electricity, and hydrogenated synfuels would make it a much cleaner, safer, and "happier" world for our descendants.

No combination of today's renewable power/energy sources and "batteries" could meet 100% of any modern civilization's power demands. They would have to be backed up by more reliable power plants, which today mostly means coal or natural-gas powered turbines. If we try to "electrify everything" as we should (EVs & trams for people transport, heat pumps for home heating, and so forth) the demand for electricity will grow even faster and today's renewable energy sources will inevitably fail to meet it. It'd be nice if wind, solar, and bio renewables could power us forever but will remain as much of a pipe dream as was Hitler's Thousand Year

Reich until someone invents a grid scale battery two orders of cheaper than are those being installed today to profit from arbitrage[7].

Unfortunately, human decision making is mostly hope, faith, and laziness-driven meaning that many of us choose to believe that building lots more of today's favorite "renewables" could solve everything. That notion is reinforced by the technical experts being paid to come up with models/predictions consistent with whatever their customers wish to hear. Providing such reassurances is a good way for an expert to get attention and make some money but won't change Mother Nature's behavior.

The biggest barriers to implementing both hers and the once-obvious-to-us-humans solution to the world's energy related problems (Hubbert 1956, Perry and Weinberg 1972, Goeller and Weinberg 1976) – a sustainable "nuclear renaissance" - are posed by our, not our "Mother's", nature. DOE NE's interminable studying, modeling, "road mapping", & safety/radwaste boondoggling keeps some of its pet technical experts busy and apparently satisfies its political masters, contractors, and other industrial partners but doesn't prove anything to the degree required to implement anything "controversial". It also wastes so much time and money that many of the western world's intelligent outsiders have concluded that a nuclear solution to their & their children's energy issues is impossible.

This rewrite goes into the nitty gritty of how today's unsustainable nuclear fuel cycle works and how a nuclear renaissance implemented with a "renewable" fuel cycle could and should address the root causes of most of mankind's economic, environmental, and social issues. I'll first try to explain why nuclear power should and likely could become the world's primary energy/power source and then point out why it has become so difficult to implement a "nuclear" technological fix for its energy & environmental conundrums. The point that I'll be repeatedly making is that there's no good reason for almost everything we need to do here in the good ol' USA to have become as constipated with "wicked" problems as is the case now. Those reasons boil down to 1) the USA's leadership's decision to "privatize" most of its government's responsibilities and 2) that most of their constituents – normal humans - have short attention spans and are naturally both lazy & don't like to raise a fuss (cowardly). Consequently, our society's "wolves" have learned that if they take almost everything of value away from the rest of us slowly enough, their victims won't even notice that they are being fleeced. One of the ways that that wolfpack ("the 1%") does this is to keep everything that's "technical" so complicated by offering

[7] This means temporarily storing a privatized electrical grid's energy when it's cheap and selling when it back when demand spikes therefore raising its price.

the sheep lots of "choices" none of which are good[8] that it takes a politically autistic technical nerd like me to even recognize what's happening.

The western world's privatization of nuclear power is one of the reasons that it has become too expensive to build any sort of new reactor. For instance, that industry has recently published many press releases having to do with the hows, whys, and estimated costs of a bevy of "small modular reactor" concepts (see http://smrstart.org) suitable for unsustainably serving niche markets in regions served by energy suppliers competing with other suppliers of the same fungible product.

There has been an immense amount of hype, and considerable nonsense written about Small Modular Reactors. When you are trying to solve a problem as big as the Gordian knot, the closely coupled issues of electricity poverty and planet heating, small is not beautiful. There are strong economies of scale in nuclear power generation. Any solution that does not recognize this will be hopelessly wasteful. But it is also true that we must take advantage of the order of magnitude improvement in productivity and quality associated with assembly line manufacture, as compared to conventional on-site construction. What we need are Big Modular Reactors, the biggest reactors we can build on an assembly line.

Jack Devanney 14Dec2022

As usual, Jack is right about this too. Also, as usual DOE NE experts apparently remain more interested in emphasizing/maximizing adjectives (e.g., "smallness") than in facts or addressing real problems.

A common theme throughout such reports is the assumption that private utilities would be responsible for building/owning/fueling reactors. That along with the fact that anything having to do with them is over-regulated by technically clueless bureaucrats that don't answer to anyone other than their politically driven bosses, is the reason that build costs have gotten as far out of whack as they have. In the US no person or institution is responsible for seeing to it that what must be done to benefit everyone happens.

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[8] For example, the purveyors of each of the USA's energy products seem to favor the use of special units peculiar to their business. In the natural gas business, your monthly "energy bill" may be based upon your consumption of whatever was piped into your house in terms of kilowatt hours, joules, therms, BTUs, MBTUs, "standard" cubic feet, "standard" cubic meters, horsepower hours, ergs, or electron volts. Similar situations obtain in its liquid energy type product businesses (e.g., raw petroleum in terms of 42 US gallon barrels, BTUs, Joules, or quads, gasoline in terms of gallons or liters, jet fuel in tons, propane in pounds, etc.). DOE's/EIA's energy gurus often choose to use different units than those you see in your utility bills. The common feature is that individual retail customers pay much more per unit of their product/service than does the distribution utility itself or its "big" customers.

In this book I'm assuming that people working for the "state" (federal government) would be empowered to take on the responsibility of contracting, building, owning, running, and regulating the USA's energy supply system for the sake of its citizens & their environment. That's how "infrastructure" like the TVA's dams and the interstate highway system got built on time/budget back before the USA stopped producing much of anything other than "cash crops" commodities, rules, restrictions, limits, paperwork, obstacles, and social networking superstars; i.e., back when America was "great" for everyone who wasn't born "black" or female.

One reason for this is that the USA's technical experts are often paid to "study" the wrong questions. The issue here is not whether an energy producing technology could be endlessly but erratically fueled by sunlight, wind, and water—but rather if it is "*clean*", reliable, scalable (potentially big enough), sustainable, and affordable. If we are genuinely serious about "saving the world", we should be choosing to "study" technologies that could deliver the biggest environmental benefit at the lowest possible cost, not crippling ourselves with unnecessarily high prices, senseless regulations, and the notion that whatever we end up doing must be "small", invented by our own tribe, and not "nuclear".

The most realistic way for us to kick our fossil fuels addiction to would be to implement a sustainable nuclear renaissance capable of meeting the energy needs of a bigger, cleaner, and much fairer world. Fission-based nuclear reactors utilizing any sort of once-through nuclear fuel cycle regardless of how "advanced", "modular, "or "small", its reactors happen to be can't serve that purpose because fueling them would be impossibly expensive over the long haul[9]. This means building roughly 20 thousand big, affordable, breeder-type reactors coupled with the recycling/reprocessing systems required to render their power sustainable (aka, renewable). Since most of the rest of this century's anthropogenic greenhouse gas emissions will be generated by countries neither able to overpay for energy nor undertake another "Manhattan Project" to develop their own sustainable nuclear fuel cycle, today's technologically advantaged countries have the responsibility of doing so.

Once through-type nuclear reactors can't "save the world" because it's impossible to build them in a way that "burns" essentially all the actinides fed to them. That fact was understood by all of the big thinkers who invented nuclear power (Weinberg, Fermi, Wigner, …) because it was then and still is the only way that their efforts could "save this world"[10]. It was also the assumption

[9] Only about 0.2 percent of the EARTH's natural actinide fuel resources (thorium and uranium) are directly fissionable with conventional reactors. "Perfect" breeders could "burn" the other 99.8% as well.

[10] A hangover from those good ol' days is a convention that a reactor's fuel "burnup" is quoted in terms of the fraction of the total "heavy metals"(actinides) -not just the readily fissionable isotopes- – within its fresh fuel assemblies converted to fission products by the time they've become "spent".

made by the western world industrialists who built the world's commercial fuel reprocessing plants – those facilities would start out by recycling LWR fuel and then gradually switch over to supporting breeders. The reprocessing of "spent" once through-type reactor fuel just to make Mixed Oxide fuel (MOX) to feed back into the same reactors just once doesn't make much sense which explains why it never really caught on.

The implementation of a breeder-based nuclear renaissance would mean that we wouldn't have to consider energy as a limiting resource. It wouldn't have to be conserved because the clean (no greenhouse gas (GHG)) "burning" of the natural actinides in rocks and seawater would then be affordable. We would also not have to destroy the world's remaining wild places and the creatures living therein to generate the food and energy required to keep our civilization going. Energy-wise the natural world wouldn't have to do anything other than serve as a passive heat sink for reactor cooling which service would impact/heat it over two orders of magnitude less than does today's fossil-fueled energy supply system.

Most – not all – of the Western World's climate activists are pushing plans exclusively based upon currently favored renewable energy sources, primarily wind and solar power and imaginary batteries. Unfortunately, their version of a "Green New Deal" is doomed to fail because today's civilization requires reliable power and as I'll demonstrate with "real" numbers, replacing today's fossil fuel dominated (>80%) energy supply with solar panels, windfarms, hydropower, biofuels, and batteries would be both prohibitively expensive and environmentally disastrous.

Today's remaining fossil fuels constitute a finite resource and Mother Nature can't/won't replace them within a time scale relevant to our species. Since most of the "easy" such fuel has already been discovered/mined, it is now and will become ever more expensive as time goes on. Unless something very much like this book's rosy alternative scenario comes to pass, people in poor counties will remain poor and richer nations' "middle class" citizens will riot over cost-of-living increases (especially fuel costs) as has already happened in France, the Netherlands, Mexico, Venezuela, Zimbabwe, Haiti, and Jamaica. Both the obtaining and burning of fossil fuels pollutes the world that we all must share. Because those fuels represent the most efficient/sensible source of the raw materials necessary to make the plastics, lubricants, insulation, fabrics etc., that render the lives of "developed nation" people relatively pleasant, we must quit wasting/burning them just to generate "energy services". Wind and solar power backed up with plenty of batteries is suitable for niche applications like powering the "cabins" back in the wilderness that the super-rich occasionally helicopter-in to visit during trysts, vacations, or pandemics. They are unsuitable (too unreliable) for powering the factories, ships, trains, cars, trucks, farm, and mining machinery, etc., that have brought the benefits of modern civilization to the rest of us.

This means that we must devise/implement something that can provide such power. Because today's nuclear fuel cycle is not scalable (fuel limited), I've been trying to convince both my current and ex-colleagues(?) that we/they must develop/implement a genuinely suitable replacement.

The near future's electrical grid operators will face three big problems.

The first is that because the incoming Biden Administration's almost inevitable barrage of additional windmills and solar panels *should* be backed up with something that is reliable, a likely consequence is more leakage of natural gas from the thousands of new gas fracking, cleanup, transporting, storage, and consumption facilities… see https://www.cnn.com/2021/02/05/us/climate-crisis-texas-methane-emissions-weir-wxc/index.html) required to fuel the therefore necessary barrage of new gas powered "peaker plants. That leakage is apt to be more environmentally impactful GHG-wise than was the carbon dioxide emitted by their coal & oil-fired predecessors.

The second problem is that because batteries capable of rendering an all-renewable-sourced electrical energy system sufficiently reliable are now and will continue to be prohibitively expensive, such sources are and will continue to be primarily backed up by turbines burning natural gas delivered "just-in-time" through fragile pipelines, not stored on site. Many things can and do interfere with natural gas delivery, especially during the winter in regions with grid management systems that refuse to prepare for it, e.g., Texas' ERCOT. Homes generally have priority on the gas within pipelines everywhere which means that gas-fired electrical power plants often shut down when they are most needed – when the wind dies down and clouds roll in during extended cold spells.

The third problem is that individual power grid operators are encouraged to believe that when things get tough, they can always rely upon their neighbors to supply whatever's needed to satisfy their customers. That's not apt to work because the most common cause of such problems is unusual weather which their neighbors are also likely experiencing and will take care of themselves rather than rescuing you/yours. This will lead to widespread blackouts, property damage, misery, and deaths which will likely be blamed on "God" or unimportant-enough system operators who hadn't "followed procedures".

Unlike the "controlled fusion" will-o-the-wisp that has dominated DOE's nuclear reactor development efforts/funding for several decades, there is no doubt that safe, scalable, sustainable, and affordable fission-type nuclear reactors could be built because the Russians have already done it. They have been building/running relevant-sized ("big", not micro, mini, or small), sustainable, breeder-type power reactors (BN-350, 600, & 800) for almost as long as they've been building/ operating/selling the same sort of unsustainable, pressurized water cooled/moderated reactors (VVERs) that the US built to satisfy its 1960's-era power industry's business model. The USA simply hasn't been willing to embrace the right paradigm, do the necessary development, or even admit that other countries have already "done the research".

Russia's political leaders are too smart and their nation is too poor [11] to ignore practical/economic considerations in establishing its technical policies. Besides, they/it aren't as gung-ho about addressing global warming's root causes as we here in the West claim to be because 1) Global warming will likely improve - not hurt - Russia's weather & farmlands, 2)Mr. Putin and his oligarch buddies have been getting richer selling natural gas to the EU, 3) global warming will definitely make it easier for Russia to exploit the Arctic's oil/gas resources as well, 4) they might be able to replace some of their country' relatively expensive nuclear-powered ice breakers with cheaper gas-powered ships, and 5) of course, unlike our country's dear leaders, Russia's don't care about anything or anyone but themselves because "*they're 'soulless commies' just like the Chinese"*.

Since Russia's production of sustainable nuclear power has already been amply demonstrated[12], DOE's reactor R&D priorities should be refocused upon 1) optimizing fuel recycling/reprocessing and 2) determining whether molten salt-type reactors represent an even better solution to the world's energy conundrums – not persist in trying to convince its stakeholders that a few especially advanced and especially "small" (micro?) examples of its nuclear industry's burner-type reactors could render an overall energy system dominated by wind/solar/bio "energy farms" both big enough and sufficiently reliable.

Solving the tough technical problems posed by Mother Nature's rules requires hard work and intellectual honesty – seeking her sometimes-not-obvious opinions regardless of whether it agrees with yours, your peer groups, or your boss's hopes or personal beliefs. It's about finding reasonable solutions, not winning arguments, or pleasing the people funding your research.

It seems that we here in the USA would prefer to keep wringing our hands about "wicked" problems & trying to convince everyone to become more "resilient" than adopt anything designed/made/sold by godless, socialistic, and not-so-"free" foreigners[13].

Although much of what I'll be discussing has to do with the downsides of trying to power everything we need to do with wind and solar "farms", I don't "dislike" those technologies &

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[11] Russia's GDP is officially only about one half that of the state of California's. That's nonsense if consider anything other than each's "service industry" contributions to that figure. In practice, Russia's breeder reactors haven't been operated in ways that render their fuel cycle "renewable" because it's always been cheaper to refuel all of its power reactors with "fresh" enriched U, not with the fissile (mostly plutonium) recovered by its fuel reprocessing facilities.(https://fissilematerials.org/library/insc.pdf.)

[12] Here's a very well-done explanation of how one of Russia's real sodium-cooled breeder reactors works
Nuclear Power Plant virtual tour (Beloyarsk NPP) - YouTube APPENDIX

[13] Our country's energy problems wouldn't remain "wicked" if someone like Admiral Rickover or General Groves had been empowered to solve them. They worked for their country, not for "the industry".

appreciate how they can/could be valuable/useful under some circumstances[14]. I also admit that here in the Western World there is no immediately implementable nuclear alternative to building even more such "farms" if we are to keep the promises that our refreshingly sane-seeming new President is making.

However, the fact remains that doing what must be done would be much easier, much cheaper, and less environmentally impactful if we develop a genuinely sustainable & affordable nuclear fuel cycle by the time that the last of the next few year's new PV panels & wind turbines have bitten the dust 2 or 3 decades from now.[15]

President Biden has promised that America will be "back to normal" soon. Since he is normal, and Trump is almost gone we are supposed to believe that there's nothing to worry about. "Normal" isn't good enough because the USA's dysfunctional political system, triple-digit heat waves, persistent housing shortages, $4/pound apples, rolling blackouts, nine-month-long fire seasons, billionaires paying zero income taxes, rampant voter suppression, 25,000 person-long food bank queues, and hundreds of mass shootings every year, shouldn't be "normal".

Returning to the status quo before the more easily led, almost-half of the USA's electorate succeeded in electing their uber-champion six years ago means accepting a planet that's burning up, a broken economy, and governmental policies/actions consistent with the wishes of undertaxed, deregulated, selfish billionaires[16]. Because we're no longer able to build nuclear

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[14] For instance, last summer I tried to suppress my swimming pool's algae growth with a homemade "copper ionizer" powered by a 1.5-watt, $15 solar panel (it did rapidly corrode its copper pipe anode but doing so didn't kill the algae). Holland has lots of reliable windmills and has been using them for time-insensitive applications like water pumping and grain grinding for centuries. The Dutch were serious about "renewable" energy long before it became a fad. However, they now must and do render their power grid reliable by importing natural gas, nuclear, coal, and hydropower.

[15] Here's an engineering solution (technical fix) to one of the problems I'm discussing – rebuild our houses correctly (also see this book's "homework" problems having to do with solar heating). Though not mentioned in that newspaper article I suspect that the Habitat for Humanity guys putting those things together are also equipping them with moveable window shutters. https://www.abqjournal.com/2443994/foam-sweet-home-ex-habitat-volunteers-help-build-homes-usin. APPENDIX XLIII describes how I'd go about solar powering myself if I were young enough for it to make good sense.

[16] Although I'm an unabashed "liberal", I consider RFD-TV to be the best (most intelligent, realistic, & honest) source of information about the USA's economic, agricultural, and energy systems (check out Scott Shellady's -

reactors or any other sort of big infrastructure related project efficiently, the only immediately available alternative to a massive ramp-up of nuclear power would be to scale up wind and solar energy production sufficiently to provide >80% of our total energy demand (not just electricity) backed up with lots of fracked natural gas some of which will inevitably leak negating any immediate GHG benefit [17]. Other clean energy sources - hydroelectric, wave, geothermal, and biomass - cannot realistically be scaled up to satisfy over ~80% of our industrialized world's demand.

A hugely expensive infrastructure would be required to support that degree of reliance upon such unreliable and land/mineral resource-intensive energy sources. The effort would entail total restructuring of the USA's electricity grid[18] and adding an impossibly expensive amount of electricity storage and transmission capacity.

There's not much sense in just continuing to go along with whatever DOE's nuke experts are saying.

The brutal fact is that we've known about the energy related/driven problems that our kids will struggle with for over 50 years & had succeeded in working out "workable" solutions to them almost that long ago. For instance , Kazakhstan's BN-350 fast breeder reactor situated on the shore of the Caspian Sea first went online (produced electricity) in 1973. In addition to providing power for nearby cities & towns, it desalinated 120,000 m^3 of water/day for local consumption and Russia reprocessed its fuel to supply plutonium for its nuclear weapons program. The reason that it was shut down 26 years later(1997) was that Russia was no longer willing to continue refueling it – not because it no longer "worked".

"The Cow Guy's" - daily "marketing" show). That channel is the USA's first 24-hour television network focused on information about agribusiness and the rural lifestyle, along with lots of traditional country music, entertainment, and patriotic stuff.

[17] For example, Bloomberg/Business Week has recently published several articles describing the spate of anthropogenic methane releases occurring all over the world. Here's one about Romania: Infrared Cameras Detect Methane Leaks Across Romania - Bloomberg

[18] Such a transmission system would entail rebuilding the existing system overlain by a super high powered "interregional highway" capable of moving much-larger-than-average amounts of energy that works electrically and acceptable to landowners and the ratepayers who would be paying for everything. "*The design of a transmission system can't be done until you know what the generation system is going to look like which we don't yet and shouldn't decide upon yet. Every one of these things can be a deal killer which all are at this time. There is absolutely no way to do it yet*   (Gene Preston, personal communication) .

DOE's topmost NE R&D experts have been pretending that that never happened during that same 50 years & are still trying to convince decision makers that we should be building whatever they currently think is "best" (apparently anything that's got TRISO -type fuel kernels in it) irrespective of how unsustainable or too-small it might be.

A properly implemented nuclear renaissance would render most of those changes unnecessary which means that Mr. Biden's Green New Deal planners should be doing their utmost to convince him that rendering nuclear reactors both more affordable and genuinely sustainable, not just "smaller" and more "advanced", should be receiving topmost priority. Addressing the next generation's energy-related environmental, economic, and social conundrums will require over 20 thousand, full-sized (~1 GW_e) , sustainable fuel cycled reactors to power a world-wide "green new deal" like that envisioned by Alvin Weinberg a lifetime ago, not just more "all of the above everywhere" privatized energy muddling that we've been assuming recently. The USA itself will need about 2000 of them. If thinking that way means that I'm a "troublemaker" or "unpatriotic", that's something that I've been called most of my life and never did lose much sleep about because I've always felt the same way that Thomas Paine did about "duty."

"It is the duty of every man, as far as his ability extends, to detect and expose delusion and error"

&

"He who dares not offend cannot be honest".

Thomas Paine

This book's basis scenario is that by circa 2100 AD, that " nuclear renaissance" – not an "all of the above" mix of currently politically correct renewable energy sources with the help of a few additional "advanced" unstainable fuel-cycle "small" nuclear reactors– will be addressing the root causes of most of mankind's misery. Among the wonderful things that it would provide, food production would become genuinely sustainable because cheap/clean electrical power would simultaneously address the world's water woes and enable the mining, grinding, shipping, and distribution of sufficient powdered basalt over farmland to affect Mother Nature's too slow, notoriously unreliable, and sometimes even catastrophic (volcanic) approach to both soil-building and atmospheric CO_2 sequestration. It would also enable the mining, grinding, shipping, and distribution of sufficient ultramafic rock-based sand to seashores and reefs to reverse oceanic acidification and protect us from rising sea levels (Schuiling & Kingsman, 2006).

Weathering is the reaction of an acid (usually hydrated CO_2 , r "carbonic acid") by basic (mafic) rock minerals which converts that CO_2 into the innocuous bicarbonate ion in solution. For the abundantly available magnesium-silicate olivine, the reaction is as follows: $Mg_2SiO4 + 4\ CO_2 + 4\ H_2O\ \ 2\ Mg^{2+} + 4\ HCO3^- + H_4SiO_4$. The bicarbonate solutions are carried by water (creeks, rivers, and eventually the ocean) where they are eventually deposited as travertine, limestone, and dolomitic rockd. Those carbonate rock minerals are Nature's ultimate carbon sink over

1,500 times more than in biomass, fossil fuels, the atmosphere, and seawater combined .(Dunsmore (1992) I

The key advantage of any nuclear power plant relative to a wind and/or solar power plant is that it can provide greenhouse gas (GHG)-free baseload power regardless of what the time of day, year, or weather happens to be. Such a "baseload-capable" energy source could efficiently/affordably meet an advanced technological civilization's around-the-clock demands (aluminum production/smelting, cement & glass making, steel mills, electric locomotives, etc.) as opposed to immediate/peak demands which change according to consumer requirements (for example, when people get home from work, plug in their electric car, and start cooking dinner).

The major downsides of today's civilian nuclear power are its excessive reactor build-costs plus the fact that its burner-type reactors are grossly inefficient[19] at converting the world's natural actinide energy resources to useful power – a fact that renders conventional nuclear power unsustainable (not renewable) & therefore, just another "temporary" energy/power source like fossil fuels are and always have been. The world's nuclear scientists, especially the USA's, must screw up enough courage to eschew their leaderships' current business models and phony assertions[20] and commit themselves to developing a nuclear fuel cycle that renders nuclear power, safe, affordable, and sustainable.

Unfortunately, while his book's[21] clean, green, and "fairer" nuclear-powered world is possible, I do not consider it a certainty because that outcome would require that technical-based reasoning and border-ignoring philanthropy, not "human nature", determines what's done. We here in the Western World are too apt decide to follow our 100% renewables Pied Pipers into the mountain crippling our economies, covering our seacoasts and landscapes with solar

[19] "Inefficient" because well under 1% of the natural uranium mined & processed to fuel today's power reactors is "burned" – the rest is discarded. Likewise, none of today's power reactors are fueled with the world's ~three times more abundant thorium. Since the beginning of the nuclear age, the possibility of fueling reactors with thorium rather than uranium has been attractive even though it's only natural isotope, ^{232}Th, is fertile, not fissile, meaning that reactors fueled with it must first be started up with some combination of ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu, etc. after which they would "breed" (create/transmute) enough new ^{233}U fissile to keep going indefinitely. Thorium's upsides include: 1) ~three times greater natural abundance than uranium , 2) lower mass number meaning that much less of it would be transmuted to the high mass (>238) transuranic (TRU) isotopes responsible for most of any nuclear fuel cycle's long-term radiotoxicity; and 3) unlike ^{238}U it can "breed" with slow moving (thermalized or epithermal) neutrons meaning that appropriately designed reactors could achieve criticality (operate) with relatively small amounts of fissile.

[20] For example, this book will demonstrate that the commonly heard assertion that if we were to simply build enough more of today's power reactors, we could then power everything with seawater uranium is wrong.

[21] and therefore, not necessarily "realistic"

panels/windmills, and gradually sink ourselves so far into debt that we won't be able to afford to buy China's inevitably cheap new breeder reactors.

I'm going to end this introduction with a quote from the polymath, Ann Druyan, who forty years earlier (1980) along with her husband Carl Sagan co-wrote & produced the most iconic television series that I've ever seen, COSMOS.

I feel that I am a member of a civilization that cannot awaken to the challenges that threaten to destroy it. One of the ways to awaken people is to give a dream of what the future could be if we use our science and technology with wisdom and foresight and begin to think in the timescales of science, not the next balance sheet, the next election, but 1000 years from now. Ann Druyan Is Reimagining the Future - Scientific American (March 2020)

One year before he died (1995), she and Carl co-wrote an equally iconic book, "*The Demon-Haunted World: Science as a Candle in the Dark*" to explain the scientific method to laypeople and encourage them to learn critical and skeptical thinking.

I feel that a science nerd's mission in today's world should be to realize the same goal expressed by George Eliot (Mary Ann Evans) Victorian Age writer & poet, almost 200 years ago

"*What do we live for, if it is not to make life less difficult to each other?*"

Notes:

- I've decided to add a GLOSSARY to this rewrite. It is by no means complete but a bit of GOOGLING will unearth the meanings of acronyms that I didn't include.
- One of the reasons that this book has such a negative "tone" in some places is lingering resentment. The reason for that is that I'm a technical nerd who's never been afraid to tackle problems in arenas that established experts have come to consider their bailiwick, e.g., anything having to do with atmospheric carbon dioxide removal, "managing" the USA's reprocessing waste, ferreting out a practical way to implement an appropriate nuclear renaissance, or addressing the USA's "food insecurity" issues, and have therefore had to dodge lots of slings & arrows. What's "worse" is that in several cases I've discovered & then insisted upon pointing out to my bosses, friends, & colleagues that there's a better way of doing something other than that way that's currently considered "best". Already-established experts and their bosses invariably dislike such meddling which has often made it tough to publish my work/conclusions in peer-reviewed technical journals devoted to subjects that I hadn't already become a recognized authority in - that's

one of the reasons why my official publication count will probably never exceed 100[22]. So do their managers, which if they also happened to be in my chain of command, translated to career disenhancement. However, by 2006 I'd managed to save up enough money to retire & thereby become even freer[23] to say & do whatever I wish - mostly think, flyfish, do simple calculations/experiments, & recently, write books about the world's, energy, environmental, and "food insecurity" issues.

- Regardless of why you have decided to read this book, pay attention to its footnotes & try to work out your own answers to its homework problems - some of mine might be wrong. Their/my goal is to enable readers to learn how to put concepts, claims, suggestions, and numbers into proper perspective and thereby enable themselves to make reasoned, not "feelings" or faith-based, decisions about technical things. Anyone able to grasp what they were exposed to in their high school science/mathematics classes along with access to the internet (esp. GOOGLE & Wikipedia) and a computerized spreadsheet should eventually figure out how to do them. Learning how to do "technical stuff" properly is not really tough but does require an open mind and sincere effort.

I do not like to state an opinion on a matter unless I know the precise facts.

Albert Einstein

The world would be a better place if its decision makers, talking heads, and voters took Einstein's sentiments to heart.

If you want to contact me, correct me, or suggest an addition and/or improvement to a future book, feel free to call (208 521 5418) or send me a note (d.siemer@hotmail.com).

[22] The other reasons are that scientific reports must be written in a "conservative" fashion that dilutes their message and most of society's decision makers neither read, understand, nor care about the world's technical literature. Individual scientists are still being taught to believe that their contributions to their specialty's literature is terribly important which simply is not true.

[23] This book's section, **9.8.4 DOE's "ethics training"**, explains why I considered it to be "safe" to become a "troublemaker" while still working. Although they nominally work for private contractors, "site workers" really work do for a "national laboratory" and have special protections if they're willing to use them.

Chapter 1. Basic reactor concepts

Since neutron behavior is key to producing nuclear power, I'll begin this book with a description of them and their reactions.

A neutron is a tiny subatomic particle with no positive or negative electrostatic charge possessing a mass just slightly greater than that of a proton. A cluster of protons and neutrons together constitute the nucleus of an atom which in turn occupies about the same fraction of its total volume as does a "*fly buzzing around within a cathedral*" (Earnest Rutherford circa 1907). Since protons and neutrons behave similarly when within a nucleus and each has a mass of approximately one atomic mass unit (AMU ≈ 1.66E-24 g), they are both referred to as nucleons. Nuclear physics is the discipline that describes their properties and interactions.

An atom's chemical characteristics are almost entirely determined by the electrons orbiting its much heavier (typically >2000 times heavier) nucleus. If one or more electrons is temporarily added to or removed from that "cloud", the atom becomes an ion: a plus-charged cation (e.g., Na^+) if electrons are removed & negatively charged anion (e.g., Cl^-) if electrons are added. The number of negatively charged electrons within an atom - that atom's atomic number - exactly equals the number of positively charged protons in its nucleus. Neutrons do not affect an atom's electron configuration or chemical behavior, but the sum of its atomic and neutron numbers is the mass of its nucleus. Atoms of an individual element differing only in neutron number are called isotopes. For example, the element carbon with atomic number 6 (6 protons)is comprised of an abundant isotope, ^{12}C, with 6 neutrons and a relatively rare isotope (0.016% number-wise) ^{13}C, possessing 7 neutrons. A few natural elements like fluorine consist of only one stable (stable means very long lived) isotope. Other elements like tin may have as many as ten stable isotopes.

The properties of an atomic nucleus depend on both atomic and neutron numbers. With their positive charge, the protons within the nucleus are repelled by the long-range electromagnetic force, but the much stronger, but short-range, nuclear force binds the nucleons closely together. It's this "nuclear force" that renders the energy released by the fission of an actinide atom roughly 100 million times greater (~200 million electron volts or 3.2E-11 J) than is the bond-breaking responsible for a fossil fuel burning's energy release.

Neutrons are required for the stability of all nuclei with the single exception of the unique one-proton hydrogen nucleus. Neutrons are produced copiously in both nuclear fission and fusion. They are a primary contributor to the nucleosynthesis of chemical elements within stars through fission, fusion, and neutron capture processes.

In the decade after its discovery by James Chadwick in 1932, neutrons were employed to induce many different types of nuclear transmutations. Soon after Hahn and Meitner discovered nuclear fission in 1938, it was quickly realized that, if a fission event also produced neutrons as was rather likely ("likely" because the nuclei of the stable isotopes of heavy elements possess a higher proportion of neutrons to protons than does their array of lighter-element fission product progeny (Figure 1), each of these neutrons might cause further fission events in a cascade "chain reaction". Since the prospect of losing another world war was imminent, the Western World's political and technical leadership wasted very little time creating the world's first self-sustaining nuclear reactor (Fermi's "Chicago Pile 1"- 1942), Wigner's Hanford plutonium production reactors - 1943-44, and Grove's/Oppenheimer's first nuclear weapons which were completed & "demonstrated" the year that I was born - 1945).

The key to all of this is the neutron itself. Neutrons are stable when within a nucleus but a "free" neutron (one that's been kicked out of a nucleus) soon decays with a half-life of about 10 minutes to form a proton (hydrogen atom nucleus), a fast moving (energetic) free electron (beta particle), and an antineutrino.

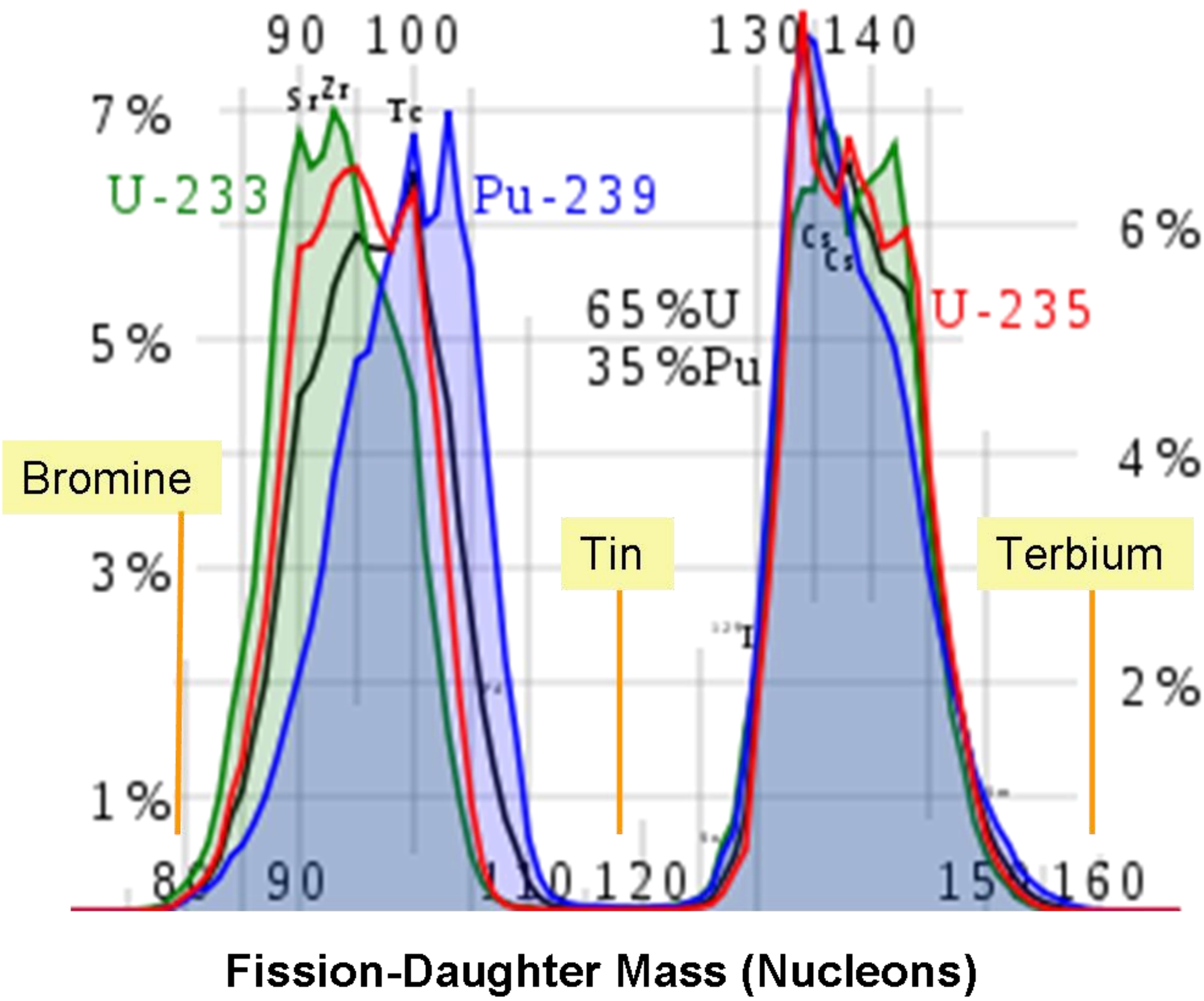

Figure 1 Fissile isotope fission product distributions

However,   in anything other than the hard vacuum of outer space, a free neutron will collide with many atoms before it decays. Most of those encounters will simply change its direction an/or slow it down ("moderate" it) but some will cause it to become trapped/absorbed by/within another atom's nucleus. Such reactions create another either stable or unstable ("activated") isotope of that atom. If it is unstable, that atom's nucleus will spontaneously rearrange itself to become more stable. In most cases that's done by kicking out an electron (beta particle emission) and a neutrino which transmutes (converts) it to its next higher neighbor in the periodic table at a rate characterized by the time required for one half of it to occur, e.g., one half of "neutron activated" ^{23}Na atoms become stable ^{24}Mg within 15 hours (that's ^{24}Na's "half-life") .   If the atom absorbing/trapping the neutron happens to be another fissile isotope (e.g., ^{235}U), its thusly activated nucleus generally[24] splits/fissions to form two entirely different atomic isotopes plus either 2 or 3 new, fresh, highly energetic (fast), neutrons.

- Of the natural world's ~254 stable (existing) isotopes, only one fissile isotope, ^{235}U, is sufficiently long-lived   (~0.7 billion year half-life) to still exist. In today's nuclear reactors, power plants, and nuclear weapons, it may be accompanied with or even replaced by breeder/production reactor-manufactured fissile isotopes, the primary examples being ^{233}U, ^{239}Pu, and ^{241}Pu. The term fissile means that unlike most of their actinide isotope brethren, they are easily fissioned by slow-moving neutrons (possess high thermal fission cross sections) - all actinide isotopes are fissionable to at least some degree in fast reactors.

The reactions utilized to make/breed/produce such new fissile isotopes all involve irradiating "fertile" actinides (e.g., ^{232}Th & ^{238}U with neutrons whereupon their absorption they are transmuted (changed to another element) to the desired isotope.

For instance

$$n + {}^{232}Th_{fertile} \rightarrow {}^{233}Pa + e^- \text{ (beta particle)} \rightarrow {}^{233}U_{fissile} + e^- \text{(beta particle)}$$

$$n + {}^{238}U_{fertile} \rightarrow {}^{239}Pu_{fissile} + e^- \text{ (beta particle)}$$

The term "cross section" represents the probability of something happening (fission, scattering, or transmutation) to an atom's nucleus when a wandering neutron collides with it expressed in terms of a geometric area. If that probability is high (e.g., the probability of ^{235}U being fissioned by a thermalized neutron is about 80%), that nucleus acts like a big target – under those conditions, its cross-sectional area in "barn" units (1E-28 m^2) is large (e.g., ~750 barns) for room-temperature "moderated" (slow) neutrons. Cross sections vary with the speed at which

[24] ~20% of neutron-activated ^{235}U nuclei will decay to form almost-stable ^{236}U (half life ~23 million years).

neutrons are moving because the probability of its interaction with a fixed nucleus is roughly proportional to the time that they are close to each other which is inversely proportional to the neutron's velocity. One of the reasons that most of today's power reactors are moderated is that fissile isotope fission cross sections are very high with slower neutrons thereby permitting operation with a smaller (cheaper) fissile loading.

A moderator's purpose is to slow the extremely fast moving (high energy- 1-2 Mev) neutrons generated by actinide fission and thereby increase their probability of capture by other fissile atoms. The world's first nuclear reactors had to be moderated with either carbon or "heavy water" (deuterium) because they had to be fueled with natural uranium containing very little fissile ^{235}U. Natural uranium's (NU's) "poisonous" ^{238}U atoms out-number its fissile ^{235}U atoms ~140:1 (1/0.0071). That's important because ^{238}U tends to irreversibly absorb neutrons moving at speeds intermediate between what they possessed when first released and after slowing down to a speeds corresponding to that of a room temperature gas (i.e., within its "resonance absorption region"). If small chunks of uranium are surrounded with the right amount of an almost perfect moderator (carbon or deuterium) enough neutrons can get through ^{238}U's "resonance absorption" gauntlet to trigger fission of the next ^{235}U atom they blunder into and thereby keep the chain reaction going. A perfect moderator atom does not "capture" (irreversibly absorb) any neutrons, it's just something that they can repeatedly collide with and thereby lose kinetic energy in excess of that consistent with their surrounding's temperature. All else being equal, the lighter the atom, the better it serves that purpose. While hydrogen (one atomic mass unit)is better at slowing neutrons than is deuterium (two atomic mass units), it irreversibly absorbs too many of them to permit reactors containing only natural uranium (only 0.71% fissile ^{235}U) to achieve criticality.   That's the reason that a light water-moderated reactor's uranium must be "enriched" and why Canada, Germany, Great Britain and France decided to start off with graphite & heavy water (deuterium) moderated reactors.

Since the purpose of a reactor's moderator is to simply slow down neutrons, its absorption (fission + transmutation) collisional cross sections must be very low, e.g., for ^{12}C it's about 0.0005 barn). A neutron moderator reduces the speed of fast (1-2 Mev) freshly generated fission neutrons - ideally without capturing any of them - leaving them with only thermalized kinetic energy [25]

One of the key downsides of moderation is that the fissions engendered by slow-moving neutrons striking a fissile atom don't generate as many new neutrons per collision as do those caused by fast neutron hits. This means that there's enough extra neutrons in a fast reactor's core

[25] At a temperature of 290°K (17°C or 63°F), that energy for any monatomic species (e.g., a neutron, helium atom, argon atom, etc.) is $3/2*k*290 = (1/2)*AMU*(m/s)^2 = 4.0E-21$ J = 0.025 ev   where k= Boltzmann's constant).

to breed at least as much new fissile (^{233}U or ^{239}Pu) from the much more abundant but otherwise useless fertile isotope atoms (^{232}Th or ^{238}U) accompanying its fissile.

The other big downside is that the parasitic neutron capture (poisoning) cross sections of fission products and the materials that the reactor is made of go up faster upon moderation than do the fission cross sections of its fissile fuel isotope. This means that fast reactors can operate with greater concentrations of such things within their cores which translates to requiring less frequent reprocessing and/or fuel replacement.

Nuclear reactors are configured and operated so that during normal operation exactly one of the new neutrons generated when one of its fissile atoms fissions/splits is absorbed by another fissile "heavy metal" (actinide) isotope which goes on to do the same thing.

The fate of those neutrons is characterized by the term "k_{eff}". K_{eff} is the average number of neutrons generated by a fission event that go on to cause the next fission. The extra neutrons are either absorbed in non-fission reactions or leave the system (leak) without being absorbed. The value of k_{eff} determines how a nuclear chain reaction proceeds:

If $k_{eff} < 1$ (sub criticality), the system cannot sustain a chain reaction, and any beginning of one will die out over time. For every fission that is induced in the system, an average total of $1/(1 - k)$ fissions occur. This is the situation when too many neutrons simply leak out to the reactors core or are absorbed by something other than other fissile neuclei.

If $k_{eff} = 1$ (criticality), every fission causes an average of one more fission, leading to a fission (and power) level that is constant. Nuclear power plants operate with k_{eff} exactly equal to 1.000 unless its power level is being deliberately increased or decreased.

If $k_{eff} > 1$ (super criticality) for every fission in the material, it is likely that there will be more than another after the next mean generation time cycle which is on the order of 10^{-4} to 10^{-6} second. The result is that the number of fissions increases exponentially which could quickly make the whole thing go "boom" if not halted in one way or another. On the other hand, nuclear weapons are deliberately designed/configured to so-operate (i.e., evince positive not negative feedback).

Since each individual neutron absorption/fission event occurs far more quickly than either human or automated control systems can respond, all practical reactor concepts rely upon rapid natural negative feedback mechanisms (e.g., Doppler broadening & thermal expansion) for stability which can work because a fraction of the neutrons ("delayed neutrons") generated per fission are not immediately released. Most of such delayed neutrons are generated by the decay of "hot" (relatively short lived) fission product isotopes.

Thermal expansion increases the distance between atoms thereby reducing the probability that a neutron emitted by one will strike another.

The thermally(or particle speed) -driven Doppler effect broadens the reactor fuel's fertile material's (e.g., ^{238}U) resonance capture (absorption) cross section thereby increasing the probability that neutrons will interact with it rather than with its fissile. That is responsible for most of a thermal (moderated) reactor's negative (power stabilizing) temperature reactivity coefficient.

Several kinetic factors impact the rate at which the power (heat) produced in a nuclear reactor responds to changes in the position of a control rod. Other features of the design govern how rapidly heat is transferred from the reactor fuel to the coolant.

The nuclear chain reaction has a positive feedback component whenever a critical mass is created; specifically, excess neutrons are produced for every fission. Inside a nuclear reactor, these excess neutrons must be controlled as long as a critical mass exists. The most significant and effective control mechanism is the use of control rods to absorb the excess neutrons. Other controls include the size and shape of the reactor and the presence of neutron reflectors in and around its core. Changing the amount of absorption or reflection of neutrons affects neutron flux, and therefore, the reactor's power.

One kinetics factor is the tendency of most light-water-moderated reactor (LWR) designs to have negative moderator temperature and void reactivity coefficients. A negative reactivity coefficient means that as the water moderator heats up, molecules move farther apart (water expands and eventually boils) and neutrons are less likely to be slowed by collisions to energies favorable for inducing fission in the fuel. Because of these negative feedback mechanisms, most LWRs will naturally tend to decrease fission rate in response to additional heat within their core. If enough heat is produced that water will boils within core , drastically decreasing fission rates in that region.

However, when power output from the nuclear reaction increases rapidly, it may take longer for the water to heat up and boil than it does for steam voids to cause the nuclear reactions to decrease. In such events, reactor power can grow rapidly without that negative feedback from the expansion/boiling of the water, even if it is in a channel just 1 cm away. Dramatic heating will occur to the nuclear fuel, leading to melting and vaporization of the metals within the core. Rapid expansion, increases in pressure, and failure of core components may lead to the destruction of the nuclear reactor, as was the case with the US Army's SL-1. As the energy of expansion and heat travel from the nuclear fuel to the water and the vessel, it becomes likely that the nuclear reaction will shut down, either from the lack of sufficient moderator or from the fuel expanding beyond the realm of a critical mass. In the post-accident analysis of SL-1, scientists determined that the two shutdown mechanisms were almost equally matched

The term 'positive void coefficient' is often associated with Russia's graphite moderated, water cooled, RBMK reactors one of which blew up at its Chernobyl power plant. Reactors cooled by boiling water contain a mix of steam and liquid within their core. Because liquid water is a more efficient coolant and a stronger neutron absorber than is steam, a change in the proportion of steam bubbles, or 'voids', in the coolant changes reactor core reactivity. The ratio of these changes is its “void coefficient of reactivity’. When that coefficient is negative, an increase in steam will lead to a decrease in reactivity. In those reactors where the same water circuit acts as both moderator and coolant, excess steam generation reduces the slowing of neutrons necessary to sustain the nuclear chain reaction leading to the reduction in power constituting a basic safety feature of most of the Western world’s LWRs. In reactor designs where the moderator and coolant are of different materials as is the case with the RBMK and the USA’s first-generation weapons plutonium production reactors, excess steam reduces cooling but because the moderator remains intact the nuclear chain reaction continues. In some of them most notably the RBMK, the neutron absorbing properties of the cooling water is a significant factor in their operating characteristics. In RBMK reactors the void coefficient is the dominant contributor to overall reactivity coefficient of. At the time of Chernobyl’s accident, that reactor’s void coefficient of reactivity was so positive that it overwhelmed the other components of the power coefficient, resulting in an overall positive power coefficient thereby creating a “positive feedback” loop responding much faster than its operators could reinsert its control rods into the core. When the power began to increase, more steam was produced, which in turn led to an increase in power which meant less cooling and less neutron absorption, resulting in a rapid (explosive) power increase roughly two orders of magnitude greater than that reactor's rated capacity.

Another relevant kinetics factor is the contribution of what are called delayed neutrons to the chain reaction in the core. Most neutrons (the prompt neutrons) are produced nearly instantaneously via fission. But a few — approximately 0.7 percent in a ^{235}U-fueled reactor operating at steady-state — are produced through the relatively slow radioactive decay of certain fission products. That delayed production of a fraction of the neutrons is what allows reactor power changes to be controllable on a time scale amenable to both humans and machinery. In the case of a rapidly ejected control assembly, it is possible for the reactor to become critical on the prompt neutrons alone (i.e., prompt critical). When the reactor is prompt critical, the time required to double its power is on the order of 10 microseconds. The duration necessary for temperature to follow the power level depends on the design of the reactor core. In a properly operated conventional LWR, coolant temperature typically lags behind power output by 3 to 5 seconds. In the SL-1 design, it was about 6 milliseconds before immediate formation blew the whole thing up.

Finally, one measure of a reactor's performance is its "conversion ratio" (CR), the ratio of new fissile atoms produced to fissile atoms consumed. All nuclear reactors except those specially designed and operated as “waste” burners” accomplish some degree of conversion. As long as there is any amount of any fertile (e.g., ^{238}U or ^{232}Th) material within a reactors’ neutron flux some new fissile material is created. When the conversion ratio is greater than 1, it is usually called its "breeding ratio (BR)."

For example, the nuclear power industry's now dominant light water moderated reactors (LWRs) typically have conversion ratios of ~0.6. Pressurized heavy water moderated reactors (PHWR or CANDU reactors) running on natural uranium exhibit conversion ratios of ~0.8 because that moderator (D_2O rather than H_2O) is less wasteful . In breeder reactors, the conversion ratio is higher than 1. "Break-even" is achieved when a reactor's conversion ratio reaches 1.0 and it produces exactly much fissile material as it "burns".

The doubling time is the what it would take for a breeder reactor to produce enough new fissile material to replace its original fuel and produce an equivalent amount of new fuel for another such reactor (for more about this see Breeder reactor - Wikipedia)

An excellent source of more information about nuclear physics is freely available at https://www.nuclear-power.net/nuclear-power/reactor-physics/.

Chapter 2. Africa's especially special issues

Apparently because I am among a minority of scientists (Springer 2014, Sims 2011, Hansen 2008, Sachs 2012, Hansen 2016, and EFN 2018) willing to say that today's politically correct (non-nuclear) renewable energy sources couldn't support even the near future's (~2050 AD) human population without severe environmental consequences, three years ago I was asked to contribute a chapter to Professor Ratten Lal's latest soil science volume describing how a "nuclear renaissance" could address Africa's especially imposing technical/social/environmental issues (Siemer 2018). That morphed into one of QUORA's longest-ever winded "answers" which, in turn, inspired the first version of this book (QUORA 2018).

Since I like to use specific numeric examples to support whatever point I'm trying to make, many of this book's examples will address some of the African continent's especially imposing future issues[26]. Unlike most first world nations, most Africa's 54 countries continue to exhibit alarmingly high rates of both population growth and poverty (ESA 2015). Approximately 380 million of its ~1.2 billion people are extremely poor – often hungry – and ten of the world's most underdeveloped (Trump 2018) countries – Mozambique, Guinea, Burundi, Burkina Faso, Eritrea, Sierra Leone, Chad, Central African Republic, Democratic Republic of Congo, and Niger – are located therein. Furthermore, although considered to be exceptionally underdeveloped, none of them are among the twenty countries recognized to possess the world's lowest living costs (Cheap 2018) meaning that Africa's poor people are considerably poorer in fact than are those in more technologically advanced but poor by OECD standards nations like Romania. Most of Africa's people are plagued by a lack of basic infrastructure due to dysfunctional, self-serving governance exacerbated by long-festering civil/tribal/religious conflicts and therefore face bleak futures[27]. Much of Africa is also apt to be particularly hard-hit by anthropogenic driven climate

[26] More so than is the case in other continents, African agriculture is dominated by human powered family farming. ~80% of Africa's ~33 million farms are tiny - under 2 hectares. While women mainly comprise its agricultural labor force, the rules governing land ownership and transfer rights are less favorable to them than is the case in Asia or Latin America. Over the last decade, large-scale African investment contracts have covered 20 million hectares, representing more than the combined arable areas of South Africa and Zimbabwe. What's worse is that Africa's agricultural potential is under threat. Many of its farmers struggle to replenish soil fertility due to unsustainable operations, lack of investment capacity, and/or secure land tenure. Impressed by the gains made by industrial farming elsewhere, Africa's topmost decision-makers often make it easy for "outside" investors to acquire land in ways that shortchange its current tenants (Mayaki 2020).

[27] "*Life has become more brutal and brutish*", Wole Soyinka (84-year-old Nigerian playwright & philosopher). CGTN interview, 16Feb2019.

change – as is happening within the USA, its deserts are getting bigger[28]. The fact that most of its countries are ill equipped to deal with any sort of natural disaster, possess economies comprised primarily of subsistence farming on progressively poorer-quality land, and have grossly underfunded public health, physical infrastructure, and education services constitute only some of the factors considered in compiling quality-of-life rankings. Most of the United Nation's measures of Human Development (UNDP 2018) also consider the fairness of income/wealth distribution for which Africa's countries are also especially low-ranking (GINI 2018). Cambridge's Sir Partha Dasgupta, recipient of almost every award that economists can bestow, has pointed out that most of the recent GNP increases of 2nd/3rd world countries have come at the expense of their average citizens' personal assets (Dasgupta 2003).

Africa's (and the World's) still burgeoning population growth exacerbate all of its problems. As of 2015, the UN's mid-range population growth projection is that Africa will have ~4.5 billion inhabitants by 2100 AD – about three times the number anticipated for today's most populous nation, China. The populations of 28 of Africa's countries are predicted to more than double between 2015 and 2050 and, by 2100, those of Angola (see APPENDIX XXXVIII) , Burundi, Democratic Republic of Congo, Malawi, Mali, Niger, Somalia, Uganda, United Republic of Tanzania and Zambia are to increase at least five-fold.

Frankly, I consider such projections unrealistic. First, polls suggest that a third or more of Americans younger than 45 either won't have children or expect to have fewer than they might otherwise because they are worried about climate change and the future in general. Some of the Western World's prominent people like Miley Cyrus have vowed not to have a baby on a "piece-of-shit planet." https://www.theatlantic.com/politics/archive/2021/09/millennials-babies-climate-change/ and Representative Alexandria Ocasio-Cortez recently mused about whether it's still okay to have children. The Western World's Millennials and Gen Z are not the first generations to face the potential of imminent, catastrophic, irreversible change to the world they will inherit. However, they seem to be the first to seriously entertain whether that means they should stop having children.

Second, the western world's increasing "populism" (extreme polarization often bordering upon fascism) driven primarily by rapidly increasing class, power, and wealth disparities but usually blamed upon Jews or foreigners.

Third, the armed-to-the teeth "leader of the western world" is anxious about the fact that its dominance of the world's economic system is rapidly diminishing which could lead to the

[28] Much of Spain, Portugal and southwestern US is becoming even more desert-like and each year's heat waves are killing more people everywhere.

election of an “unstable” commander in chief who might start a third world war far more impactful than were its predecessors[29].

Fourth, more refugees than ever are being forced to flee their homes due to war, terrorism, persecution, and the consequences of climate change[30] but often have no place to go in an increasingly crowded world.

Fifth and finally, there’s the fact that within another human lifetime we will inevitably be faced with the consequences of   “peak oil”, “peak coal”, “peak gas” and “peak soil” but act as if neither we nor our leaders believe it.

Most of human history suggests that those factors are apt to ignite another “world war” likely to kill far more people than did its 20th century’s predecessors and thereby reverse this century’s still-ongoing population boom.

A surprisingly large fraction of the people fearing the effects of overpopulation upon the environment feel that other people should be left to starve, or freeze, or die of overwork, or…etc., to cut their numbers (“Social Darwinism”). Over population remains an issue because today’s business and cultural models severely impact the natural world while leaving many of its human inhabitants poor, ignorant, desperate, miserable, but nevertheless still overly fertile. We must confront, not ignore such uncomfortable facts[31].

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[29] ‘”*U.S. officials crafting retaliatory actions against China over coronavirus as President Trump fumes*.” https://www.washingtonpost.com/business/2020/04/30/trump-china-coronavirus-retaliation/?utm_campaign=wp_evening_edition&utm_medium=email&utm_source=newsletter&wpisrc=nl_evening . The USA is also planning to resume nuclear bomb testing https://www.defensenews.com/smr/nuclear-arsenal/2020/05/26/live-nuclear-testing-could-resume-in-months-if-needed-official-says/ .

[30] Over human history, climate changes –usually drought—have forced more people to abandon their homes than has anything else (Toonen at al 2020). Today’s climate refugees are finding it difficult to settle elsewhere because the world is much more crowded than when the people who had colonized Greenland (Norsemen), the Ottoman & Khmer empires, or the Mexican, Mayan, and Indus Valley civilizations had to abandon their homelands.

[31] It may happen that when we humans all get rich enough & smart enough to quite stuffing the world with still more people, we’ll voluntarily quit doing it & (over)population growth will end. However, it seems likely that that’s not going to happen before many of the people currently living are killed off by “resources” war/wars engendered by most of them (not the super-rich of course) experiencing the consequences of their world’s reaching multiple “peaks” (oil, coal, gas, water, soil, & food). It’s no coincidence that China didn’t begin to become genuinely “great” again until its bosses decided to impose/enforce a one child per woman policy.

If we sincerely wish to enhance "brotherhood", "equality", and/or "compassion" we must change our leadership's business models, the first step of which be to see that they provide everyone with abundant, cheap, clean, and reliable nuclear energy ASAP. If that comes to pass, there won't be a "population problem", global warming will abate, the rivers can be allowed to run free again, and we'll stop converting the world's remaining natural regions into palm oil plantations, cattle feedlots, corn/soybean farms, and deserts. Doing so might even bring an end to the Anthropocene's galloping "Sixth Extinction" (Kolbert 2014)[32].

Unless a new, worldwide, "Fair Deal" " somehow comes to pass[33]; the relative demographic weight of the world's developed countries will drop shifting economic power to developing nations. The already-developed countries' labor forces will age and decline constraining economic growth and raising the demand for cheap" non-documented immigrant workers which will then likely further increase the frequency of killings, burnings, and bombings driven by jingoistic populism[34]. It's also likely that most of that growth will occur in the poorest, youngest, and most heavily faith-based (mostly Muslim) countries many of which will be unable to provide adequate education, capital, and employment opportunities for the majority of their young people.

Finally, most of the world's population will likely live within cities, with the largest such urbanized areas in the poorest countries, where adequate policing, sanitation, health care, and even clean water are now available to only their richest inhabitants. Such urbanization is apt to be profoundly destabilizing. People moving to cities within developing countries during the rest of this century are apt to have far lower per capita incomes than did those of most of today's industrial countries when they did so. The United States did not reach 65 percent urbanization until 1950, when its per capita income was nearly $118,000 in 2019's dollars. By contrast, countries like Nigeria, Pakistan, and the Philippines now approaching similar levels of urbanization, have per capita incomes of 2,300–5,200 such dollars. Countries with younger populations are especially prone to civil unrest and less able to create or sustain democratic institutions. The more heavily urbanized they become, the more they are apt to experience

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[32]"Invasive alien species" is the major cause of anthropogenic extinctions, not climate change. Of course, we humans along with our pets and livestock are the most impactful of those aliens.

[33] The Fair Deal revealed by U.S. President Harry S. Truman in his 1949 State of the Union address was an ambitious set of proposals continuing Roosevelt's New Deal liberalism. Its key proposals included aid to education, universal health insurance, the Fair Employment Practices Commission, and repeal of the Taft–Hartley (anti-union) Act. However, because then as now, a "Conservative Coalition" controlled Congress they were all turned down.

[34] The Trump administration's "anti-foreigner" policies and actions didn't just harm the people that wanted to immigrate to the USA; they also hurt its chance of becoming "great" again. Over 70 % of the workers that its government officially deemed « essential » are immigrants. Over 50% of the patents currently issued in the US are to immigrants some of whom represent ~60% of Silicon Valley's high-tech workforce.

grinding poverty and anarchic violence. In good times, a thriving economy might keep urban residents employed and governments flush with sufficient resources to meet everyone's basic needs. However, more often people living in sprawling, impoverished cities are victimized by crime lords, gangs, and petty rebellions. Thus, the rapid urbanization of the developing world is apt to bring in more exaggerated form, the same problems that urbanization brought to nineteenth-century Europe: cyclical employment, inadequate policing, and limited sanitation and education which spawned wide-spread labor strife, periodic violence, and sometimes, even revolutions. International terrorism originates in fast urbanizing developing countries. Within poor sprawling megacities like Mogadishu and Damascus, neighborhood gangs armed with internet-enabled social networking capabilities offer excellent opportunities for the recruitment, maintenance, and hiding of terrorist networks (Goldstone 2010). These cities are apt to become increasing dirty and polluted because they are apt to remain on the rising edge of the "environmental Kuznets curve"[35].

When life is cheap, worthwhile jobs unavailable, and the future looks worse, history suggests that people are apt to go to war.

US Pentagon studies (CNA 2014) concluded that the root cause of most such deaths will be disease and starvation engendered by the disintegration of technology-dependent societies dependent upon increasingly limited/degraded resources (land, food, fuel, high grade ores, etc.). In his book, "Small is Beautiful: A Study of Economics as if People Mattered", Ernst Schumacher (Schumacher 1973) observed that today's technological civilization is unsustainable because the finite resources enabling it are treated as inventory (income) rather than capital. The sustainability of today's economic systems therefore requires continued growth of both population[36] and nominal wealth (GDP), both of which are impossible in a finite world.

Consequently, our leadership's objective should become encouraging the development of a genuinely sustainable and much more egalitarian world in which everyone regardless of where

[35] The environmental Kuznets curve (GOOGLE it) is a relationship between environmental quality and economic development: several indicators of environmental degradation (e.g., air pollution) tend to get worse as economic growth occurs until an average person finally becomes rich/influential enough to insist that the powers-that-be implement something along the lines of the USA's "Environmental Protection Agency".

[36] The Earth now supports about three times as many people as it did when I was born and five times more than when my grandfather was. Most of that growth is due to the energy-driven technological advances that decreased child mortality while rendering it possible to feed more of us. I suspect that if this book's utopian scenario were to come to pass, human population would gradually drop back to a level (2-3 billion?) consistent with both more pleasant lives for individuals (increasing total happiness) and more room for other living creatures – it's possible: after all, we humans are supposed to be sapient.

he/she lives or who they know does indeed matter[37]. Until the USA's leaders acknowledge these points, embrace appropriate goals, and begin to act accordingly, we'll just continue to spin our wheels, blame scapegoats, and bitch about everything and everyone.

What are those goals?

Since food represents any living creature's most fundamental need and its source for humanity is farmland, I'll begin by describing what's been happening along those lines within the world's most undeveloped continent, Africa. A recent Brookings Institute report (McArthur 2013), points out that, "*no matter how effectively other conditions are remedied, per capita food production in Africa will continue to decrease unless soil fertility depletion is effectively addressed*." It goes on to say that a second major problem with the oft-assumed African "land abundance" hypothesis is its inconsistency with convincing evidence that its soils are being simultaneously depleted and eroded by today's agricultural practices which includes a decline in fallowing. While some African leaders along with the management of "land grabbing" (?) international agribusiness concerns seem to feel that Africa still has plenty of yet-undeveloped arable land, many of Africa's poorest people (mostly subsistence farmers) can't afford to let any of theirs lie fallow and thereby eventually recover: some families live on 0.36 ha (0.9 US acre) farms yielding under 1 t of grain/ha (t = tonne = 10^{+3} kg = 10^{+6} grams: ha = hectare = 10^{+4} m^2=2.59 US acre) while the first-world's farmers routinely produce 3 to12 t/ha of whatever cash crop they chose to plant on their several order of magnitude larger farms[38].

The key differences between the agricultural practices of developed nations and most of Africa's include:

• Developed nations heavily fertilize their croplands – most of Africa's farmers can't afford artificial fertilizers and, moreover, often must burn any manures, weeds, sticks, or crop residues they can gather to cook their food[39].

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[37] "— Franklin D. Roosevelt *The test of our progress is not whether we add more to the abundance of those who have much; it is whether we provide enough for those who have too little*."

[38] During the last forty years, farming has been the primary exception to the USA's "deindustrialization" which policy has rendered them very expensive to operate and intensely competitive . Including its little "hobby farms", the average size of a USA Corn Belt farm is now up to about 350 acres, and such land is now worth about $12000/acre. Unfortunately, many of its therefore seemingly "rich" farmers are going bankrupt because their incomes often don't exceed their expenditures.

[39] Cooking is a uniquely human capability without which >80% of us would starve.

• Developed nations' farmers can afford to irrigate their croplands – most of Africa's can't. That issue is exacerbated by the fact that much of Africa's nominally arable land doesn't get enough rain to reliably support anything other than skeletal cow or goat grazing.

• Most developed-nation farms are both large and productive enough to enable their owners to buy/utilize specialized machinery which renders their labor far less exhausting and much more rewarding. The world's poorest farmers still work themselves to death with primitive tools

•Developed nation farmers can afford to use better seeds[40] that increase yields and better resist the effects of herbicides, drought, fungus, insects, or microbes.

• Developed nation farmers can afford to use advanced herbicides and insecticides

• Developed nation farmers are supported by adequate storage facilities and efficient food distribution networks

Chapter 3. Why almost everything boils down to energy inputs

It is evident that the fortunes of the world's human population, for better or for worse, are inextricably interrelated with the use that is made of energy resources.

M. King Hubbert

The differences between the lifestyles of the world's rich vs poor people reflect the relative amounts of raw/primary energy supporting their lifestyles, which still as of 2021 just boils down to their relative per capita fossil fuel consumptions. Since I'm going to be demonstrating/supporting most of my contentions with ball-park calculations, let's start off with a table containing many of the numbers/terms that will be used throughout complete with their units (for brevity's sake I'll be leaving the units out of most of this book's example calculations using them)

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[40] This includes seeds improved by traditional slow/laborious back-crossing/selection techniques, genome editing (no introduced DNA), and full-blown Genetic Modification (GMO) which adds snippets of DNA. Unfortunately, at this time (mid-2020) the European Union's plant scientists are baffled/frustrated by a 2018 European Court of Justice decision that departed from the international definition of GMOs to include genome-edited plants. Nonsensically politicized "technical" decisions like that decrease yields, impact biodiversity, and increase both food costs and pesticide/herbicide usage. APPENDIX XXXVIII describes how those sorts of decisions are also impacting many of Africa's people.

Table 1 "Special numbers" along with their units (try to memorize them)

3.15E+7	= number of seconds per year [3600*24*365]
24	= 24 hr/day (8760 hr/year)
8760	= number of hours per year
365	= 365 days/year =365 days/a
3.2E-11	(energy) = # of Joules generated by the fission of a single actinide atom (≈'s 200 million electron volts (MeV) or 5.23E-21 barrel of oil equivalents (BOE – the oil industry's favorite energy unit)
6.023E+23	= number of atoms, molecules, etc., per gram mole of anything (Avogadro's number)
1.6E-19	= number of electron volts per Joule (oxygen combustion of a single carbon atom generates ~ 4.1 electron volts or ~2.05E-6 of one percent as much heat energy as does the fission of a single actinide atom)
Watt (power)	(power) = W = energy/second = Joule/s = J/second = J/s = 0.00134 mechanical horsepower=10^7 ergs per second
kWh	(energy) kilowatt hour = 1 J/s*3600 s/hr*1000 = 3.6E+6 Joules (most common unit for electrical energy)
GWyear (energy)	= Giga $W_x$yr = one million kwh per year=1E+9*3600*24*365 = 3.15E+16 J where (x) is either thermal (x=t) or electrical, x=e (e.g., GWe)
Calorie)	(energy) = 4.19 J = 0.001 kilocalorie = 0.001 kcal
Acre (area)	= 43560 ft^2 = 4049 m^2 = 0.4049 ha = 0.0015625 $mile^2$
BTU (energy)	= British Thermal Unit =252 calories=1055 J (energy required to heat one pound (454 g of water) 1 degree F or 5/9 degree C)
Quad	(energy)= one quadrillion BTU = 1.055E+18 J
BOE	(energy) = barrel of oil equivalent=6.1E+9 J (assumes a 42 US gallon barrel, 10 kcal/g, and 0.916 g/cc oil)
nX	= 10^{-9}*X = nano X ,
kX	= 10^{+3}*X = kilo X
MX	= 10^{+6}*X = Mega X
GX	= 10^{+9}*X= Giga X
TX	= 10^{+12}*X=Terra X
EX	= 10^{+18}*X= Exa X

In his latest book, “Question of Power”, journalist Robert Bryce tells the uniquely human story of electricity and shows how our cities, money, health, and livelihood depend upon a reliable and sufficient supply of it (Bryce 2020). He highlights the factors needed for successful electrification and explains why so many of the world’s people remain stuck in the dark. He also debunks the notion that the future’s energy needs could be met solely with today’s “renewables” and demonstrates why that if we are genuinely serious about addressing

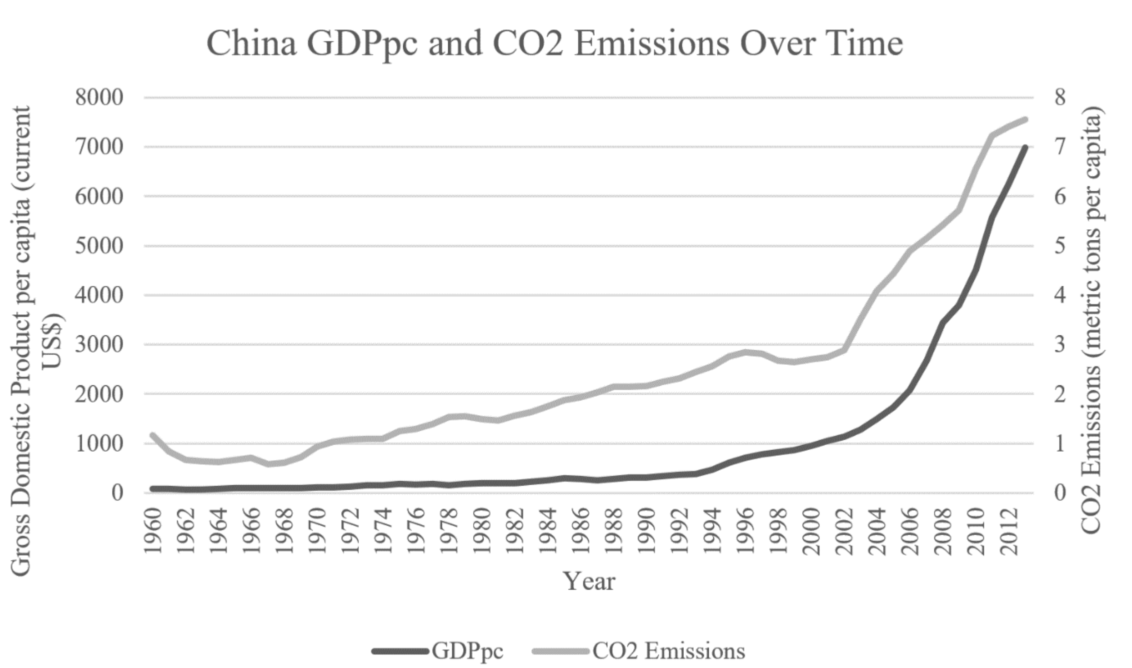

Figure 2 the whys of excessive anthropogenic greenhouse gases

climate change, nuclear energy must play a much bigger role than most of the world’s energy experts currently assume.

After first describing the history & probable future of all of mankind’s energy/power sources, another book written by an even more veteran journalist arrives at the same conclusion (Rhodes 2018).

They are both following in the six decade-old footsteps of Alvin, Weinberg, Eugene Wigner, and M. King Hubbert.

There is a tremendous need to develop better ways of providing the “energy services” required to fuel economic development and provide energy security for everyone, not just for the world’s richest people. One of the best-written descriptions I have seen yet of both what that problem is and how it might be addressed is a book written/published by the Post Carbon Institute and freely available at its website (Heinberg & Fridley 2016). Unfortunately, its authors do not include nuclear power in their much constrained[41], all renewables-powered, hypothetical future world because "*nuclear fuel is not renewable*". Heinberg & Fridley were right in the sense that we here in the West do not yet have renewable nuclear power, but wrong to completely write off that possibility because it should[42], could, and must eventually become available to everyone regardless of where they live. Addressing the hows and whys of accomplishing that will be the main subject of this book.

There are three types of natural primary ("raw") energy sources:

- The first are energy flows-processes primarily driven by sunlight from which some useful-to-humans energy can be extracted, e.g., solar radiation, winds, and rain/snow water flowing downstream in rivers. Most of the potentially useful energy represented by such flows is both diffuse (low power potential per unit area or mass which means that harvesting it requires lots of time and large equipment) and intermittent which means unreliable with respect to many of humanity's energy/power demands. However, because the sun will continue to shine long after humans become extinct, such flows are also "renewable" meaning that they are inexhaustible as far as we are concerned.

- The second is fossil fuels comprised of relatively concentrated, biologically generated, forms of stored solar energy. There are two types of them: 1) renewables or "fresh" biofuels including the wood, bioethanol, and sundry biodiesels produced in modest quantities every year by still-existing lifeforms, and 2) relatively large, eons-old, fossilized ("dead") biofuel accumulations including peat, bitumen, coal, petroleum, and natural gas that Mother Nature does not replace at rates relevant to maintaining today's consumption rates.

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[41] "As we have seen, relying entirely on renewable energy entails some hefty challenges. We have discussed at some length the problem of source intermittency and the need for energy storage, grid redesign, and capacity redundancy; the environmental and land use challenges of installing very large numbers of solar panels and wind turbines; electrification and the revamping of energy-consuming equipment; and the requirements for very high levels of investment. The conclusion we have reached so far is that, realistically, a mostly wind-and-solar future will likely provide less energy overall, less mobility, and less manufacturing capacity. This conclusion is likely to be unwelcome to many readers, again leading to objections regarding the study's narrow boundary assumptions. This chapter addresses three of the most likely of those objections" (Heinberg & Fridley 2016)"

[42] A year ago University of Notre Dame philosophy professor Don Howard (Howard 2019) wrote a wonderful 28 page essay explaining the moral/ethical reasons for pursuing this book's goals – it's free at https://www.researchgate.net/publication/338955643_The_Moral_Imperative_of_Green_Nuclear_Energy_Production_Notre_Dame_Journal_on_Emerging_Technologies_1_2020_64-91

• The third is nuclear fuel comprising natural (i.e., still existing, meaning long-lived) isotopes of elements at the extremes of the periodic table (e.g., hydrogen and the actinides, uranium & thorium, which possess nuclei unstable with respect to those of elements (e.g., iron) near its center. Isotopes at the light end of that table were generated by the "big bang" that created the universe and their heavier cousins were subsequently generated by the supernovas that created our solar system's heavier elements. Useful energy can be generated by either fusing those lightest element nuclei together ("fusion energy") which the outcome of over 50 years of study and experimentation suggests is virtually impossible to controllably implement here on Earth, or by fissioning two of the elements (actinides) at that table's heavy extreme. Many, many different fission reactor concepts have been proposed some of which have been demonstrated and even used to accomplish useful things.

According to the dictionary, renewable electricity is generated by either naturally replenished or inexhaustible sources. A sustainable source can supply a specified amount of power (energy/time) for a long, definite, period, e.g., "the foreseeable future" *if* "forseeable" means >1000 years. Some forms of renewable power – for example, a cod liver oil-based "biofuel" - must be used cautiously so that it isn't quickly depleted, its source (codfish) destroyed, or otherwise rendered unavailable. Conversely, a non-renewable resource can be sustainable if used at the rate that our Neanderthal ancestors burned coal. However, if such things are used as we do now, they will be effectively exhausted[43] well within another single human lifetime. As this book will establish, today's civilian nuclear fuel cycle is neither sustainable nor renewable and that tomorrow's could, should, and must become so.

By circa 2100 AD (and preferably sooner) we must build – not just "demonstrate" clean (greenhouse gas (GHG)-free) energy generating technologies capable of powering the homes, factories, transportation systems, and cities of a world that's probably even more environmentally compromised with ~50% more people to support than is the one we live in. The speed and scale of such change is unprecedented. Those needs cannot continue to be satisfied for a few "special" people at the expense of the majority – the rich cannot keep getting richer while everyone else's lives continue to become more precarious.

On-farm agricultural energy consumption in richer ("developed") countries entails burning diesel oil, gasoline, and/or LP gas by internal combustion engines (ICSs) plus electricity made by burning other fossil fuels, usually coal because there's more of it & it's cheaper. Consumption is higher in high-GDP countries (around 20.4 GJ/ha) than it is in low-GDP countries (around 11.1 GJ/ha) and far greater than by Africa's subsistence farms (Giampietro 2002). For example, most

[43] "effectively" because getting the reminder will become too difficult/expensive – there'll always be some of all of them left.

of a subsistence farm's energy input consists of human labor which, throughout an 8-hour workday, averages about 75 watts per person (Human Power 2018). If 100% of such useful (in this case, mechanical) energy [2.16E+6 J/day = 75 J/s*8hr*3600 s/hr.] is devoted to cultivating a 0.9 acre (0.36 ha) plot throughout a 6 month-long growing season, the area-normalized "energy services" devoted to it is 1.08 GJ/ha/a [2.16E+6 J/a*365days*6/12/2.47 acre/ha/1E+9], which is about ten percent of the raw/primary food energy required to keep each person so-occupied alive throughout an entire year [~2500 kcal/day *365 days/a]. Energy-wise that's not very efficient – state of the art farm machinery generates 20-30% of one joule's worth of useful energy from a joule's worth of its fuel's heat energy and doesn't consume anything when not actually doing something useful.

According to a "Food and Agriculture Organization of the United Nations" (FAO) report (Sims 2011), the raw/primary energy consumed by the world's "food sector" amounts to ~95 EJ (exa (10^{+18}) Joules) per year – approximately 20 percent of current total global raw/primary energy consumption (~570 EJ/a =18 TW) – and generates over 20 percent of mankind's greenhouse gas emissions. Land use changes, particularly the deforestation caused by the expansion of agricultural lands to raise food (mostly for livestock) crops and biofuels (IPCC 2007) constitutes another ~15 percent of anthropogenic GHG emissions. Only about 5% of that energy, ~6 EJ, directly supports on-farm activities such as cultivating and harvesting crops, pumping water, housing livestock, heating protected crops, drying, and short-term storage. The majority of the agricultural sector's energy demand is devoted to fertilizer and pesticide production, transport, food processing, packaging, storage, and distribution.

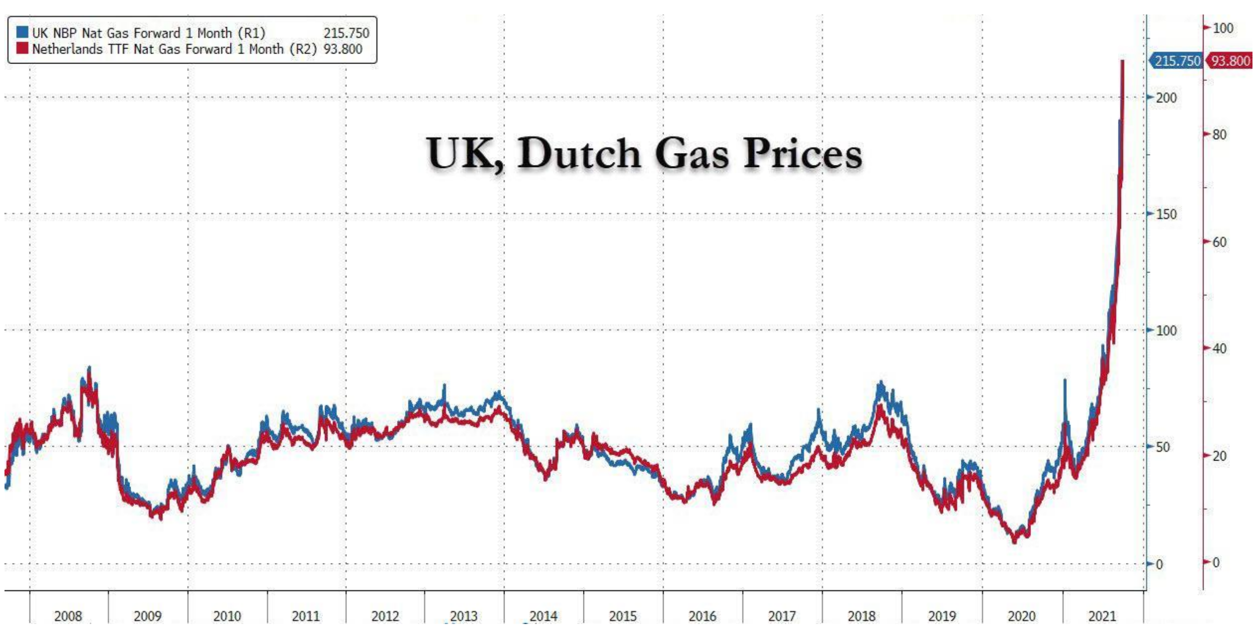

Figure 3. "Peak gas"? (Also see Figure 86 and Figure 72)

All the world's developed countries have adopted Dr. Borlaug's fossil-fueled "Green Revolution" which has enabled ~90% of today's ~7.7 billion people to consume as much food –

both necessities along with some luxury items – as they want (Borlaug 2019). Approximately one half of the world's current population would quickly starve if that hadn't happened.

As I'm writing this paragraph (2Oct2021) global food prices are reaching new highs FAO - News Article: Global food commodity prices rebound in August because the cost of the energy required to produce and distribute it is spiking everywhere Figure 3. "Peak gas"? (Also see Figure 86 and Figure 72)Figure 3 , Figure 72, and Figure 86). Cindy van Rijswick, a senior analyst at Rabobank, said the hyperinflation in European gas , electricity, and now food prices is having a "massive impact" on its greenhouses and has forced some producers to reduce lighting, end the growing season early, or just plant again next spring when (if?) natural gas prices subside."

3.1 Energy's environmental effects

" From Day One, the Biden-Harris Administration has prioritized addressing the climate crisis both at home and as a core element of our national security and foreign policy. The climate crisis is reshaping our physical world, with the Earth's climate changing faster than at any point in modern history and extreme weather events becoming more frequent and severe. In just 2021, wildfires raged across the western United States, throughout the Mediterranean region, and eastern Russia; Europe, China, and India experienced extreme flooding, and the world has suffered unprecedented levels of drought. The scientific community is clear: human activities have directly contributed to climate change. We are already experiencing the devastating impacts that climate has wreaked on almost every aspect of our lives, from food and water insecurity to infrastructure and public health, this crisis is exacerbating inequalities that intersect with gender, race, ethnicity, and economic security. We have reached a point where we cannot reverse some of the changes to the climate system."

https://www.whitehouse.gov/wp-content/uploads/2021/10/Report-on-the-Impact-of-Climate-Change-on-Migration.pdf

I'm going to begin this section with a recommendation that readers put this book down and spend 40 minutes listening to Professor Sylvia Dee's outstanding lecture explaining the hows, proofs, and consequences of anthropogenic climate change Shared Talks - Google Drive.

Anthropogenic climate change is currently contributing to a man-made "sixth extinction" comparable in scale to that which killed off the dinosaurs (Kolbert 2014). A recent paper published in the Proceedings of the National Academy of Science (Sherwood & Huber 2010) points out that the continuation of present trends could cause humans to also become "extinct" over much of their current range by 2100AD[44].

Three years have passed since Hurricane Maria tore into Puerto Rico just two weeks after Hurricane Irma had also hit it. Those "events" uprooted many of that US territory's trees, utility poles and cellphone towers; flooded homes and destroyed its fragile renewables-powered electrical grid's windmills and solar panels (see https://www.youtube.com/watch?v=1AAHJs-j3uw). The subsequent lack of clean water, refrigeration, and fully functional health care system claimed an estimated 3000 additional victims during the next few months. Its electrical power system still has not fully recovered, and long-range future plans remain unresolved[45]. It is only a matter of time before the same sorts of climate change supercharged hurricanes similarly impact millions of US citizens living in states along its Gulf of Mexico and Atlantic Ocean coastlines.

Global warming has severely reduced rainfall along the western coasts of both north and south America. For example, the Andean mountains' glaciers are disappearing which means that many of Chile's reservoirs and rivers are running dry which is forcing its six-million-person capital city, Santiago, to begin the rationing of tap water in the same way that many nations must ration electricity, i.e., with "rolling dryouts".   A contributing reason for its peoples' food (e.g., potatoes and quinoa) and now drinking water issues is that a military dictatorship (the Pinochet government") had "privatized' its water several decades ago which therefore became the property of a few rich people that raise "cash crops" for export (wine, fresh fruit, dairy, pork, poultry, and forestry products) with it.

Something that virtually everyone who understands the scientific method now agrees upon is that we need to stop burning fossil fuels if we are to avoid breakdown of the world's ecosystems and

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[44] Sherwood & Huber's argument is based upon scientific facts, not polled opinions. Human core temperatures must remain at about 37°C and, even while resting in the shade, we generate ∼100 W of metabolic heat that must be dissipated via some combination of heat conduction, evaporative cooling, and infrared radiative cooling. Net conductive and evaporative cooling can occur only if the object (human) is warmer than its environment's wet-bulb temperature which is rising world-wide due to enhanced seawater evaporation. If the ambient wet-bulb temperature reading gets above ~35°C, the human body can no longer cool itself off, even when fully drenched with sweat & standing in front of a fan. This is when serious health problems set in for even young and healthy people not rich enough to live/work in buildings featuring energy needful compression/expansion-type air conditioning.

[45] The most often-parroted proposals assert that "micro grids" would solve Puerto Rico's problems, i.e., when another big hurricane destroys most of that island's solar panels and windmills again, the people in its most-affected regions wouldn't mind being unable to import power from the other side of that island. Here's an update on what's been happening there recently (October 2021) Puerto Ricans fume as outages threaten health, work, school (apnews.com)

stop runaway global warming. Even the managers of the world's second largest publicly traded oil and gas producer, Royal Dutch Shell, have finally come to admit that. In 2020, that company's CEO, Ben van Beurden, said "*The future of energy needs to evolve as something else, and we find a role for ourselves in it."* His is the same company that knew its product was causing the planet to warm for decades, but nevertheless spent vast sums obfuscating the truth by funding myriad climate change denying think tanks and lobbying politicians across the globe. Van Beurden himself admitted his company's guilt when he said, "*Yeah, we knew. Everybody knew, and somehow we all ignored it.*"[46] However, it was only in 2019 that Shell finally opted to

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[46] STATEMENT OF MARTIN HOFFERT, FORMER EXXON CONSULTANT, PROFESSOR EMERITUS, PHYSICS, NEW YORK UNIVERSITY

Wednesday, October 23, 2019, US House of Representatives Subcommittee on Civil Rights and Civil Liberties Committee on Oversight and Reform, Washington, D.C.

The managers of oil companies like Exxon knew the scientific reality 40 years ago but waged a war of deception that cost us precious time in the fight to save our planet.

In 1977, an Exxon scientist told his company's top executives that fossil fuel usage was releasing enough carbon dioxide to change the planet's climate.

Two years later an internal Exxon memo noted that the buildup of CO2 in the atmosphere would, ``*bring about dramatic changes in the world's environment*."

In a 1981 memo, Exxon executive Roger Cohen cautioned against understating the threat to our planet, warning that the Earth's temperature could rise so high that it would, quote, ``*produce effects which will indeed be catastrophic, at least for a substantial fraction of the population*."

Decades ago, Exxon's decision makers knew that climate change was real and would have devastating consequences if left uncorrected. In fact, according to Exxon scientist Ed Garvey, Exxon was so certain of its science that it originally sought to be part of the solution and launched a sophisticated research program aimed at further understanding the full range of carbon dioxide's effects on our planet.

To Exxon's credit, its scientists were at the forefront of this research, and their dire predictions turned out to be frighteningly accurate. Unfortunately, scientists rarely set policies. When faced with the reality of the massive damage fossil fuels were likely to cause, Exxon's leadership could have chosen to present that truth to the public, redirect its own research and development resources, and lead the way to a global shift toward alternative energy sources.

They didn't. they instead sold off its renewable energy companies, doubled down on fossil fuels, and along with other big oil companies like, Shell and Mobil, launched an extensive climate denial campaign that undermined the work and warnings of its own scientists.

We are thankfully beginning to see momentum shifting toward actions to prevent the further destruction of our climate but must remain wary of the feel-good commercials and empty promises of companies still intent upon deceiving the public. Exxon and their allies are continuing to fund climate denialism and look for new oil fields to exploit, as the warnings from most of the world's independent scientists grow increasingly dire.

leave the American Fuel & Petrochemical Manufacturers lobbyist group, citing an incompatible position on climate change as its reason for exiting.

The fossil fuels that had enabled the 20th century's agricultural, industrial and information revolutions also generated huge environmental impacts including the greenhouse gas (GHG) emissions responsible for the effects of global warming/climate change.

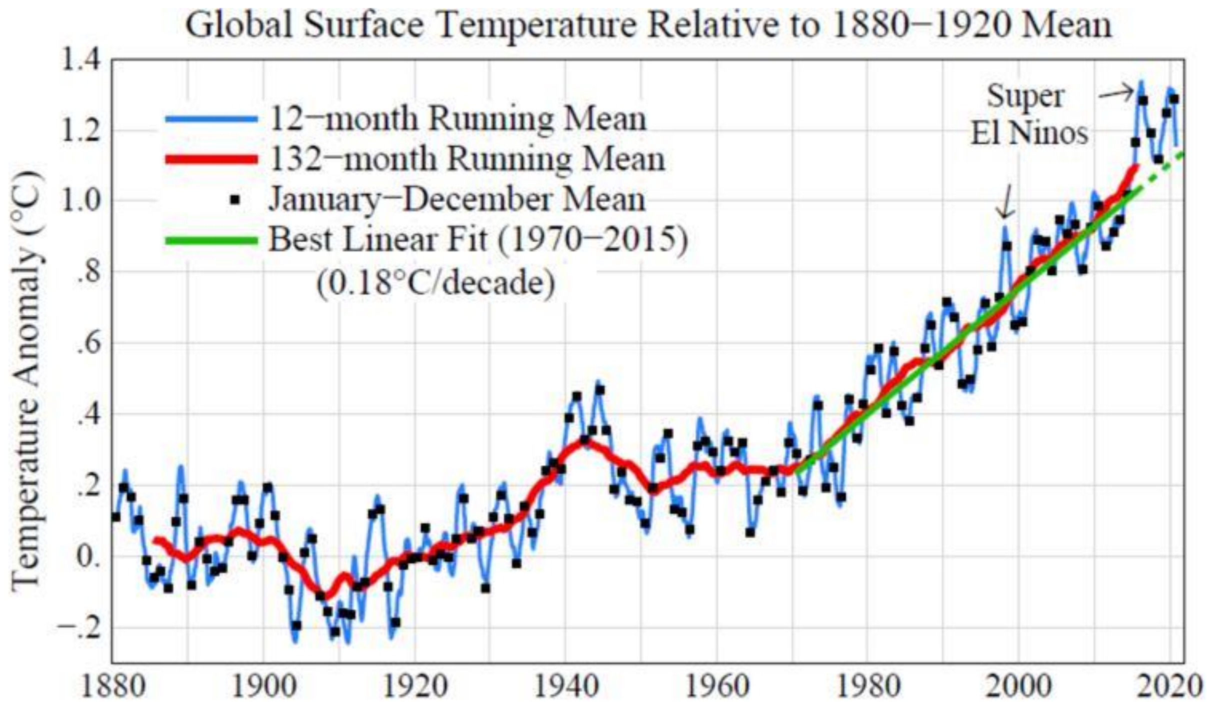

Figure 4 The root cause of climate change

The French polymath Jean-Baptiste Joseph Fourier (1768 – 1830) is credited with the discovery of the greenhouse effect. In 1821, he concluded that the Earth must be covered with some sort of invisible blanket because calculations based upon balancing its sunlight heating energy input and its thermal energy emissions output[47] (cooling), indicated that its mean temperature is about

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[47] A surface's re-emission of absorbed energy is $Q=\sigma\varepsilon AT^4$ where…

- Q is the radiation heat emission/loss in joules/sec (watts (W)
- , σ is the Stefan-Boltzmann constant = 5.67E-8 W/m^2 &
- ε is the surface's emissivity and
- … A is t surface area in m^2 (from the sun's point of view, the earth's area is that of a circle whereas its total area is that of a sphere; i.e. 4 times larger
- T is the surface's absolute temperature (K)

30 Centigrade degrees higher than it would be otherwise. Then in 1856, an American polymath, Eunice Foote, wrote one of the world's first scientific papers submitted by a woman accepted/published anywhere***,("Circumstances affecting the heat of the sun's rays"***, American Journal of Science and Arts). It describes the experiments that she had done to identify Fourier's mysterious blanket (she'd measured the temperatures of otherwise identical glass tubes filled with different gases exposed to sunlight. '"Carbonic acid gas" (CO_2), stood out because its tube heated more quickly, reached a higher temperature, & then cooled down more slowly[48].)

The next big breakthrough was in 1896 when Swedish physical chemist Svante Arrhenius calculated/published that a doubling of the atmosphere's CO_2 would raise the Earth's temperature by about 5 Centigrade (or Kelvin) degrees, and predicted that, at the rate at which civilization was then consuming coal, it might become "important" towards the end of the next millennium.

In 1957 Roger Revelle and Hans Suess published the opening shot in what eventually turned into "the great global warming debate". Before most other scientists and their sponsors would take greenhouse-effect driven global warming seriously, Revelle/Suess had to get past the long-standing, soothing-sounding, counterargument parroted by almost everyone else, i.e., that the immense mass of the Earth's oceans would quickly absorb carbon dioxide produced by human activities. In the mid 1950's, Revelle & Suess discovered that even though CO_2's residence time in the atmosphere before being absorbed was indeed rather short - roughly 10 years – the oceans' capacity to continue absorbing it is both rather limited and shrinking. The reason for this is something that most of us were exposed to in an undergraduate chemistry class, i.e., that an aqueous solution's ability to absorb CO_2 is determined by its pH, acid/base buffering capacity, and temperature. Its acid buffering capacity is determined by its relatively small amount of dissolved inorganic carbon's basic form, the carbonate anion. Only about 10% of the ~0.002 moles/liter of total carbon in "clean" seawater is present as carbonate and its proportion is shrinking because the absorption of atmospheric carbon converts it to the bicarbonate anion which results in a lower oceanic pH. This means that seawater can absorb only about a tenth as much CO_2 as the prior, simpler-minded; calculators had concluded. While it is true that most of the CO_2 added to the atmosphere would wind up in the oceans within a few years, most of it (or an equal amount of that already in them) would promptly reevaporate back out again.

Assuming that its surface emissivity ='s absorption coefficient and 1000 watts/m^2 input when the sun is directly overhead, and & that only half of the earth's s surface gets sunlight at any given time, solve for T sans "blanket"

='s $(1/4*1/2*1000/(1*5.67E\text{-}8*1))^{1/4}$ = 258°K = -12°C = 10°F

(due to its GHG "blanket", the EARTH'S s total area/time-averaged temperature is now ~70°F)

[48] John Tyndal, not her, generally gets credited for that revelation, He rediscovered (or stole) her ideas & published them himself in a more prominent journal five years later.

In 1958, Revelle's second most famous student (that honor is held by Al Gore), David Keeling, set up the atmospheric CO_2 measuring system that's still pumping out data on the top of Hawaii's Mauna Loa.
Plots of that data generate what's now referred to as the Keeling curve - one of the 20th century's most important scientific accomplishments.

In 1980, NASA's James Hansen finally put everything together and set out to try to convince his/our country's topmost decision makers to actually do something about it…in other words, he too started to become a "troublemaker".

From 1870 to the present, fossil fuel burning dumped about 580 Gt (Giga or 10^9 tonnes) of carbon into the atmosphere in the form of ~2100 Gt of CO_2. That gas partitioned between the atmosphere, oceans and land, warming all of them and thereby causing increasingly severe and frequent weather events including "Super El Niños" (Hong 2016), ocean acidification, drought and biofuel production-driven food cost escalation, air pollution, deforestation, potable/irrigation water shortages, sea-shoreline erosion/flooding, and relentless cost of living increases in the world's poorer regions. Those effects constitute threat multipliers that aggravate human stressors – poverty, environmental degradation, hunger, political instability, and social tensions[49] – and thereby engender mass migrations along with a great deal of terrorist activity and other forms of violence.

James Hansen probably possesses the world's most "educated" opinions about the causes, effects, and consequences of global warming. They've been summarized as follows (Hansen 2018):

1. Climate has always changed, but humans are now the main driver for change

a. Rising atmospheric CO_2 levels, primarily a result of fossil fuel emissions, have become the predominant cause of continuing climate change

b. Climate change is driven by cumulative CO_2 emissions. The U.S. has contributed a disproportionately large share of cumulative global emissions.

2. Current levels of atmospheric greenhouse gases (GHGs), mainly CO_2, cause Earth to be out of energy balance. This imbalance is driving climate change.

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[49] For instance, because of Arizona's lax environmental laws there is no restriction upon either how much water landowners can suck up out of the ground, how such water is used, or who can own that land. Consequently, petrodollar rich foreign investors are rendering many of its communities' potable water wells useless by raising cash crops - mostly alfalfa – upon huge corporate farms irrigated with "fossil" water drawn from surrounding areas.

a. Earth's energy imbalance is now measured and large. As long as Earth remains out of energy balance, the planet will continue to get hotter.

b. If GHG amounts continue to rise unabated, the energy imbalance will drive global warming to levels with climate impacts beyond the pale (see 3)

3. If high fossil fuel emissions continue unabated, its consequences will be mostly negative for humanity, especially for its young people.

a. Sea level: Continued high fossil fuel emissions will eventually make coastal cities dysfunctional, with incalculable consequences.

b. Species exterminations: Shifting of climate zones, with other stresses, may commit many species to extinction, leaving a more desolate planet.

c. Regional climate: subtropics and tropics will become dangerously hot, if high emissions continue. Emigration chaos may threaten global governance.

4. Required actions to avoid dangerous climate change are guided by Earth's climate history and by the need to restore Earth's energy balance

a. Science can specify initial targets, sufficient to define policy needs

b. Emission reductions must begin promptly, or climate will be pushed beyond a point at which changes proceed out of human control

5. The U.S. government, via both actions and inactions, is behaving with flagrant disregard of rights and well-being of the public, especially young people

a. Action: authorizing, permitting, subsidizing massive fossil fuel extraction

b. Inaction: absence of any coherent, effective program to reduce them

Dr. Hansen sent me (25 Jan 2021) a chapter of a book ("Sophie's Planet) he's writing about the effects that our generations' bull headedness will have upon our descendants (read it - its free). .http://www.columbia.edu/~jeh1/SophiePlanet/Planet.Chapter46.pdf

During the ~150 years since we began to power ourselves with fossil fuels, two world wars and numerous smaller ones have been fought over natural resources – primarily those fuels (usually petroleum) and "lebensraum" (land). Some of those wars have resulted in the Christian-country "winners" creating new countries in the especially oil-rich Islamic Persian Gulf, which, of course, eventually engendered more conflict.

Securing that resource has proven to be expensive to those war's winners. A Princeton University report concluded that simply keeping the US Navy's fifth fleet within the Persian Gulf from 1976 to 2006 had cost its taxpayers ~$6.8 trillion 2008 dollars and would probably cost them another $0.5 trillion during 2007 (Stern 2010) which figures didn't include the costs of actual conflicts. Since that fleet remains on station, the total cost of "maintaining presence" therein has now probably reached about $12 trillion. A 2013 Kennedy School of Government report (Foreignpolicy 2013) concluded that the total cost of the USA's most recent wars in the Middle East and Northern Africa would probably be $4-6 trillion and had accounted for roughly 20 percent of its national debt increase between 2001 and 2012 (wars are fought with borrowed money).

41 years ago, scientists from 50 different countries met at the First World Climate Conference (Geneva 1979) and concluded that alarming trends in both environmental changes and demographics made it urgently necessary to begin action. Since then, similar alarms have been raised through the 1992 Rio Summit, the 1997 Kyoto Protocol, and the 2015 Paris Agreement, as well as scores of other global assemblies at which scientists have repeatedly raised warnings that insufficient progress was being made. However, greenhouse gas (GHG) emissions are still rising, with increasingly damaging effects on the Earth's weather and climate. Profoundly troubling signs since 1979 include large increases in human populations, per capita meat and livestock production, world gross domestic product, global tree cover loss, soil pollution/desertification, fossil fuel consumption, the number of airline passengers and automobiles, and both total and per capita GHG emissions.

It's time to quit "studying" those issues and get on with first devising and then implementing practical solutions to them – not just more "*all of the above*" research muddling, spuddling, whining, and foot-dragging.

Concerted international effort to address fossil fuel's environmental impacts began with the UN's 1997 Kyoto Protocol to which many, mostly small and not particularly impactful, countries signed up. While the billions of dollars spent on climate science studies since then have generated thousands of papers/reports and paid for hundreds of other conferences both large and small, neither that science nor the policy changes of many countries favoring/subsidizing politically correct renewable energy have had much effect upon mankind's total GHG emissions Figure 5 . As the first version of this book was being written (circa December 2018) representatives from 195 countries had again gathered (in Katowice, Poland) for that year's United Nations Climate Change Conference, COP 24 (COP = "Conference Of the Parties"). That meeting was focused upon producing rules to flesh out the "details" of the 2015 Paris Climate

Accord (COP 21), the landmark agreement

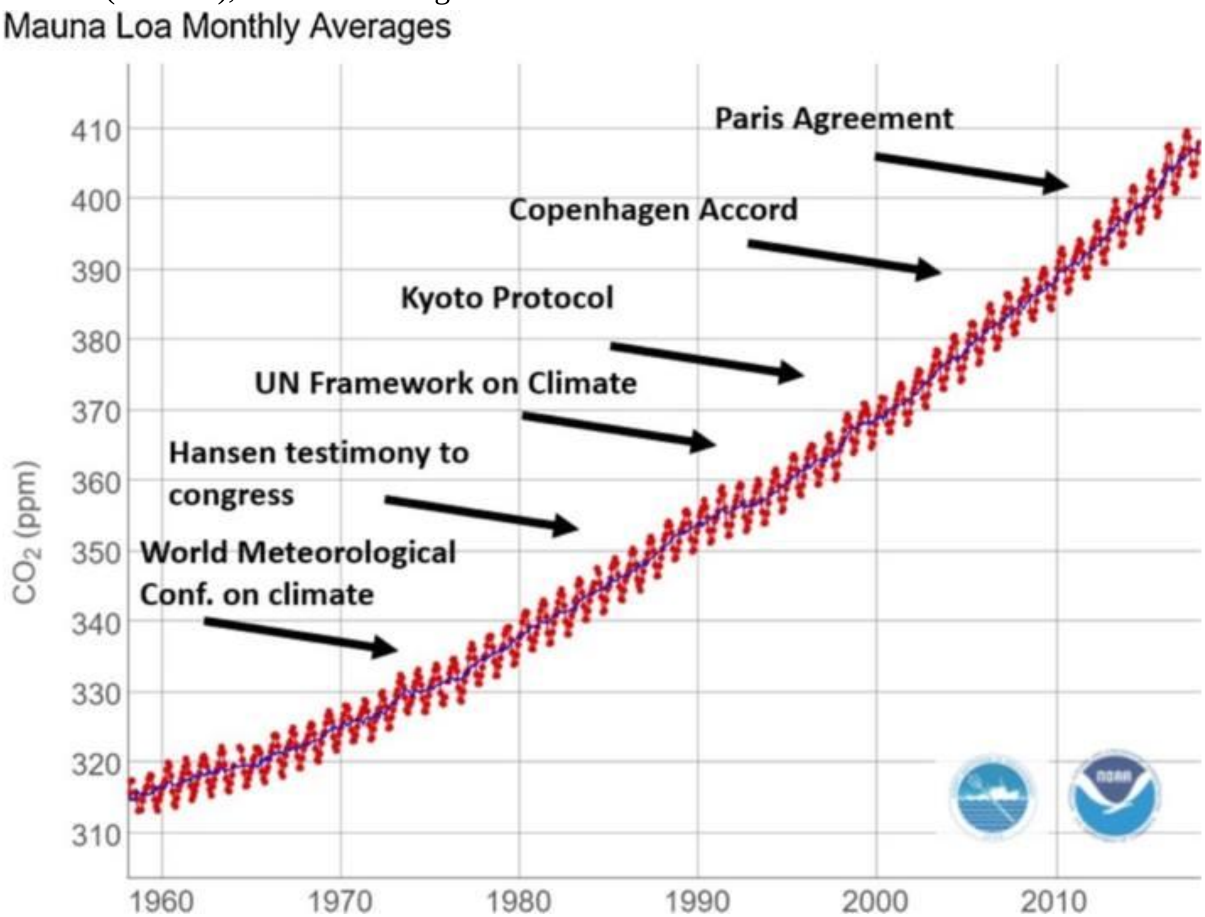

Figure 5 Atmospheric CO_2 ppmv

signed by its attendees except Nicaragua and Syria, to battle climate change and, hopefully, limit global warming to 1.5-degree Celsius, one-half degree under the 2°C limit set earlier at COP 15 (Copenhagen conference). Since 2015, the International Panel on Climate Change's (IPCC's) leadership has been trying to breathe new life into that accord amid backsliding from several key nations, most notably the United States, over commitments made when they signed it. To date, the IPCC's efforts have not really accomplished much because its key "parties" (biggest, richest, & most potentially capable countries) refuse to agree upon a mechanism ensuring that they honor their commitments with respect to either GHG emissions or contributions to an agreed-upon $100 billion/year fixit fund.

As far as sponsoring yet another international climate conference to study this situation is concerned, I doubt that more-of-the-same is apt to accomplish much. I grew up in Bismarck, North Dakota. When I wrote this paragraph (February 2021) its projected low temperatures throughout the next week were -16, -14, -21,-18, -25, -14, -3, and +2°F. It was likely colder than that in northern Minnesota or Norway. If the USA's energy policy setters really wanted to get realistic assessments from their scientific experts, they would insist that the energy conferences that their constituents' taxes are paying for were held in places like the University of Minnesota's Duluth Campus during the winter when there's not much wind or sunlight, rather than during the spring/fall in places like UCal's Stanford campus.

The British Petroleum company's annual Statistical Review of World Energy (BP 2018) contains not only information from the preceding year, but also historic data on consumption and production of all forms of energy during the last few decades[50]. Their principal conclusions are that humanity is not reaching the goals established by the Paris Agreement (Figure 6). In 2017, Mankind took a step backwards with respect to timid advances made during the two preceding years: the use of fossil fuels had grown, increasing CO_2 emissions by ~1.6%. That trend continues – anthropogenic CO_2 emissions rose another 2.7% in 2018 (Jackson et al, 2018). Worse, most climate models indicate that by 2100 AD, even if the emission "commitments" made by COP 21-24's attendees were to be honored, they would likely cause global warming of between 2.7 and 3.2 degrees Celsius, well above the 1.5–2 degree threshold that most of the world's climate modeling experts consider a tipping point beyond which Nature's positive (?) feedback mechanisms will render catastrophic impacts inevitable (Hansen 2008, Hansen 2016)[51].

One such mechanism would be sudden release of the vast amounts of methane trapped along continental shelves in the form of "methane hydrate" (aka methane clathrate). Such methane is produced when microorganisms or chemical processes break down organic matter that has settled to the seafloor, including dead fish, krill, miscellaneous plankton, and bacteria. A methane hydrate "ice" accumulation can form only when temperatures are low and pressures high. If part of such a deposit is exposed to warmer temperatures or a drop in pressure, it can turn to gas thereby tremendously expanding its volume which stirs up everything surrounding it. That in turn increases convective heat transfer to any nearby, similarly buried, surrounding "ice" destabilizing it as well. This constitutes a positive feedback driven "chain reaction" which may cause sudden release of the entire formation's methane accumulation. That release in turn heats the atmosphere which further warms coastal waters containing other methane ice deposits. This

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[50] Now almost three years later, global emissions are still rising. after the world has spent a few trillion dollars since 2010 trying to decarbonize, $503 billion in 2020 alone, carbon emissions are still increasing https://www.forbes.com/sites/jamesconca/2021/07/23/whats-happening-global-emissions-are-still-rising. Even though the COVID 19 pandemic slowed it a bit during 2020-2021, total GHG emissions in 2022-2023 will break all records exceeding 55 billion tons/year. According to the International Energy Agency, global electricity demand will increase by 5% in 2021 and 4% in 2022, half of which will be met by burning fossil fuels, particularly coal in the developing world. CO2 emissions from the power sector will rise to record levels in 2022, exceeding 34 billion tons.

[51] A tipping point is that magic moment when an idea, trend, or social behavior crosses a threshold, tips, and spreads like a pandemic. Kitty world's tipping point was when supermarkets began to stock/sell some genius' calcined-clay "cat sand" invention.

positive feedback loop is probably what set off the Paleocene–Eocene Thermal Maximum (PETM), 55 million years ago that spiked global temperatures upwards by 5-8 °C - (far more than that required to melt both Greenland and Antarctica's ice caps & thereby raise worldwide sea levels by several hundred meters.[52]

Researchers have identified another "positive" feedback mechanism that's apt to contribute to pushing the Earth's ecosystems past such a tipping point (Zhu 2020). Freshwater ecosystems release more methane than expected from predictions strictly based upon temperature increases due to a shifting balance of the microbial communities within them. Methane's production and removal therein regulated by two types of microorganisms, methanogens -- which naturally produce it-- and methanotrophs that convert it to the much less harmful GHG-wise, carbon dioxide. Those microbes have different sensitivities to temperature and global warming is likely to shift their equilibria in the wrong direction.

"*We are waking up the methane dragon. And that's a dragon that we really want to keep in the box*". Samantha Joye, oceanographer and microbiologist.

Scientists with NASA's Arctic Boreal Vulnerability Experiment (ABoVE) are using planes equipped with the Airborne Visible Infrared Imaging Spectrometer (AVIRIS – NG) to fly over some 30,000 square kilometers of the Arctic landscape to detect methane hotspots. They are finding lots of them (Elder 2020).

Furthermore, for each degree that the Earth's temperature rises, the amount of methane entering its atmosphere from microorganisms dwelling in lake sediment and freshwater wetlands - currently the primary sources of that gas - increases several-fold (Yvon-Durocher. 2014). As temperatures rise, the relative increase of methane emissions will outpace that of carbon dioxide from those sources. There are also vast amounts of methane trapped within the Arctic's currently

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[5252] This mechanism also works in reverse. The Eocene's "Azolla Event" 47-49 million years ago is likely responsible for most of today's huge subsurface arctic methane hydrate accumulations. During that period, the atmosphere's CO_2 concentration dropped fivefold and the surface temperature at the Earth's then almost land-locked ~4 million km^2 arctic region dropped by over 20 Centigrade degrees. Temperatures elsewhere dropped too which is likely the reason that Antarctica's icecap started to develop then. When Azolla (a rapid growing surface water plant which can double its biomass in under two days) dies, it settles to the bottom. Because that region's sea-bottom water was already anoxic, some of that accumulation didn't oxidize & therefore eventually turned into a soup of fossil fuel compounds including methane. Since that water was also cool, this event formed methane hydrate deposits consisting of biologically "sequestered" atmospheric carbon (Stein 2006). The discovery of frozen plants under Greenland's ice sheet confirms that it has melted entirely during recent warm periods like the one we are now creating with anthropogenic climate change. That study (Christ et al 2021) indicates that Greenland is more sensitive to climate change than previously understood -- and at risk of irreversibly melting. That much fresh water would raise sea levels by about 7 meters.

frozen muskeg, which, along with that emitted by southern wetlands and rice fields, is apt to cause runaway global warming.

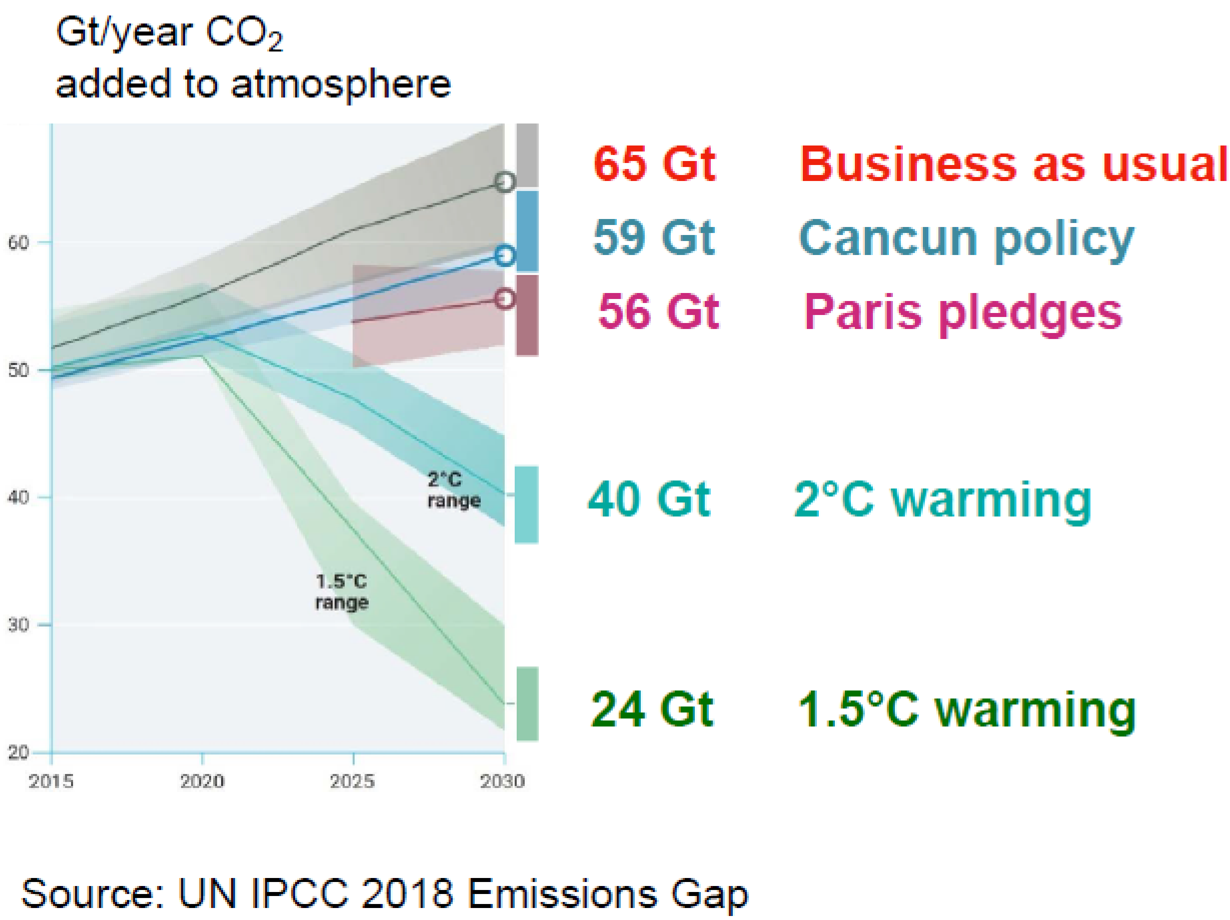

Figure 6 Mankind's CO_2 equivalent "Emissions Gap"

Methane's molecular (or volume wise) global warming potential (GWP) is initially about 150 times greater than that of CO_2 and averages about 84 time worse during the first twenty years thereafter[53]. Both gases are currently in a positive feedback loop initiated by global warming. Fracking leakage has recently been recognized to be an important contributor to methane's total radiative forcing which now amounts to about 25% that of carbon dioxide. It's possible that we may have already triggered a methane runaway event which our descendants won't be able to stop.

[53] That figure (84) is consistent with atmospheric half -lives of 9.1 and 100 years for methane and carbon dioxide respectively.

Another positive feedback mechanism that's pushing the world towards catastrophe, is that the vast amounts of organic carbon stored in Arctic soils -much of which is combustible peat - is being dumped into the atmosphere by wildfires. This of course dries more peatland increasing the likelihood of bigger and more frequent wildfires.

What is particularly scary is that if "wet bulb" temperatures were to rise above ~95°F over most the world during summer months, most of its mammals including those humans unable to pay for air conditioning may become extinct as the earth turns back into same hot house planet it was during the age of the dinosaurs.

The number of countries announcing pledges to achieve net-zero emissions over the coming decades continues to grow[54]. But the pledges by governments to date – even if fully achieved – fall well short of what is required to bring global energy-related carbon dioxide emissions to net zero by 2050 and give the world an even chance of limiting the global temperature rise to 1.5 °C (Cherp et al, 2021).

According to its authors the IEA's " roadmap to net zero by 2050" published May 2021 represents, " *the world's first comprehensive study of how to transition to a net zero energy system by 2050 while ensuring stable and affordable energy supplies, providing universal energy access, and enabling robust economic growth. It sets out a cost-effective and economically productive pathway, resulting in a clean, dynamic and resilient energy economy dominated by renewables like solar and wind instead of fossil fuels. The report also examines key uncertainties, such as the roles of bioenergy, carbon capture[55] and behavioural changes in reaching net zero*" https://www.iea.org/reports/world-energy-outlook-2021 .

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[54] Since 1995 the countries bound by the UN Framework Convention on Climate Change (UNFCCC) have missed just one opportunity to have another conference of the parties (COP) - when the pandemic struck in 2020. These COPs have produced action plans (Bali, 2007), mandates (Berlin, 1995), protocols (Kyoto, 1997), platforms (Durban, 2011, acrimonious breakdowns (Copenhagen , 2009) and agreements 2015) (Paris, 2015). Greta Thunburg has accurately characterized them as just more "blah, blah, blah".

[55] Carbon capture and storage (CSS) is a technology first commercialized in the 1970s. Back then it was called "enhanced oil recovery" because the carbon dioxide recovered from oil and gas production was injected into depleted oil and gas reservoirs to re-pressurize them to extract more fossil fuel. As the climate change movement gained momentum, the oil/gas industry rebranded it as a "climate-friendly" process with a new name: "carbon capture utilization and storage". Today (2022) over 70 percent of carbon capture projects are still, in fact, enhanced oil recovery projects facilitating yet more greenhouse gas emissions. The Institute for Energy Economics and Financial Analysis estimates that 80–90 percent carbon of the captured throughout history were so-used found its use in enhanced oil recovery— only 10 to 20 percent has been stored within dedicated geological structures. Despite its long history, carbon capture remains problematic. Another IEEFA study found that 10 of the 13 13 flagship projects failed or underperformed against their designed capacities, mostly by large margins. To me this problem sounds like another of Westinghouse's "Opportunities for Excellence". Here's my suggestion: As far as permanent "carbon" disposal sites go, there's also the moon to consider. No one's drilled any deep holes up there

A source close to the World Bank's (IMF's) October 2021 discussions of that road map indicated that some of the world's biggest financial institutions believe that that roadmap is "*a fairytale*" that "*no one is willing to put their name against*". https://www.edie.net/news/6/Finance-giants-to-G20-leaders--Close-policy-loopholes-to-end-financing-for-activities-that-will-derail-net-zero/

One of the members of the little group of old technical nerds that I've become a member of opined that "*its report predicts a seven-fold increase in wind and solar and a two- fold increase in nuclear. I would have guessed a more practical roadmap would have been a seven-fold increase in nuclear and two-fold increase in wind and solar. Critical mineral requirements increase more than five-fold. The financial investment requirements are 4 to 5 trillion dollars per year. The world GDP is 80 trillion a year by comparison. That means about 6% of its GDP will be needed for investments in that energy transition, not including its ongoing operating and maintenance costs.*

I don't see a lot of international cooperation to get to net zero by 2050. IEA has included a chart suggesting it might take as long as 2090 to get to net zero. If that actually transpires, perhaps we may want to start to pay more attention to climate change adaptation, either at the national level or at the personal level."

To which another member responded with, "*It's a plan for global poverty. The world currently has 1.3 billion "middle class: people out of a total of 7.5 billion that's scheduled to rise to 10 billion before leveling off. Energy efficiency improvements are in the noise level in terms of energy savings for most of that "poor" world. 90% of the money required for a low-carbon switch will have to be spent in the less developed world. Does anybody seriously think the U.S. and Europe will send a couple of trillion per year to the rest of the world? What this really says is that if we want to stop climate change, spend $10 billion per year for geoengineering and then spend the next century working on the energy source transition . It is a powerful statement that at the end of the day, the only "cure" will probably be geoengineering—probably Chinese geoengineering*."

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yet & the Chinese say that they will be going back there soon. Maybe we could ask 'em to drag a Kevlar rope along behind their rocket & tie it off to a mountain or some other substantial anchoring point. If they did that for us, whenever we do finally screw up enough resolve to go back again, all we'd have to do in winch ourselves up along that rope dragging a CO_2 pipe/hose behind us – no having to get ourselves to >17,000 mph with a super expensive, atmosphere polluting, rocket engine. If they/we did that, we could do our GHG sequestering up there where nobody gives a sh.. about the "environment".

I'm hoping that we don't have to resort to what "*geoengineering"* usually means (dumping enough sulfur trioxide into the stratosphere to reflect incoming sunlight back into space) but it may become necessary if we don't get on with implementing the sort of nuclear renaissance that I'm advocating **soon** – not after another 50 years of "studies".

Since today's economic development models are largely based upon the continued consumption of fossil fuels, they pose serious threats to the environment. The term "climate change" is an ameliorative for "global warming" which is itself a blanket term for the effects of excessive anthropogenic GHG emissions: ocean acidification, pollution, droughts, floods, desertification, hurricanes, tornados, and extinctions. While some regions are likely to get wetter as our world warms, others already too dry are likely to get drier. Since the turn of this century, Central Europe has experienced six summer heat waves and droughts, which killed thousands of people and caused millions of Euros worth of damage. When the Aprils of those years were too warm with little precipitation, too much of that region's soil's moisture evaporated thereby engendering a subsequent summer drought. One of the reasons for Central Europe's droughts is that the decreasing temperature differential between Arctic and middle latitude shifts the jet stream thusly forming a blocking high-pressure system over the North Sea and parts of Germany.

"Albedo (surface reflectivity) enhancement" is another "positive" feedback mechanism likely to cause or exacerbate thermal runaway[56]. Major changes in the Earth's surface temperature are not driven directly by greenhouse gases but by changes in albedo caused by changes in vegetation, snow, ice, and water cover which are, in turn, a function of atmospheric GHG concentrations and dust (soot) deposition. Surfaces covered with clean snow reflect most of the sunlight striking them back into space. When some of that snow/ice melts, more sunlight is absorbed and subsequently degraded to heat energy which, of course, tends to melt still more of it[57]. That's the main reason that there's been a lot more "global warming" going on in the Arctic than near the equator. In Canada, that mechanism is currently tripling the Earth's average warming rate.

In the Earth's equatorial and lower temperate regions, the average annual snow cover/ice is small meaning that the so-induced changes in albedo are relatively small. At its north and south poles there is constant ice cover, meaning that changes in mean albedo are also small there.

[56] Dr. Charles Rhodes helped me with this section.

[57] Because solar panels absorb almost all the light striking them, covering a typical desert's light-colored (reflective) sand with them further heats that desert's ground level air making everything worse for everyone except those panel owners' pocketbooks. It's another reason why the world's poor people are apt to just keep getting poorer.

However, in much of northern Canada and Russia, where there is snow cover for about 50% of the year, small increases in atmospheric CO_2 concentration or dust/soot deposition produces relatively large changes in temperature and their consequences both good and bad. In the Northern hemisphere anthropogenic pollution has greatly increased summer melting of the southern edges of the Arctic Ocean's ice pack resulting in enormous swings of that region's albedo and mean temperatures (seawater is practically a "black hole" as far as sunlight is concerned).

As was amply demonstrated in 2021, those changes affect the position of the Earth's "jet streams" which can trigger severe winter cold snaps as far south as Texas via a "polar vortex". Since the atmosphere's CO_2 concentrations are not apt to be going down soon, we can reasonably expect to experience repeats of that and other extreme weather events.

It is important for the USA's leaders to grasp that these extreme weather events are a product of their fossil fuel policies and our subsequent uses of them. The solution was obvious 50 years ago, but short-term political and financial drivers overrode rational scientific thought/actions and continue to do so.

In 2020, the US alone experienced 22 weather/climate disaster events with losses exceeding $1 billion each (NOAA 2021). Those events included 1 drought, 13 severe storms, 7 tropical cyclones, and one giant wildfire plus lots of smaller ones. Overall, they resulted in the deaths of 262 people and had significant economic effects in the impacted areas. The 1980–2020 annual CPI-adjusted billion-dollar disaster rate was 7.0/year; the annual average for the most recent 5 years (2016–2020) is 16.2 events year. 2021 will almost surely exceed that figure – probably substantially.

The second week of February 2021 began with the most destructive weather-caused electrical system blackout that the US has ever experienced. In Texas at least 140 people died and over $50 billion dollars' worth of damage was done. That's not too surprising because 126 of the USA's 286 $billion-plus weather disasters between 1980 and 2020 have hit the same state.

Texas's Governor responded by blaming environmentalists, renewable power, and, of course, the Democrats.

The USA's Western states from Wyoming to the Mexican border and from the Pacific to the Mississippi, have been experiencing both abnormally low snowpack/rain levels and abnormally high temperatures for over two decades. During the last ten days of June 2021, NASA tracked the course of huge heat dome as it moved from the ocean across the USA's Pacific Northwest and Western Canada. Temperatures reached 109°F in downtown Seattle, WA 114°F in Wenatchee, WA, and 116°F degrees in Portland OR. Surprisingly, it was even hotter further north - British Columbia's village of Lytton set a new all-time Canadian heat record of 119 degrees Fahrenheit (48 degrees Celsius) on June 29 and broke it the next day with 121 °F (49 degrees Celsius).

Of the 800 deaths in British Columbia from June 25 to July 1, 2021, the BC Coroners Service has determined that 691 were heat related.

Only a third of that region's homes including many recently built condos and apartments have air conditioning because it has traditionally been unnecessary. That belief system has just been mugged. Without air conditioning, heat waves like 2021 summers are truly life threatening and most of the region's people have not prepared for it. Of course, its richest people aren't being seriously inconvenienced but everyone else must get highly creative (or lucky) to keep their home cool enough and hopefully able to seek refuge elsewhere when it becomes too hot.

Lots of businesses either shut down completely or only operated for half days. Cooling centers opened in many of Oregon, Washington, and California's cities.

Some relief is expected for that region's seaboard cities, but the heat wave will continue for inland cities. Water flows are far below normal in its Columbia and Colorado river dams. Those dams which have served as the lifelines of much of the West for many decades are soon apt to become far less useful, i.e., "stranded assets".

The Southwestern USA's merciless summertime heat and ongoing "megadrought" is set to cause massive disruptions in the rest of that country as well. Last summer's relentless, 100-degree heat and drought killed a record 520 people in just one state, Arizona — twice the total deaths reported nationally from hurricanes, wildfires, tornadoes, severe storms and floods, and a significant increase from the past decade, when heat-related deaths there had never exceeded 283.

Insufficient water means much of the Western USA's economic activity may slow or cease. Its inhabitants' electricity will be constrained and likely curtailed due to reduced hydroelectric production because many of them had recently gotten much of their electricity from hydropower dams many of which are experiencing record-low water levels.

Farmers depend on electricity to water their crops and livestock, milk cows, dry grain, and preserve produce. Low surface water levels and depleted underground aquifers mean the USA's farmers will not be able to produce crops or raise livestock. Already too-high US food prices due to the COVID 19 pandemic's disruptions will continue to escalate.

This most obvious manifestation of this is the ridiculously high cost of fruits and vegetables in US supermarkets. This is largely due to breakdowns in California's Central Valley agricultural system which serves as the entire nation's truck farm – much of what's on your table except the meat(s) and starches (breads, pasta, cereals, etc.) was probably grown there[58]. That's about to end because there's no longer enough fresh water to keep irrigating its crops. California's once huge underground aquifer has been sucked almost completely dry, there's very little water left in its reservoirs, and little prospect of refilling them[59].

This means that California's leadership should assume that they will soon have to build another 15-20 gigawatts worth of reliable generating capacity to power new seawater desalination systems. not just more huge, ugly, and unreliable windmills and solar farms.

Climate modelers expect the amount of the earth's land affected by drought to grow and water resources in those areas to decline as much as 30 percent by mid-century. These changes will be partly due to an expanding atmospheric circulation pattern known as the Hadley Cell in which warm tropical air rises, loses its moisture to thunderstorms, and descends in the subtropics as dry air.

The USA's recent spate of "polar vortex" cold spells are caused by the fact that warm moist air is less dense[60] than cold dry air and therefore does not keep the latter at bay when polar air decides to spread southward. Weather is and always been variable, and no single anomaly or storm can be attributed to climate change, but disasters like those experienced by many of Texas's inhabitants during February 2021 and the Pacific Northwest's a few months later will inevitably occur more frequently. The earth's polar regions have warmed faster reducing the lessened global temperature gradient which keeps Arctic air from spilling southwards. Its semi-arid and desert areas are expected to expand as jet streams and storm patterns continue to shift to higher latitudes[61].

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[58] The Central Valley produces 40% of the nation's table fruits, vegetables, and nuts on 1% of U.S. farmland. annually. That's only possible due to intensive groundwater pumping for irrigation and river and stream flow captured in reservoirs. For over 60 years, growers have been pumping more water from its aquifers than can be replenished by natural sources, causing the ground level to sink and wells repeatedly redrilled deeper and deeper.

[59] The same thing is happening to the huge Ogallala aquifer underlying the USA's Central Plains - most of Nebraska, eastern Colorado, Kansas, western Oklahoma, & central Texas. Their crops are primarily commodities raised for export & over fattening livestock – not as "people food". In that region, remaining competitive with the USA's naturally better-watered eastern corn belt states is totally dependent upon pumped irrigation Relief is not in sight - as of 3April2022, California's mountain snowpack was 4% of "normal".

[60] Much of the Earth's weather is driven by the facts that its molecular weight (18 g/mole) is well under that of air (~29), the amount of water vapor in its atmosphere varies with temperature, and it's both condensable and freezable.

[61] https://www.climatehotmap.org/global-warming-effects/drought.html

An expert meteorologist interviewed by CGTN'S reporter (30Nov2022) in the wake of its latest hurricane: "*The hurricanes of the 2020s are not those of the 1990's - they're now larger, slower moving, windier, wetter, and doing more damage part of which due to the Florida coastline's 9-inch higher sea leve*"

Figure 7 Other manifestations of climate change: Norway's winter 2019-2020[62] & a typical, late-summer, California reservoir (https://www.thenation.com/article/archive/the-california-drought-is-just-the-beginning-of-our-national-water-emergency/)

Global warming affects evapotranspiration (the movement of water into the atmosphere from land, water, and plant surfaces due to evaporation and transpiration) which will likely lead to increasingly below-normal river, lake, and groundwater levels and insufficient soil moisture in agricultural areas. Precipitation has been declining in the tropics and subtropics since 1970: Southern Africa, its Sahel region, Brazil, southern Asia, Australia, the Mediterranean, and the US Southwest are all getting drier (Williams 2020). Even areas that remain relatively wet can experience long, dry conditions between extreme precipitation (flooding) events like those currently (Jul2021) occurring in the Northeastern US and China, Germany, Belgium, and Switzerland – over a thousand dead and many more unaccounted for[63].

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[62] Snow extent in the Northern Hemisphere is now (26/11/2022) among the highest levels seen in 56 years increasing the likelihood of a cold Early Winter in both North America and Europe.

[63] These floods happen when "atmospheric rivers" consisting of wind streams bearing lots of tropical water vapor encounter cool land. Because they can transport as much water as 27 Mississippi Rivers if the conditions are "right" (wrong?) their relentless rains often cause extensive flooding and mudslides. They're rated by a system called Integrated Water Vapor Transport (IVT). Meteorologists base initial AR ratings on the forecasted IVT (the "river's" total mass atmospheric water/m^2) assuming that the storm will last 24-48 hours. 250-500 kg/m2 is a Category 1 IVT, 500-750 is a Category 2 etc. Anything over 1,250 is considered Category 5. . If a storm is expected to last

Due both to anthropogenic pressures and global warming, a good deal of the soils in Europe's Mediterranean region are reaching "*critical limits for their ability to provide ecosystem services*," which includes farming and absorbing carbon (Ferreira et al, 2022). About 25 percent of the land in the EU half of the Mediterranean basin are experiencing high or very high risk of desertification, mainly due to erosion, declining organic matter and biodiversity, contamination, salinization, sealing (e.g., due to road & building construction) and compaction from farm machinery and domestic animals. Many of the physical, chemical, and biological degradation processes are well-documented, while others -- such as the loss of soil biodiversity -- are not. Organisms and species such as worms and ants which provide biodiversity and enrich the soil are under threat from depletion of organic matter, pollution from pesticides and from urban/industrial areas, compaction, and erosion

Climate change will change crop yields if agriculture continues with current plant varieties and cropping systems. On average, heat stress will not pose problems for European crops when there is sufficient rainfall. However, it will pose a problem for their/our most productive food crop, maize (corn), in particular. Drought poses problems that higher CO_2 concentrations would not help as it *might* when there's enough rain. "Might" because another consequence of anthropogenic carbon dumping is that while it may seem that there's an upside to rising atmosphere carbon dioxide concentrations - some plants will grow faster - that's not necessarily "good". Researchers at Ohio State University (Demartini 2018) have recently shown that for food-type crops, quantity isn't the same as quality. Most such plants are indeed growing faster but contain more starch and less protein and vitamins That change is happening because the atmosphere's carbon dioxide concentration is ~50% higher than it was at the beginning of the industrial revolution. Though CO_2 is necessary for plants, too much of it can reduce the amount of "protective" nutrients in them, including antioxidants vitamins C and E and trace minerals like iron and zinc[64]. In Europe it is likely that drought will be a bigger problem than higher temperatures, and worse for maize than wheat (Webber et al 2018).

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over 48 hours, it moves up a rung on the scale, while any expected to blow through in under 24 hours is downgraded a rung. (Average Mississippi flow =22,000m^3/s (about 10% of that the of the AMAZON))

[64] Mechanistically what's been happening is that higher atmospheric carbon dioxide levels reduce photorespiration during which plants take in oxygen, release excess carbon dioxide, and produce things like glycolic acid that they can't immediately use. For C3-type plants (most of our food-type plants, corn is an exception) to turn glycolic acid into something useful to them (glucose), they must do more photosynthesis. Lowered photorespiration rates enabled by higher atmospheric carbon dioxide concentrations lower the plants' stress level which is unfortunate because plants respond to stress by producing additional" protective" things like protein and antioxidants (e.g., vitamins C & E). In short, as atmospheric carbon dioxide rises, lessened photorespiration stress translates to increased plant growth but compromised nutritional quality. That won't help our descendants consume a better, more balanced, diet.

The Earth’s ocean’s major currents help control its climate by moving warm surface waters north and south towards the poles, with colder deep water pushing back toward the equator from them. The best known of these is the Gulf Stream running up the USA and Canada’s eastern coastlines and conveying warm tropical water towards Europe giving the UK a much more moderate climate than its location—like that of northern Ontario—would otherwise dictate. The force driving it is that when water cools off, its density increases causing it to the ocean floor and begin to flow back towards the equator. Climate scientists have detected warning signs of its collapse, “*an almost complete loss of stability over the last century*”, of what they call the Atlantic Meridional Overturning circulation (AMOC). Its currents have recently been at their slowest point for at least 1,600 years, and the latest analysis suggests that they may be nearing shutdown.

Such an event would have catastrophic consequences elsewhere too, severely disrupting the rains that billions of people depend on for food in India, South America, and West Africa; increasing storms and lowering temperatures in Europe; and pushing up the sea level off eastern North America. It would also further endanger the Amazon rainforest and Antarctic ice sheets. The temperature differences driving that flow are expected to fade as the Earth continues to warm especially towards its poles. That’s why anthropogenic “global warming” may very well cause disastrous cooling as far as Northern Europe is concerned.

The West Antarctic Ice Sheet lying atop the continent to the adjacent Amundsen Sea has been particularly interesting to climate researchers. Near the coast, its ice is still in direct contact with the soil; farther toward the open sea, it floats. Because climate change progressively warms seawater, it is increasingly eroding the ice shelf from below. The grounding line - the last point at which the ice still rests on the ground -moves farther and farther inland. Due to meltwater and calving icebergs, the Thwaites Glacier, which flows into the Amundsen Sea, now loses twice as much ice as 30 years ago. If the West Antarctic Ice Sheet were to entirely collapse, global sea levels would rise by more than three meters immediately flooding many of humanity’s biggest cities and forcing billions of people to abandon their homes and livelihoods.

The most important thing we must do is to quickly replace today’s fossil fuel-based energy system with something that is both “clean” (no GHG gas emissions) and sufficiently reliable (not intermittent) to power a bigger, more interconnected, more prosperous, cleaner, fairer, and happier world than is the one we’re living in today.

"*To prevent the worst effects of climate change, we need to reach near-zero emissions on all the things that drive it—agriculture, electricity, manufacturing, transportation, and buildings—by investing in innovation across all sectors while deploying low-cost renewables," Nuclear energy is one of these critical technologies. It's ideal for dealing with climate change because it is the only carbon-free, scalable energy source that's available 24 hours a day."* Bill Gates

In an address at Columbia University 20December, 2020, U.N. Secretary General António Guterres said…

"*To put it simply, the state of the planet is broken. Dear friends, Humanity is waging war on nature. ... Nature always strikes back -- and it is already doing so with growing force and fury*."

He went on to plead that world leaders act with more urgency pointing to the collapse of biodiversity, the bleaching of coral reefs, and "apocalyptic" fires and floods. He noted that global emissions are 62 percent higher now than when international climate negotiations began three decades ago.

3.2 How much sustainable energy will our descendants need?

As awful as global warming's environmental impacts are apt to be, its effects upon civilization will be dwarfed by those caused by our reaching peak oil, peak gas, and peak coal well before the end of this century. International internecine quarreling over what's left could set off a civilization-ending WWIII – something that Mr. Putin's latest invasion of Ukraine should remind us of.

Roughly 40% of the USA's raw/primary energy demand is currently satisfied with electricity – most of the other 60% generates heat utilized for purposes for which electricity would cost too much[65]. Global electricity demand doubles every other decade but remains the most difficult form of energy to provide in a simultaneously sufficient and reliable manner[66]. Some three billion people currently live where per-capita electricity consumption is under that of a small modern refrigerator. How well the world's leaders close the colossal gap between the world's electricity rich and the electricity poor will determine their success in addressing human/women's rights, poverty, hunger, unemployment, inequality, and climate change.

The USA's ~330 million peoples' exceptionally "rich" lifestyle[67] is nominally supported by the ~100 quads of raw/primary energy that they consume each year. That figure has remained roughly constant for over two decades because the USA's consumption-driven economy consumes energy and other resources from areas outside of its own not included in that tally (LLNL 2018). "Ecological footprint analysis" (Wackernagel 1996) provides a more realistic

[65] Examples include residential space heating and making cement.

[66] The reason for this is that electricity generation must always match demand because its suppliers and consumers can't afford enough "fuel tanks" (batteries) from which it could be drawn as needed. For instance, enough Tesla ***Power Walls*** to store the raw energy represented by one gallon of gasoline would cost about $20,000.

[67] "Rich" in terms of material things because a typical USA citizen still owns more "stuff", drives further in a bigger car, and lives in a larger house than do most Europeans.

measure of the USA's resource ...consumption.   Table 2 provides 2009's figures – about 41% of the USA's global GHG emissions originated in/by other countries.

Table 2 US Greenhouse gas emissions including those originating from products/services made abroad.

Service	Percent total GHGs
Infrastructure	1
Appliances & devices	7
Non-local passenger transport	9
Food provision:	12
Local passenger transport	13
Building HVAC & lighting	21
Provision of other goods	37

(source: Joshua Stolaro, Products, Packaging and U.S. Greenhouse Gas Emissions, Athens, GA, Product Policy Institute, September 2009).

The defining inequality in today's world is the disparity between the electricity-rich and the electricity-poor. In fact, there are more than 3 billion people today who are using less electricity than that consumed by an average American's refrigerator. Currently, all of us humans annually consume ~2,300 GW's worth of electrical power which works out to an average of ~307 continuous watts/person. However, like most of the things that determine human lifestyles, its distribution is uneven. People living in Scandinavian countries currently consume the most, about 2500 watts per person, followed by the USA's and Canada's ~1400 W. However, most of Latin America's people consume under 250 W, South Asia's below 100 W, and Africa's, under 25 W (Figure 8). Over a billion people don't have access to electricity at all. If mankind is to prosper, clean, affordable and dependable (not intermittent) power must become available to everyone and must be provided in a way that's sustainable, doesn't pollute the air, poison the land, or change the climate.

Anyway, ~80 percent of the USA's primary/raw energy is provided by fossil fuels translating to a mean per capita raw/primary energy consumption rate (power) of 9860 watts [99.5E+18J/3.15E+7/320E+6] or about eight [99.5/3.2E+8/570/7.5E+9] times that of the world's average person today. Since one joule's worth of raw/primary (heat) energy currently provides about 0.4 joules worth of useful "energy services" (the efficiency of most of fossil fuel's applications including making electricity is Carnot-limited) and Europeans can apparently live about as well consuming one-half that much raw/primary energy per capita, let's assume that supporting the life styles of each of the future's equally EU-rich people would require ~2 kW's [9860* 0.5*0.4 = 1972 ≈ 2000] worth of energy services (electricity). Consequently, a world with 11.2 billion such people must possess power plants able to supply an average of about twenty-two TWe (terawatt electrical) [11.2E+9*2000*3.15E+7/1E+12/3.17E+7 = 22.4] which figure is about 6 times higher than the world's current just-electricity energy consumption (~3.9 TWe). Finally, assuming that each individual region's peak power demand is about 40% higher than its average and that no magic world-wide, zero-loss, "super-grid" exists, our descendants would need ~30,000 [22.4*1.4*1012/109] one GWe power plants to live that well.

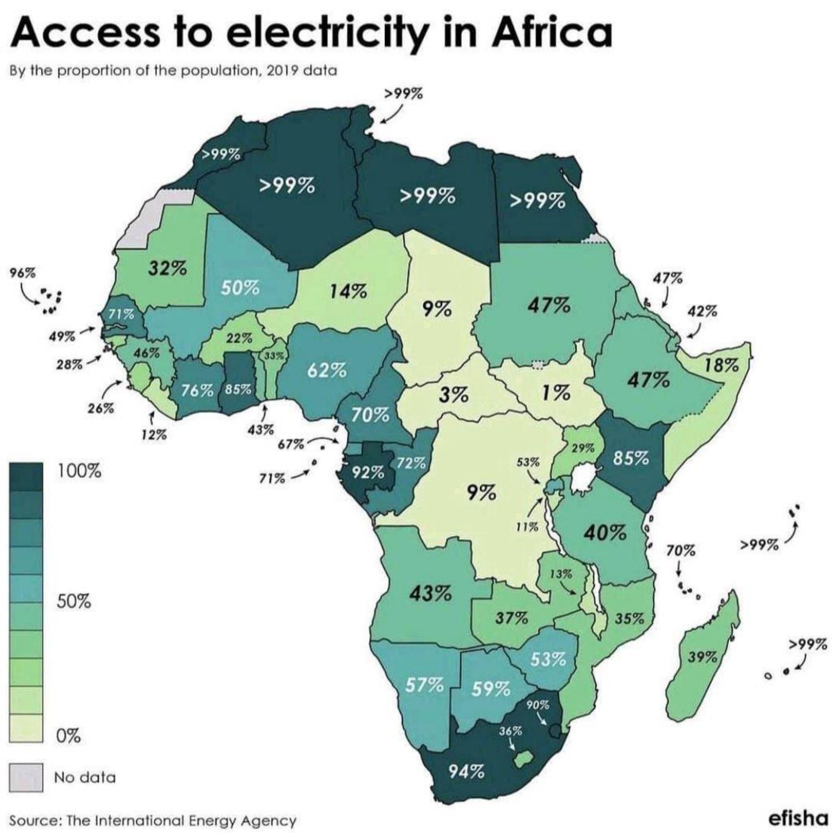


Figure 8 African electrification

That power could not be generated with fossil fuels because even if there were enough of them (there isn't[68]), burning it would have catastrophic consequences. For example, the raw/primary

[68] We often see headlines like, "*the USA has 7 to 9 trillion barrels of oil*" apparently meant to reassure us that there's nothing to worry about (Nextbigfuture 2012). However, if we bother to read beyond that headline, we discover that such oil is very "tight" and would be extremely difficult (expensive) to recover; meaning that perhaps one trillion barrels of it would be recoverable with current fracking technologies. However, we're next assured that with "*aggressive use of new fracking technologies combined with in situ 'fire flooding' and/or 'water flooding'*" perhaps 20-30% of it might be recovered. One trillion barrels of oil represents about 610 Exa Joules worth of raw heat energy which is equivalent to about one year's worth of Mankind's current, not a richer, bigger , and more egalitarian future world's peoples' energy demand.

(heat) energy represented by the world's remaining 1139 billion tonnes of coal reserves, 187 trillion m^3 of natural gas, and 1.707 trillion barrels of petroleum, (BP 2017) is about 5.0E+22 J's which, if consumed by 40% Carnot efficient power plants, could generate 22 TWe for 29 years - ~35% of an average first-world human's life span. Additionally, those reserves collectively contain about 1200 Gt of carbon which, if converted to CO_2 and dumped into the atmosphere would push global warming well past any of the "tipping points" suggested by the world's climate modeling experts[69].

To better understand what these facts and figures mean, it's necessary to consider a longer time scale than that which we customarily concern ourselves with. Figure 9 was excerpted from a paper written/delivered by the one of the petroleum industry's most influential geologists (and, eventually, its most influential gadfly), Professor M. King Hubbert, sixty-five years ago (Hubbert 1956). It depicts Mankind's total energy consumption extending from the dawn of recorded history 5000 years ago to 5000 years in the future assuming that human population eventually stabilizes, and we've chosen to replace finite fossil fuels with a sustainable (breeder reactor-based) nuclear fuel cycle before civilization collapses. To Professor Hubbert, "*on such a time scale, the discovery, exploitation, and exhaustion of the Earth's fossil fuels will constitute an ephemeral event*."

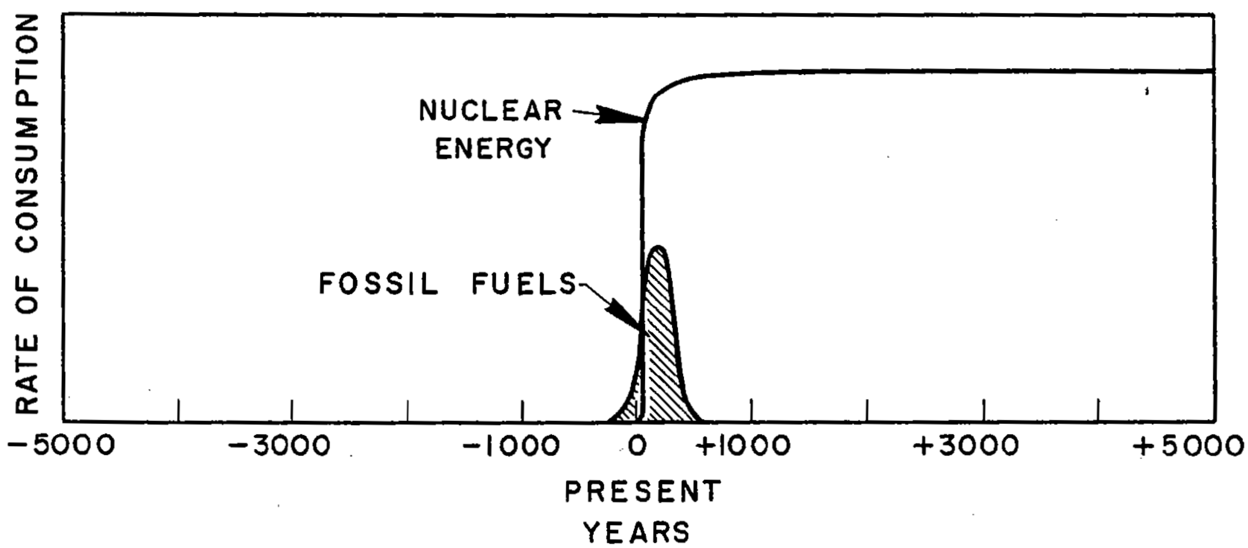


Figure 9: Mankind's long term energy consumption (Hubbert 1956)

[69] Dr. Chris Turney's book, "Ice, Mud, and Blood" (Turney 2008) is the most compelling book I've read yet about how Mother Nature's sundry "tipping point" mechanisms could convert global warming into "Global Catastrophe". The grim lesson of paleoclimatology is that our home planet seems to respond far more aggressively to small provocations than projected by most of today's climate models. His book takes its readers on a trip back to the end of the age of dinosaurs, beginning with the familiar and relatively mild climates of recorded history and ending in the feverish, high-CO_2 greenhouse planet of the early age of mammals, 50 million years ago. It's a sobering journey warning of catastrophic "surprises" likely in store for us.

To put Figure 9's timeline into proper perspective, its 10,000-years represents only about 5% of the time that we modern humans (Homo Sapiens) have existed.

Figure 10 is a more up to date (2015) depiction of the situation that we've put ourselves in. It compares the amount of energy that Mankind is currently consuming per year to the various energy resources/reserves supplying most of it. Its uranium-based number/circle area assumes

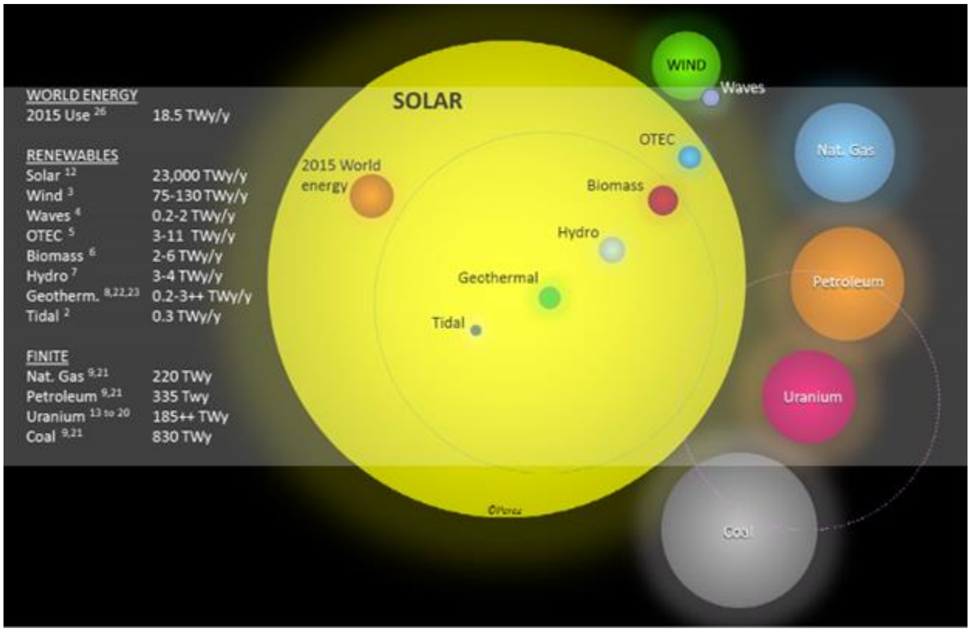


Figure 10. Total finite and potential energy resources (Perez & Perez 2015)

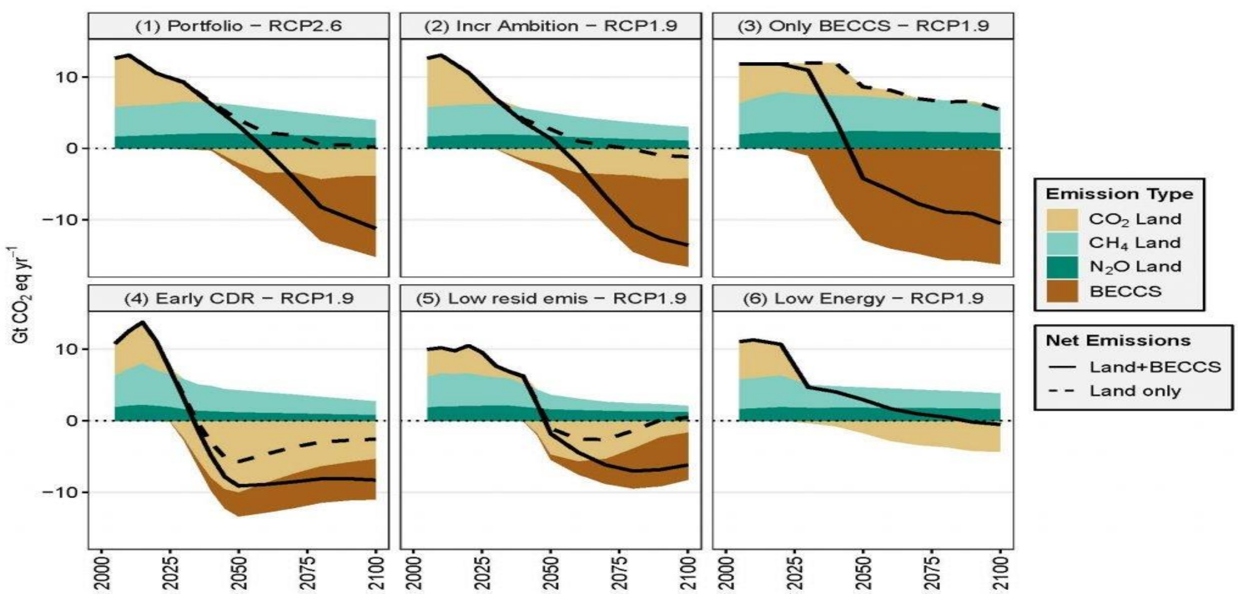
all known exploitable sources of uranium including "reasonably assured", "inferred", "prognosticated", and "speculated", plus that extractable from phosphate ores would be utilized by once-through-type power reactors similar to those being used today not breeders.

The points to be gathered from it include:

1. At today's raw/primary energy consumption rate, business as usual will consume virtually all of the world's remaining natural gas, oil, coal, ***and*** uranium by ~2100 AD
2. Building more-of-the-same nuclear reactors doesn't represent a solution to humanity's energy/environmental conundrum (fossil:nuclear energy resource ratio >7)
3. Realistically, only two of today's favored renewable energy resources are potentially large enough (Perez & Perez 2015) to satisfy some of the Green New Dealer's "100% renewables" energy schemes — solar (by far) and wind.

Unfortunately, the build-out of enough unreliable "renewables", batteries, and world-wide mega-grid required to render their brave new world's energy sufficiently reliable would be impossibly expensive. Even more unfortunately, because the "free world's topmost decision makers have been kicking the "sustainable nuclear" can on down the road for far too long and have made it difficult to build or even operate today's nuclear reactors, we'll likely continue to seek, extract, and burn fossil fuels throughout much of the rest of this century. Of them, natural gas is the best because it is relatively clean burning (little smoke & no ash), generates only about one half as much CO_2/Joule as coal, and is *purportedly* still in a relatively early phase of depletion. According to the German Federal Institute for Geosciences and Natural Resources, world cumulative natural gas production up to 2016 was 117 trillion cubic meters, world natural gas reserves were 197 trillion cubic meters, and resources[70] were 643 trillion cubic meters (BGR 2017, Table A-15). The 197 trillion cubic meters of gas that we know for sure (?) could be recovered with current technologies (our "reserves") represents 7.23E+21 Joules of heat energy which could produce about one half that much electricity. One year's worth of 22 TW_e electrical power equates to 6.94E+20 J meaning that the world's total gas reserves could power 11.2 billion EU-energy-rich people for 5.2 years while burning it was kicking the atmosphere's CO_2 concentration up by another ~50 ppm.

Because the half-life of CO_2 in the atmosphere is about a century (Moore and Braswell 1994), achieving the goals of the Paris climate accord (limiting maximum global temperature rise to 1.5 ºC) at this too(?) late point would require an almost immediate switch to clean (no GHG emissions - see Fig. 2) energy sources plus enough carbon dioxide removal (CDR) of that already in the atmosphere to reduce its concentration back to a "safe" ~350 ppm (by volume/molecule) (Hansen 2008). Consequently, some of the IPCC's more optimistic post-COP 20 scenarios/reports assume that "bio-energy with carbon capture and storage (BECCS) represents the magic bullet that could simultaneously address the future's global warming and energy supply conundrums in a politically correct (not nuclear) fashion (Martin 2016).



[70] "Resources" is defined as the sum of "proven but which cannot currently be exploited for technical and/or economic reasons and unproven but geologically possible resources which may be exploitable in the future" (world natural gas 2018)

Figure 11 ://www.ipcc.ch/srccl/chapter/chapter-2/2-6-climate-consequences-of-response-options/2-6-2-integrated-pathways-for-climate-change-mitigation/figure-2-27/

All such scenarios are unrealistic because raising sufficient switch grass, Miscanthus, palm oil, wood, etc. to power 11 billion first-world people would require vast amounts of land, water, and fertilizer which most of them (especially the hungrier ones) would consider better-utilized if applied to generating something other than fuels.

Unfortunately, Europe is now burning both its and the USA's forests to generate electricity. Fifty years ago, the USA's Amory Lovins rose to prominence as an energy guru. Back then, his green movement, prized decentralization as much as it did stopping pollution. Their fight was against the Fordist, top-down, industrial state--including its centralized structures. Lovins would go on to consult with various governments, including Germany's, on energy policy. Biomass was part of his decentralized vision.

How has that panned out for Europe?

When the EU began to subsidize wood burning over a decade ago, it was seen as a quick boost for renewable fuel and an incentive to move homes and power plants away from coal and gas. According to the New York Times, "*Chips and pellets were marketed as a way to turn sawdust waste into green power," and "those subsidies gave rise to a booming market, to the point that wood is now Europe's largest renewable energy source, far ahead of wind and solar."*

However, wood burning is carbon intensive and consumes tons of land which means that Europe is sacrificing its remaining forests to keep the lights on. This problem also showcases the awkward fit between the green vision promulgated in the 1970s and the climate-focused policy goals of the 21st century.

It's also apt to make things worse not better, climate-wise. Many climate scientists and green energy entrepreneurs are still arguing that "biomass" is an exception to the "don't burn stuff" rule. Their rationale is that when you cut down a tree and burn it, another eventually grows in its place, theoretically sucking up all the carbon dioxide that burning its predecessor emitted. However, that's neither true nor relevant. For one thing, wood burns rather inefficiently, producing a relatively large amount of GHG per unit useful energy/power produced. Moreover, it takes decades for forests to regrow and thereby suck that carbon back up which is time that we don't have because we're destroying the Earth's climate system in real, not the future's, time. So far, large-scale biomass-burning to produce electricity has not become a major business in the United States, but the fight is on to do so because current policies render doing it potentially profitable. Opponents of a proposal to build an enormous wood-burning plant in Springfield, Massachusetts, are currently trying to convince its decision makers that biomass should not be counted as renewable energy under state guidelines.

Unfortunately, because official E.U. policy still treats biomass fuels as "carbon-neutral", many big European coal-powered stations have been reconfigured to burn wood. The demand for wood pellets to keep their boilers fired—particularly in the Netherlands, Denmark, and the U.K.—is stripping forests in places such as Estonia, Latvia, and Southeastern USA. While the Dutch and the Danes may start phasing out subsidies, the British plan to give another ten billion euros to the owners of its giant Drax power plant. Much of the wood stoking its fires is being shipped from the United States where, it's "*bringing air pollution, noise and reduced biodiversity in majority Black communities*." (McKibben 2021) The carbon "payback time" for wood-burning ranges from 44 to 104 years, depending on the type of forest and while it's happening, burning wood adds more CO_2 to the atmosphere than would burning coal or natural gas, ice continues to melt, seas continue to rise, people continue to be displaced by extreme weather and science tells us that we can't wait to dramatically reduce its emissions.

BECCS is also unrealistic because carbon capture and sequestration (CCS) is intrinsically difficult, requires substantial energy input, and therefore increases a thermal power plant's fuel consumption. That's the reason that after several decades and many billions of dollars-worth of "study" and "demonstrations", only about 0.08% of anthropogenic CO_2 is currently so-"managed" (CCS 2018). Another issue is that it seems that much of the CO_2 being injected into "spent" oil fields to enhance recovery of residual gas/oil becomes reduced to the much more labile (more likely to leak) & much stronger GHG, methane. If that's true, then it's also likely to happen if the stuff is injected into black shale or lignite "sequestering" sites (see [Safer carbon capture and storage -- ScienceDaily]) total emissions will rise, not fall.

Finally, BECCS-based "save the world" scenarios are literally impossible because they don't scale. For example, burning 100% of the world's current annual grain (about 2.5 Gt, see Statista 2017) plus "bone dry wood" (about 1.9 Gt, see Wood 2018) harvests in "clean" (CCS equipped) 40% efficient (optimistic) heat-to-electricity power plants would generate useful energy services (electricity) equivalent to the output of ~935 one GW_e ("full sized") nuclear reactors. That's only ~3% of the number required to render 11.2 billion people one-half as energy rich as the USA's citizens are now. Any backup system for low-capacity factor[71] energy sources (biofuels, solar, and wind) must be able to satisfy most, not just 3%, of Mankind's total demand. Furthermore, the carbon (about 1.8 Gt) in that much biofuel (primarily carbohydrate ≈ $(CH_2O)_n$, heat of combustion[72] ~17.4E+3 J/g) represents only about 0.3% of mankind's total anthropogenic

[71]71 "Capacity factor" (CF) is the average amount of energy generated by an energy source divided by that source's name plate capacity – the amount of energy it would provide if always running full-out (e.g., for solar panels, if the sun were directly overhead in a cloud-free sky 24 hours per day- for biofuels, if such crops grew throughout the entire year). Time-averaged CF's for renewable power sources are always well under 1.0 & vary substantially from season-to-season; i.e., ineluctably unreliable. Published CF figures for renewable energy sources invariably represent yearly averages meaning that they mislead anyone trying to either determine what's apt to be produced at specific times or could "safely" replace fossil fuels.

carbon emissions to date, which means that even if 100% of the CO_2 it represents were to be captured and sequestered, it wouldn't make much difference.

Of the world's "new" biofuels, palm oil has engendered the greatest degree of deforestation, with 45% expansion between 2008 and 2015 in high natural carbon stock areas (wild forests). Palm plantations have caused huge deforestation in South-East Asia, and that problem is being compounded by the draining of peat bogs after which their extremely high "soil organic carbon" levels are quickly oxidized to CO_2. Even if biofuels would be targeted, the world would remain addicted to palm oil for food, cosmetics, and household products such as detergents, etc.

This book's homework exercises #s 84 & 85 demonstrate just how terribly inefficient the USA's primary biofuel production system (its Corn Belt's corn ethanol facilities) is at converting the sun's energy to electrical power.

Consequently, because it could not achieve either of the IPCC's goals and would surely compete with food, fiber, and construction-type wood production, all rosy primarily BECCS-based scenarios are hopelessly unrealistic and therefore do not "deserve further study"[73]. Additionally, because growing biofuels removes inorganic nutrients and soil organic carbon (humus), it's just another of our "extractive technologies" that would further degrade our environment while compromising food production (Lal 2008).

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[72] There are two ways to report combustion heats. One is the higher heat value HHV of the fuel and the other is the lower heat value LHV. The latter excludes the heat of vaporization of the formed water vapor lost out the stack. Here is a helpful Wiki. https://en.wikipedia.org/wiki/Heat_of_combustion Scroll down a ways to the table of values that shows that for methane the LHV is 91% of the HHV. The HHV is what you pay for and the LHV is what you get unless you condense the water vapor and capture that heat. The real thermodynamic efficiency is related to the HHV - the input to the system. Some gas turbine suppliers were using the LHV to calculate their CC units efficiency giving a ~60% rating which when if correctly calculated using the LHV would be more like 52%. Often the value being used marketing spiels is not clearly stated and it is hard to figure out what they are using if they don't. In generally manufacturers will use whatever values that makes their product look better.

[73] Most of every scientific field's reports conclude that its subject "deserves further study". The reason for this is that for the most part, the people writing them (scientists) are paid to "study", not solve, problems. What's more important, they're often paid to study political, not technical, issues (e.g., the disposition of "spent" nuclear fuel or reprocessing wastes) or, in other words, help their customer to rationalize more foot dragging. If the world's topmost decision makers were to commit to implementing this book's agricultural suggestions (e.g., substitute powdered basalt for artificial fertilizers and massively scale-up ocean water desalination), there would be lots of opportunities for their scientist-employees to study/determine how their program might best be implemented. For instance, would heat treatment (a properly implemented nuclear renaissance would render heat-type energy dirt cheap) somewhere during the rock powdering process make it weather more quickly? That works with clays because most of them are hydroxylated – driving out such water "activates" them which turns them into excellent pozzolans for geopolymeric concrete-making . It might help with basalt too – who knows? Another thing worth looking into is whether adding nitrogen to such powder (either as "nuclear ammonia" or nitric acid made from it) would be worthwhile. Doing so would render it a more "complete" fertilizer & might also make the rock weather more quickly – who knows? Wouldn't it be nice to be paid to study something like that?

The downsides of biofuels were best summed up a decade ago by Mario Giampietro and Kozo Mayumi's book, "*The Biofuel Delusion: The Fallacy of Large-scale Agro-biofuel Production*."

In my opinion, the most useful outcome of the climate science research performed to date is that global warming and oceanic acidification/warming/pollution have been absolutely proven to be man-caused (Hansen 2008) and that reasonably consistent/accurate estimates of global carbon fluxes, sources, sinks, etc., have joined the tremendous amount of other technical information freely available on the internet. Such information along with readily available computerized spreadsheets renders it easy for anyone to evaluate any proposal described in a properly written/edited technical paper and thereby decide for themselves whether its conclusions are reasonable.

I have yet to see a politically correct, peer-reviewed, geoengineering proposal capable of passing such muster.

For example, GOOGLEing "oceanic acidification mitigation" brings up several superficially fine-sounding electrochemical-based remediation schemes published in peer reviewed journals and subsequently heralded by press releases.(APPENDIX XX presents a worked-out example of how atmospheric CO_2 influences oceanic acidification) A typical proposal invokes giant chlor-alkali cells which would electrolyze aqueous solutions of pure NaCl (natural seawater's other components would plug up such cells) to generate sodium hydroxide that would then either be dumped directly into the ocean to counteract CO_2 engendered acidification or utilized in gas/liquid contactors to scrub it from the atmosphere (House 2007 - see reactions below). The simultaneously produced hydrogen and chlorine gases would be recombined by fuel cells to recover some of the electrical energy required by the chlor-alkali cells

Electrolysis[74]: $2NaCl + 2H_2O \rightarrow 2NaOH + Cl_2 + H_2$
Air scrubbing: NaOH +water+ CO_2 in air $\rightarrow$ $NaHCO_3$ aq
Energy recovery: H_2+Cl_2 (fuel cell) $\rightarrow$ 2HCl (in a water-based electrolyte)
HCl_{aq}+ Mg/Ca-containing rock powder $\rightarrow CaCl_2 + MgCl_2$+ rock sludge.

The fuel cells' product, HCl (a strong acid), would then be neutralized via reaction with powdered mafic (basic) rock (e.g., basalt) in giant "pressure cookers" thereby generating a waste stream comprised of decomposed rock (mostly silica) slurried with a magnesium/calcium/iron/etc., chloride-salt brine. Of the numerous "technical issues" raised by

[74] In an aqueous (water) solution of NaCl, electrolyzers generate hydrogen by splitting it off the water molecule H_2O and chlorine from the chloride ion dissolved in it (in the absence of chloride, elemental oxygen is generated instead) via a process which reverses the electrochemical recombination taking place in a fuel cell. An electric current passed between two electrodes generates hydrogen at the cathode connected to the negative voltage terminal and chlorine (or oxygen) at the anode connected to the positive supply voltage terminal. The rate at which those gases are produced is directly proportional to the current passing between the electrodes via Faraday's law: one gram mole of electrons – one Avogadro's number or 96500 coulombs (1 Faraday) of them - generates one gram mole - one gram of elemental hydrogen or one-half gram mole of H_2.

such proposals, I will just discuss their electrical energy demand. While this example was characterized as "energetically feasible", real chlor-alkali cells require about 3.9 volts to operate at a reasonably productive rate (~ 0.5 A/cm^2) and real H_2/Cl_2 fuel cells generate only about one volt at similarly realistic current densities. This means that the net energy required to produce one mole (or equivalent) of hydroxide would be 2.8E+5 J [1 equivalent*(3.9-1) volts * 96,500 coulombs/equivalent)*1J/(or volt*coulomb)]. Producing sufficient sodium hydroxide to deal with the amount of anthropogenic $_{CO2}$ that some of the IPCC's analysts apparently assumed could/would be sequestered via BECSS circa 2050 (~10 Gt/year) would require 6.36E+19J [2.8E+5 J/mole*(10E+9 t*1E+6 g/t)/44 g/mole]. If it is to be done within one year, the entire output of either ~2122 [6.36E+20 J/1 E +9 J/s (Watt)/3600 s/hr/24 hr/day/365 day/year/0.95] full-sized (~1 GW_e 0.95 capacity factor (CF) nuclear reactors, ~4.5 million 1.5 MW-rated 30% CF, wind turbines, or ~21 billion, 1 kW-rated, 10 % CF solar panels would be required.

Such schemes could not be powered with fossil fuels either. For example, since the heat of combustion of average US coal is about 24,000 J/g and burning one gram of it generates about 2.7 grams of CO_2, generating sufficient electricity to implement the above-described scenario with 50% thermal-to-electricity efficient state of the art coal fired power plants would generate about 14 Gt of "new" CO_2 – 42% more than their power could sequester in that fashion.

Another well-publicized electrochemical save-the-world scheme invoked scrubbing intrinsically acidic CO_2 from the atmosphere with a strongly basic ~750ºC Li_2CO_3/Li_2O molten salt electrolyte/adsorbent from which that carbon would be then electroplated-out/sequestered in the form of graphite (Licht 2009). Since both the electricity required to reduce carbonate's carbon to graphite and the heat needed to keep the electrolyte molten is to be provided with "solar towers", it is/was eminently politically correct and therefore received a great deal of favorable mention. Unfortunately, because: 1) STEP's ("a solar chemical process to end anthropogenic global warming ") sequestration mechanism requires four times as many electrons per carbon atom as does that of the above-described electrochemical proposal; and 2) scrubbing air with a molten salt would heat it to the latter's temperature[75], its total energy requirement would be ~four times higher *if* 90% of its process heat requirement could be recycled via heat exchangers and 19

[75]The heat capacity of air is ~1.05 J/g/degree. Consequently, the scrubbing of 10 Gt of CO2 from 400 ppmv air within one year would require heating ~1.37E+12 tonnes of CO_2 from ambient to ~750ºC requiring ~1.05E+21 J of energy which figure corresponds to the full-time output of 33,300 one GW_e nuclear (or methane or coal or wood chip or switch grass-fired thermal) power plants. If we're serious about removing CO_2 from the atmosphere, we can't invoke schemes that call for significantly heating, cooling, compressing , or expanding it – they are all too expensive. Simplistic cost estimates just based upon mixing/unmixing entropy change differences are hopelessly unrealistic.

times greater if it could not. If powered by the wind rather than solar towers, the latter figure corresponds to ~89 million 1.5 MW, 30% CF wind turbines[76].

Schemes like those[77] do not deserve "further study" regardless of who proposes them or how many warm and fuzzy "renewable" buttons are pushed by their champions' press releases[78].

The most alarming thing about how things have been going recently (see the Fourth National Climate Assessment - NCA4 2018) is that our civilization remains absolutely dependent upon resources that will inevitably become prohibitively expensive when most of the cheap/easy-to-access coal, oil, and natural gas have been consumed, which situation is likely to occur well before 2100 AD. Unless the world's decision makers have already developed/implemented a simultaneously "clean", reliable (not intermittent), and affordable alternative to fossil fuels by then, civilization is apt to collapse, heralding the onset of a dark ages akin to that depicted in the Mad Max movies.

3.3.1 Fertilizers

One reason that the productivity of Africa's farmlands is considerably lower (typically ~one third) than that of more developed regions is that relatively little fertilizer is used. The three most important components of fertilizers (macronutrients) include nitrogen in either its negative three (ammonia-type) or positive five (nitrate-type) oxidation states, potassium (invariably in its plus one oxidation state), and phosphorous (invariably in its plus five oxidation state). Nitrogen fertilizer production currently accounts for about one half of the fossil fuel (mostly natural gas) used in primary food production.

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[76] Comparisons based upon yearly averaged energy source CFs (productivities) favor wind and solar power (aren't "conservative") because CFs vary substantially throughout the year. For instance, in Eastern Idaho, weekly-averaged PV (photovoltaic) CFs are about five times higher in July than January. Similarly, Idaho's state-wide, wind turbine CFs vary by a factor of ~two from season-to-season. (https://en.wikipedia.org/wiki/Wind_power_in_Idaho). The majority of today's people and industries require reliable power which means that power source & storage decision making should be based upon "worst-case" short term CFs, not average figures (see homework problems 40-42).

[77] Although I've built, performed, & taught lots of analytical-type electrochemical equipment/techniques & found some of them to be useful, I don't feel that that it's the best way of doing most things (aluminum, hypochlorite (chlorine), and copper production are major exceptions). Electrochemical reaction rates are almost always severely surface area constrained and there is usually a more power/energy/time efficient way to do whatever must be done.

[78] Press release-type technical publishing really annoys me. I know that it's often the only info that companies and some academics are willing to "release", but genuine journalists and scientist-engineers shouldn't pay much attention to it. Here's an article appearing in my local newspaper yesterday relating the hows, whys, and consequences of that sort of "information". https://www.desmoinesregister.com/story/money/agriculture/2022/03/31/whos-bruce-rastetter-iowan-behind-summits-4-5-billion-carbon-capture-emissions-pipeline-ethanol/9418546002/   I submitted a comment lauding the reporter's courage in bringing up such controversial stuff here in the corn belt.

3.3.3.1 Nitrogen and the cost of fixing enough of it

We'll start with nitrogen. US corn farmers hoping to produce 13.1 t/ha (200 bu/acre) of maize (corn grain) are typically advised to add ~ 258 kg of N/ha (PSU 2005). Since peanuts (a legume), can recover/fix its own nitrogen from air, much less nitrogenous fertilizer would be needed for its cultivation – let's say 50 kg N/ha. Assuming those application rates, fertilizing Africa's future crop land would require ~ 29 million tonnes of ammonia each year (one kg N ≈ 1.21 kg of ammonia)[79]. An up-to-date estimate (Thyssenkrupps 2019) of energy costs concludes that each tonne of ammonia made with electrochemically-generated hydrogen, pressure swing-generated atmospheric nitrogen, and conventional Haber Bosch[80] processing equipment would require about 10 MWh's [10*3.6E+9 J] worth of electricity[81]. That, in turn, suggests that satisfying this scenario's nitrogenous fertilizer requirement would require the full-time output of ~29 one-GW_e power plants.

Universal adoption of the Rodale's Institute's "regenerative organic agriculture" recommendations (see section 3.1) would greatly lessen the world's artificial nitrogenous fertilizer requirements & more important, render agriculture genuinely sustainable.

3.3.3.2 The reasons that powdered basalt should supply the necessary phosphorous and potassium

Since…

- Much of Africa's farmland has already lost a great deal of its topsoil via erosion,·
- Much of its remaining topsoil is trace mineral-depleted,·
- Basic (mafic) rock-weathering is how Mother Nature limits the Earth's atmospheric CO_2 concentration (Figure 12 The Earth's carbon cycle (commons Wikipedia.com)6) via "mineralization",

[79] Ammonia is the second most highly produced inorganic chemical after sulfuric acid. Global production in 2018 was 175 million tons: China produced 31.9% of it, followed by Russia with 8.7%, India with 7.5%, and the United States with 7.1%. Over 80% of it used for fertilizing crops over . 50% of which is combined with CO_2 to make urea "prills". That CO_2 is re-emitted to the atmosphere when that urea is applied to soils.

[80] Other ways of making ammonia are being studied (Foster et al 2018). One of which (Kani et al 2020) forces pure nitrogen gas through a copper screen and then interacts with water which provides the hydrogen. Even though it requires similar amounts of energy compared to the traditional Haber Bosch process, it requires far less fossil fuel than does the way it's usually done today.

[81] Another report having to do with making ammonia with Australian wind power assumed 13.1 MWh of electricity to make one tonne of ammonia (https://www.ammoniaenergy.org/articles/project-geri-bp-green-ammonia-feasibility-study/?mc_cid=296653dfd2&mc_eid=b9bd2abe82

- Basaltic rocks are both intrinsically basic (contain a good deal of magnesium and calcium) and relatively rapidly weathered by the natural phenomena extant in cultivated soils (Moulton 2000),
- Most of the Earth's crust consists of basaltic rock, a good deal of which is either on or close to the surface of its continents (Figure 13 - carbonated Icelandic basalt),
- Basaltic rocks also contain relatively high concentrations of potassium and phosphorus along with all of the other biologically important elements. Therefore, soils comprised primarily of weathered volcanic ash most of which originally consisted of molten basalt are exceptionally productive (Beerling 2018)[82],

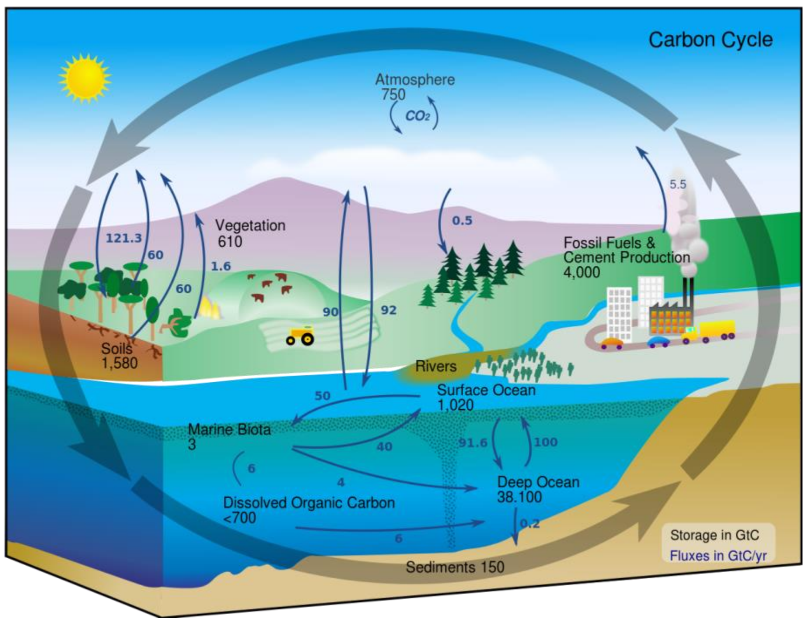

Figure 12 The Earth's carbon cycle (commons Wikipedia.com)

…we'll next assume that the phosphorous and potassium required to produce Africa's circa 2100 AD food crops will be provided by amending its farmland with powdered basalt. In order to be effective, any such amendment must weather rapidly enough to release sufficient potassium and phosphorous to support high-yield agriculture which, in

[82] Using rock powders to fertilize soil was initially proposed by Julius Hensel in 1894 His book "*Bread from Stones*", summarized the benefits of ground-rock soil amendment which is often characterized as "stone meal soil remineralization". Although forgotten for several decades, its use has gradually been increasing and several studies evaluating ways of accomplishing it have been published.

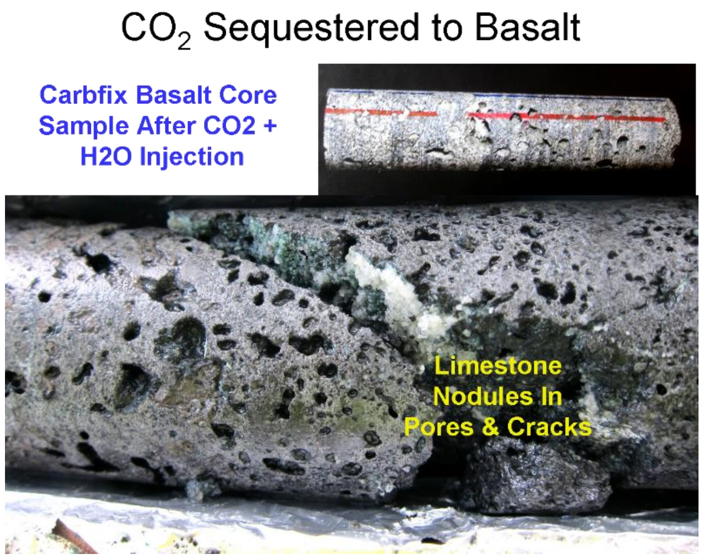

Figure 13 Product of Iceland's CARBFIX pilot plant

turn, means that the surfaces of the crushed silicate rock particles must be "fresh" - not already equilibrated with the atmosphere and thereby surface-covered/blocked with secondary phases – deliberately ground to a smaller size than are the quarry waste-type soil amendments currently being marketed to hobby farmers, and also mixed with root-zone topsoil, not just dumped upon the surface of the ground (Campbell 2009 and Priyono/Gilkes 2004). Based upon the rather limited amount of scientifically planned/supervised experimentation described in open-access (not pay walled) technical literature, I'm next going to assume that this would require grinding it so that the particles comprising >80% of it possess diameters under 10 microns. Since rock grinding is highly energy intensive – much more so than is simply recovering it from a quarry rock outcrop or waste dump – the cost estimate for this part of my scenario will be based upon that step's energy demand plus the resulting powder's transport and distribution costs.

First, how much powdered rock must be made? The food stuff P and K concentrations, land areas, and crop yield figures in the papers referenced earlier suggest that the food consumed each year by Africa's 4.5 billion future inhabitants would contain 2.64E+9 kg of potassium and 2.05E+9 kg of phosphorous. Assuming (wrongly I hope, but consistent with the way that things are usually done) that neither nutrient is subsequently recycled back to the soil (via composted night soils?), both must be replaced each year via basalt weathering. The compositions of flood basalts vary considerably but since all originate from the Earth's fairly well mixed underlying magma, for the following estimates I'm going to assume a composition with which I'm familiar (Leeman 1982 and Siemer 2019) – that of the basalt comprising Idaho's "Craters of the Moon" National Monument and covering much of the rest of Idaho's Snake River Plain. It contains an average of 0.61 wt% K_2O and 0.55 wt% P_2O_5 which translates to requiring 5.21E+8 Mg (tonnes) of it per year to provide my African scenario's potassium and 8.69E+8 Mg to supply its phosphorous. Since phosphorous happens to be the limiting nutrient, at steady state, we'd be adding 8.95 tonnes [8.69E+8/9.71E+7] of powdered basalt/ha/a.

A review of rock grinding technologies (Jankovic 2003) suggests that producing one Mg of <10-micron basalt powder would require about 100 kWh's worth of electricity. If so, making 8.69E+8 tonnes of it would require 3.13E+17 J, which if done throughout one year would require the full-time output of 13.9 one-GWe nuclear reactors.

If that powder were to be transported an average of 1930 km (1200 miles) from mine-to-farm via an electrified rail system as energy-efficient as that currently used to move US coal (185 km/L diesel fuel/short ton), its energy cost would be about 6.80+16 J (assumes 1.1 Mg/short ton, 33% heat-to-mechanical engine efficiency and 44.5 MJ/kg diesel fuel with a SpG of 0.85). Doubling that figure to account for fuel consumed by trucks and tractors at rail heads, brings the total to 2.92E+17 joules/a, which corresponds to an annual transportation/distribution energy demand requiring another 9.4 one-GWe nuclear reactors to satisfy.

An 8.95 tonne/ha/a application rate is not "large" because it only represents only about 0.5% of the mineral matter already within a six-inch deep (typical annual crop root zone) layer of normal density/composition topsoil and is also considerably under that which conventional tillage-based farming practices often lose via wind/water erosion (typically ~30 t/ha/a - Pimental 2009). Consequently, since this scenario's rock grinding/distribution costs are much lower than its irrigation water and nitrogenous fertilizer costs, it would be a great idea to at least start out with considerably larger application rates, perhaps 40-50 tonnes/ha. Doing so would also reduce the chances of crop "starving" due to slower-than-I've assumed rock weathering rates.

The 419 [240+131+29+9.9+9.4] GW_e's worth of "clean" power plants required to implement the agricultural aspects of the above-described African scenario's clean/green utopian future is about the same amount of power currently generated by all of the world's civilian nuclear reactors and ~three times greater than all of Africa currently produces in any fashion (about 650 TWh, see Energy in Africa 2018). However, it represents only ~4% of the total energy services required by this scenario's 4.5 billion EU-rich future inhabitants.[83]

[83] While it is reasonable to assert that this book's nuclear renaissance could readily provide circa 2100 AD's agricultural fertilizer, water, and energy requirements, it could not provide the light required to grow its food crops. The reasons for this include: 1) food demand would too high (~2500 kcal/day for 11 billion people 2) photosynthesis is very inefficient (about 0.25% for maize (corn)), 3) only about 25% of the energy dumped into today's most efficient light sources (LEDs) manifests itself as useful light, and 4) no thermal power plant is likely to be over 50% efficient at converting heat energy to electricity. Overall, these figures suggest that over two million 1 GW_e power plants would be required by that scenario's grow lights. Regardless of what else might happen, mankind will continue to depend upon sunlight for most of its food production.

All of the necessarily huge machinery and manufacturing facilities required to implement this book's or any other technological fix capable of "saving the world" would be much cheaper to build and operate far efficiently with reliable power than with that provided by intermittent sources[84]. While it would indeed be "possible" to run desalination/ammonia plants, aluminum smelters (see APPENDIX XXVIII), rock crushers, tractors (see APPENDIX XXX), locomotives, etc., with windmills and/or solar panels, doing so would be extremely expensive, relatively dangerous, and frustratingly unproductive to both such machinery's owner-operators and their customers. It would also require 1/CF times as much machinery to do the job at the same rate that a CF ≈ 1.0, molten salt reactor (MSR)-powered system could: typically, ~3 times as much machinery for wind and 4–10x as much for solar-sourced power.

Again, intermittent power supplies are suitable for some niche applications (e.g., charging a terrorist's cell phone), not for powering a technological civilization (Brook 2018). That's why today's farm tractors, locomotives, container ships, cruise liners, air liners, etc. are fossil-fueled, not wind or solar powered.

Also again, the above-derived ballpark numbers are approximations because the rate and degree to which powdered basalt would release its constituents (weather) under field conditions is affected by a host of factors/variables. A nutrient-specific discussion of some of them may be found in a FAO report describing the use of raw phosphate rock as fertilizer (Zapata and Roy 2004). Thankfully, this subject is beginning to receive a good deal of attention (Taylor 2017) and some more-or-less realistic experimental studies have begun (Beerling 2018, Kelland et al 2020).

Of course, there's more to implementing genuinely sustainable agriculture than just doing what I've already described.

Soil conservation invokes four guiding principles: don't till the soil more than necessary, keep it covered, keep its crops diverse, and replace any mineral matter that crop harvesting removes. Reduced tillage preserves the pathways forged by the roots of preexisting plants, insects, and earthworms. Those pathways comprise porosity which allows the ground to store water for use in dry times and soak it up more effectively during floods. Deep tilling disrupts/kills the soil biomes that convert its inorganic matter to healthy/fertile soils. For example, when a famished fungus anchors itself to an unsuspecting rock, it first unleashes acid-dissolving surface minerals to get to whatever it happens to need (e.g., iron). It then releases chemicals that extract its inorganic "food". Finally, its fast-growing fungal filaments cut into the remaining rock carving channels that break up its food-depleted surfaces exposing fresh layers for consumption - voila "more dirt". .

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[84] see APPENDIX XXII

Cover crops like alfalfa, rye, clover, and sorghum are raised first and then killed via “crimping” or herbicide addition and left in place when the cash/food crop (e.g., corn, wheat, rice, peanuts, etc.) is planted. When with the help of earthworms etc. both crops’ above ground plant matter eventually become part of the soil, they keep the soil loose, increase soil moisture and enhance yields. Since cover crops keep the soil covered and preserve its water holding capacity, they also reduce its chances of being blown away by wind or carried off by sudden flooding due to heavy rainfall. Planting diversely prevents the nutrient drain occurring when the same crops are grown season after season. Over time, rotating through different plant varieties adds a variety of soil nutrients. When necessary, planting drought-resistant crops (e.g., cowpeas instead of peanuts) could save water and use that which is available more efficiently. Soils would also be conserved by diversifying portfolios. Individual farmers might plant several kinds of crops in one area and keep their livestock on another so that extreme weather shifts would not put their entire enterprise at risk.

Another significant plus is that practicing ROG will eventually restore the earth’s soil organic carbon (SOC) levels back up to what they were before our farmers began to “mine” them by pulling excess carbon (dioxide) back out of the atmosphere. It’s the most sensible way for us to implement the “negative emissions” required to meet today’s ambitious international climate mitigation goals (Lal et al 2018). Reducing atmospheric carbon doesn’t yet provide an income stream to farmers, although incentivizing “carbon farming” has been floated by the Biden administration.

Recycling consumed K & P back to such soils in the form of composted human & domesticated animal waste would also greatly reduce their powdered rock requirements. If all of these “good practices” were to be implemented, sustainable high tech/high yield farming would require considerably less energy than my numeric examples suggest.

3.3 This book’s technological fix’s specifics

Successful implementation of any of the sustainable nuclear fuel cycles that I will be describing would satisfy 100% of Mankind’s power needs “forever” fueled with all of the Earth’s natural actinide fuel resources – not just the 0.71% of natural uranium (^{235}U) fissionable in today’s power reactors. Doing so would render clean/green/reliable nuclear power as “renewable” as is solar/wind power as well as cheaper and much less environmentally impactful (Cohen 1983, Touran 2020). For example, assuming 40% heat to electricity conversion, the U within the topmost kilometer of the Earth’s continents (i.e., 2.8 ppm of 4.2E+17 tonnes ≈ 1.2E+12 t U), could continuously generate 22 TW_e – enough clean energy to “save the world” (completely power everyone) - for 59 million years. Since the earth’s crust contains 3 to 4 times as much thorium as it does uranium - let’s say a total of ~12 ppm actinides - a “perfect” breeder reactor could generate ~2.7E+12 J’s worth of heat energy from one cubic meter of average crustal rock – ~56 times more than that generated by burning one cubic meter volume of pure “banked” (dense, not a pile of chunks) bituminous coal.

That translates to a "renewable" (effectively inexhaustible) and clean (no GHG emissions) energy source with far less environmental and esthetic/visual impact than a sufficiently overbuilt wind/solar/battery-based energy system would have.

Let's do some more ballpark calculations to demonstrate how the realization of Weinberg and Goeller's vision could address many of Africa's (and the world's) energy-related issues.

First, let's begin with some more "reasonable" assumptions. I'm (reluctantly) going to assume that the UN's population projection for what's apt to continue to be the world's most needful continent (Africa) –about 4.5 billion by 2100AD (three time's today's) – turns out to be right.

Next, since one of my goals is to demonstrate what a nuclear renaissance should be able to accomplish with respect to assuring Africa's (and also the rest of the future world's) food security, I'm going to assume that part of the useful energy (electricity) it would provide is devoted to doing that – in other words, nuclear powered machinery would provide the water, fertilizer, and soil-building minerals required to render African agriculture sustainable.

Finally, I'm going to assume that Africa's future decision makers along with who/whatever else chooses to help/enable them feel that its citizens should enjoy the same living standards as do average EU citizens today[85].

3.3.1 Which food crops should our more environmentally aware descendants raise and how much land would it take?

A leaked draft of a then upcoming Intergovernmental Panel on Climate Change (IPCC) report about land use issues scheduled for release in September 2019, indicated that there's now a near consensus by its climate modeling experts that it will be impossible to keep global temperatures at safe levels unless there is a transformation in the way that humanity produces food and manages land (Guardian 2019). "*We now exploit 72% of the planet's ice-free surface to feed, clothe and support our population*", that report warns. Currently agriculture, forestry and other land uses generate almost a quarter of our greenhouse gas emissions.

Additionally, about half of all methane emissions (our atmosphere's second most impactful greenhouse gas) are emitted by cattle and rice fields, deforestation, and peat land removal. The impact of the same Green Revolution energy intensive agricultural practices that enabled the world's human population to soar has greatly accelerated increased soil erosion and seriously reduced the amount of valuable organic material (humus) in the world's soils.

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[85] "*The test of our progress is not whether we add more to the abundance of those who have much; it is whether we provide enough for those who have too little*." Franklin D. Roosevelt

According to the IPCC's experts (2019) this situation is apt to be getting worse: "Climate change exacerbates land degradation through increased rainfall intensity, flooding, drought frequency and severity, heat stress, wind, sea-level rise and wave action". That report is a pretty bleak analysis of the dangers ahead and comes at a time when rising greenhouse gas emissions is making lots of news by triggering severe meteorological events including:

•Arctic sea-ice coverage reached near record lows during July 2019
• The heat waves that hit Europe during that month were between 1.5C and 3C higher than they would have been if we had not used the atmosphere as a "repository" for our gaseous carbon emissions
• Widespread burn offs of what recently used to be the "Amazon rain forest"[86], and …
• Mean global temperatures ~1.2°C above pre-industrial levels

The last point is particularly alarming because a decade earlier, the same experts had concluded that a temperature rise exceeding 1.5°C risks triggering climatic destabilization while anything higher than 2.0°C renders it almost certain. Bob Ward, policy director at the Grantham Research Institute on Climate Change and the Environment concludes that "*We are now getting very close to some dangerous tipping points in the behaviour of the climate*" and also that " *it is going to be very difficult to achieve the cuts needed to prevent it from happening*."

That IPCC report emphasizes that agricultural land must be managed more sustainably and release much less GHG than it presently does. Peat lands will have to be preserved by halting drainage schemes; meat consumption will have to be cut to reduce methane production, land wastage[87]; and food waste (which figure is ~40% in Africa[88]) must be curtailed. Among the

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[86] The root cause of the Amazon's fires is deliberate "land use changes", not global warming. That's also the reason that California's wildfires (e.g., last year's Paradise disaster) have become so destructive. Washington State University's Prof. Cliff Mass recently posted an analysis of recent California fires that shows that the conditions for such fires are a regular occurrence, and that global warming should if anything, decrease the wind intensity driving its wildfires (Cliffmass 2018). The biggest problem people-damage wise is that they have disregarded well established information about long standing natural processes and built communities in areas that have often burned-off before. In the case of the Paradise fire, logging and earlier fires had left a conduit of highly flammable grass and bushes, through which that fire could rapidly move. Flammable, non-native invasive grasses had also spread throughout the region. Their new homes were not built to withstand fire and roadways were inadequate for evacuation as were warnings to its population. The blown-down powerlines that started those fires had not been de-energized even though strong winds had been forecast. Preventing disasters like these will require tough decisions/regulations based upon real data and uncommon sense , not just more hand wringing about Global Warming. The University of Colorado's Professor Roger Pielke had reached the same "controversial" conclusions a decade earlier (Pielke 2010). On the other hand, Australia's and California's fires are indeed rendered more likely because climate change's ocean warming increases the amount of water vapor moved by the prevailing winds from already-dry regions to already-wet ones; e.g., from Australia to Africa's southwest coast. These "Dipole events" exacerbate droughts (fires) in the first and flooding in the second.

[87] It requires about twenty times as much corn and soybeans (therefore land) to feed people with the USA's Confined Animal Feeding Operation (CAFO) - type beef as it would to feed them with those commodities directly.

proposals towards vegetarian and vegan diets: "*The consumption of healthy and sustainable diets, such as those based on coarse grains, pulses and vegetables, and nuts and seeds … presents major opportunities for reducing greenhouse gas emissions*"[89]. There also should be big changes in how arable land is used. Governmental policies need to include "*improved access to markets, empowering women farmers, expanding access to agricultural services and strengthening land tenure security, and early warning systems for weather, crop yields, and seasonal climate events must also be established*."

Soil depletion is just another way that we humans strip-mine our planet. Its soils' readily available trace elements become depleted as does their humus (soil organic carbon) and the myriad of organisms that keep them healthy and gradually convert underlying crustal rock to new soil. We are great at hot-rodding natural processes for maximum short-term outputs/profits and then leaving depleted detritus behind when we move on to the next thing to exploit.

"Political stability, environmental quality, hunger, and poverty all have the same root. In the long run, the solution to each is restoring the most basic of all resources, the soil."
Rattan Lal

With this in mind let's try to come up with estimates of what my example's population (Africa's especially thrifty future citizens) should eat and how much of their land would be required to provide it.

Since vegetarian diets are much more efficient resource-wise than are those generally consumed by today's richer people, for simplicity's sake, I'll assume that by 2100 AD everyone will be consuming 2500 kcal/day (~1.05E+7 J), most of which is provided by two especially productive crops raised upon the minimum amount of soil capable of providing yields currently achieved in the USA.

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[88] I don't waste much food because I'm not a "magical" thinker and have taught myself to garden, fish, cook, brew, dry, pickle, and can. For instance, I recently spent a Saturday evening canning up about 25 pounds of chicken that had been in our malfunctioning, state-of-the-art, impossible-to-repair, ~$1500 "Life is Good" refrigerator's freezing compartment (its weak point was its new "linear" compressor). One of the really unwasteful things I've taught myself to do is to pressure can/cook chickens, meat, bones, skin, and all. If you do that those birds have given up their lives for a truly noble cause - we humans wouldn't have to buy/consume as much of the Earth's alternative finite calcium and phosphorous resources. What could possibly be "greener" than that?

[89] Speaking of personal carbon emissions, I've debated whether I should mention that eating a fiber-free diet reduces the amount of GHG-rich (esp.CO_2) gases that humans (males anyway) occasionally emit from our nethermost region. I suppose that in balance it's still better for the planet if we all become vegans rather than consume corn & soybeans second-hand after they've been converted to meat, milk & eggs by our even more GHG impactful (both male and female) livestock.

A recent paper (Clark and Tillman 2017) discussing the amount of land (m^2) required to produce protein with different crops, USDA reports (http://usda.mannlib.cornell.edu/...) US crop yields/acre, and candidate food crop characteristics listed in WIKIPEDIA entries suggest that an efficient combination would comprise maize (corn aka "Zea Mays") because it's exceptionally productive, nutritious, and already widely produced/consumed/accepted in Africa plus some sort of pulse (legume) to complement its unbalanced-for-humans mix of amino acids (not enough lysine - Lal 2017). Of the likely pulses, peanuts seem to make the most sense to me because they are a "hot weather" crop, taste considerably better, contain more fat/oil (but somewhat less protein), also already widely produced/consumed/accepted by Africans, and apparently would not extract as much phosphorous and potassium (key macronutrients) from its soil per food-calorie as would the next runner-up crop, soybeans.

Assuming zero waste, providing 2500 kcal/day of food for 4.5 billion people translates to 4.1E+15 kcal (1.72E+19 Joule (J)) worth of foodstuffs per year. If we also assume that 75% of their food calories are to be provided by maize, a bit of algebra (see APPENDIX XXX) will suggest that the total amount of land required to feed every African person circa 2100 AD adds up to 1.36E+8 hectare (ha), of which 7.54E+7 ha would be devoted to maize and 6.04E+7 ha to peanuts

That combination of foodstuffs would provide everyone with ~76 grams of "complete" protein per day along with virtually everything else that we humans need to first grow up and then remain healthy[90]. Africa's future folks would probably also both want to and should devote perhaps an additional 5-10% of similarly productive/managed land to raising the lower calorie/protein but tastier fruits, vegetables, and spices that render vegetarian diets far more palatable than most of the world's "rich" people realize[91]. Additionally, if Africa's hopefully much more-prosperous future inhabitants were to decide that chicken should provide 20% of their food calories (500 kcal/day/person – about fourteen times as much as its people currently

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[90] Of course, I'm just doing semi-quantitative theorizing here because people typically waste about one third of their food which means that my calculations similarly underestimate the amounts of land, water, fertilizer, etc. needed to feed our descendants. It's probably also unreasonable to assume that our world's established agricultural interests would ever permit their elected representatives to eliminate their lucrative woodchip, bioalcohol, palm oil, and biodiesel subsidies. I'm also assuming that people can learn how to convert the modern world's mountains of "number 1 or 2 yellow dent corn" and soybeans to something that they can digest efficiently and even enjoy (while accomplishing that is not rocket science, it's not trivially easy either and requires substantial cooking-type energy input).

[91] Some of those "supplemental" food crops (e.g., potatoes, carrots, tomatoes, and onions) are as productive as are the grains currently dominating US agriculture (wheat, corn, soybeans, etc.). This means that "healthy" veggies' relative contribution to our diets could be greatly enhanced if we chose to raise them rather than today's predominant "cash" crops .

consume), similar calculations suggest that roughly 10% additional land would be required to raise the additional peanuts and maize required by those birds as well. The substitution of the purportedly equally nutritious/delicious cricket "meat" (Van Huis 2012) for chicken apparently would require only about 5% more peanuts/corn/land than would a strictly vegetarian dietary[92].

1.36E+8 ha is only about 40% more cropland than the USA currently devotes to producing the crops listed in Clark and Tillman's paper to support its ~320 million people (~7% of the number assumed herein for Africa circa 2100 AD). Thanks to artificial fertilizers, improved crop genetics including GMOs , and pesticides, today's first world farmers need ~68% less land to produce any given quantity of food than did their mid-20th century predecessors utilizing that era's somewhat more "natural" (aka somewhat more "organic") farming practices.

Unfortunately, the way that we've gone about implementing Dr. Borlaug's Green Revolution simplified major cropping systems by growing monocultures in huge fields within landscapes that we've homogenized by killing everything else. A team of scientists led by Professor Andrew Balmford of Cambridge University recently showed that the best way for humanity to preserve the world's biodiversity would be to minimize the amount of land used to serve its own needs and thereby allow the set-aside (sparing) of larger areas capable of supporting natural lifeforms in a natural fashion, i.e., the set aside of "good" land, not already desertified land [Phalan 2011].
Consequently, heading off today's anthropogenic "sixth extinction" will require near-universal adoption of the Rodale Institute's and other like-minded groups/individuals' only moderately energy-intensive approach to "regenerative organic agriculture"[93], not the already developed world's currently much less efficient ways of producing its officially "organic" foodstuffs.

The USA's organic/natural food business sector primarily seeks to protect its especially well-off citizens from the imaginary "terrible threats" being posed by gluten, GMO[94]s, and the cheap

[92] My calculations assumed that chicken offal - guts, feathers, blood, bones, & beaks – would become chicken feed. It would also be interesting to see if the locust hordes that often consume almost everything that Africa's subsistence farmers raise to subsist upon could be substituted for those crops. Unlike farm-raised crickets, such "meat" would be free & especially plentiful when most needed.

[93] Regenerative organic agriculture also fertilizes soils by rendering them capable of doing for themselves the same things that the deliberate addition of manure accomplishes, i.e., such soils' abundant biomes along with their high SOC-substrate food sources generates a soup of organic acids and chelating agents capable of freeing-up a soil's otherwise-unavailable inorganic plant food constituents within its rock, sand, silt, and clay fractions.

[94] The ingestion of the nucleic acid in genetically modified food has attracted lots of attention and research dollars. The bottom line is that they are digested efficiently (destroyed) by human gastric juice which means that whatever GM rendered the plant you've eaten bullet proof as far as a particular bug or pesticide is concerned isn't going to either endanger or protect you from anything Digestion of Nucleic Acids Starts in the Stomach (nih.gov) .

foodstuffs that might encourage their less fortunate neighbors to overbreed.   For instance while ADM (Archer-Daniels-Midland) currently sells its distributors 50 pound bags of "regular" US-made wheat flour for about $11 (that's about twice as much as its farmers were paid for the wheat), a concerned person who's been told that only "natural" flour is good/safe enough for his/her family, might buy a 2 pound sack of Whole Food's organic wheat flour for "only" $4.29 (that's a ~25-fold "value added service" markup). That is cheap compared to Whole Food's "natural quinoa flour" - $10.79 for just 18 ounces. Another characteristic of the USA's approach to people-feeding, is that it's virtually impossible for an individual consumer to purchase most of its genuinely "whole foods" (e.g., raw field corn, wheat, or soybeans) in its food markets and almost as difficult to buy them anywhere else. The current demand for expensive fad-food substitutes like quinoa ("keen wah") is a consequence of "elites" promoting "traditional crops" as a culturally sensitive agricultural development strategy—a move to refashion localized indigeneity (e.g., Andean Mountain quinona) for commercialization in the "modern world." Well-meaning institutions like the UN Food and Agriculture Organization (FAO), Biodiversity International, the International Foundation for Agricultural Development (IFAD), and the World Bank, promote the development of markets for "peasant foods" ranging from Peruvian quinoa to Indian millet as a means to alleviate poverty therein and increase global food system diversity. "*NUS present tremendous opportunities for fighting poverty, hunger and malnutrition. And they can help make agricultural production systems more resilient to climate change grains.*"

To me those sorts of political rationalizations don't make much sense. Plant life's unique characteristic is   that, empowered by nothing other than sunlight, they can convert the earth's raw inorganic resources - water, carbon dioxide plus soil-solution-derived nitrate, phosphate, potassium, and low/trace mineral ions – to humanity's necessarily-already-organic (carbon-based covalent bonded molecular assemblage) food stuffs. A GMO/gluten-bearing, hydroponic-raised, wheat berry is just as "organic" as is the seed of a new wild quinona variety just discovered in an isolated Peruvian mountain meadow. We humans, like any other animal require adequate amounts of food consisting primarily of organic materials (proteins, carbohydrates, and fats along with several low-concentration vitamins etc. that any properly chosen & raised food plant can produce from its inorganic "foods". If our leaders really want to "save the world', they should, 1) commit to raising our mostly plant-based foodstuffs efficiently and sustainably, not stupidly, and, 2) making those foodstuffs readily available to everyone, not just continue to cater to the whims of the first world's already-rich people[95].

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[95] Except for some relatively low calorie/protein vegetables etc., the majority of the USA's people food (e.g., beer, soda pop, pizzas, hotdogs, hamburgers, & breakfast cereals) consists of artfully reassembled fractions of its massive grain crops along with portions of the livestock (mostly cows, pigs, and chickens) fed/fattened with the same grains. Eating beef rather than those "whole food" commodities themselves wastes about 95% of their food value. Convincing its citizens to want/consume its plastic wrapped, value-added, concoctions rather than the whole grains

Diversification includes rotating both cover and cash crops, planting flower strips, reducing tillage, adding organic amendments to enrich soil biomes (e.g., grazing non-constipated cows/sheep/ducks/chickens or carp on fields), and establishing/ restoring species-rich habitats (e.g.., ponds) in the land surrounding such fields. According to a just-off-the-press international study comparing 42,000 examples of diversified and simplified agricultural practices, increasing diversity in crop production benefits biodiversity without compromising crop yields (Tamburini et al 2020, Lockeretz et al 1981).

It is possible for us to consume more of Nature's resources than she is producing for as long as sufficient stocks of fuels, ores, forests, soils, and groundwater remain and there's still enough room left in her waste sinks (e.g., the atmosphere, lands, and oceans) currently absorbing our GHG emissions. This quantitative mismatch drives the loss of biological diversity with consequent deterioration of the Earth's ecological goods and services. More specifically, the loss of terrestrial, marine, and freshwater ecosystem biodiversity around the world is a consequence of five direct anthropogenic pressures/ threats:

habitat destruction, degradation and fragmentation;

over-exploitation of wild-harvested species;

invasive species;

pollution;

climate change.

The above threats to our planet's biodiversity arise from indirect drivers, all of which contribute to ecological overshoot. However, such overshoot cannot indefinitely continue any more than can natural-gas fracking or pumping groundwater from under deserts. Mankind's current degree of its home's biological resource overshoot – roughly two-fold - puts many of its human inhabitants' security at risk, particularly if they don't possess the financial means required to get their necessities from somewhere else.

Given that anthropogenic climate change is one of the more widely discussed threats to biodiversity and, in particular, to our own, mankind's lackadaisical reaction to it is surprising. To put it bluntly, since climate change's "issues" are widely recognized to be becoming storms, it is mind-boggling to witness how many of us continue to argue, "*I will fix my boat only if those*

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themselves constitutes the US food sector's chief business goal. Consequently, it's become almost impossible for a US food shopper to buy "raw" (no "added value") wheat, soybeans, corn, or peanuts for under four times what its farmers got for producing them.

guys fix theirs first" - the predominant narrative at most of the world's international climate conferences. That's self-defeating because in the absence of international collaboration, each "state" bears even more risk and has an even higher incentive to prepare itself for an eminently predictable future featuring severe climate changes and resource constraints. However, since human history provides us with lots of examples of how earlier civilizations have failed to appropriately respond to obvious threats, it's not a given that ours will either,

A FAO estimate (FAO 2002) of the area under "*managed water and land development in Africa totals some 12.6 million ha, equivalent to only 8 percent of its arable land*". Since Africa's total area is about 30.3 million km^2, this suggests that 1.58E+8 ha [12.6E+6 km^2/100 ha/km^2/0.08 or 5.2%] of it is considered "arable". Since my estimate of the total area required to feed its 4.5 billion future inhabitants (1.36E+8 ha) represents only 87% of that figure, hopefully, they will choose to continue to share some of their continent's still-useful land with its iconic suite of wild animals.

3.3.3 The whys and costs of desalination

Like wind and solar power, water is a renewable resource characterized by highly variable and limited "capacity ". Rainfall, temperature, evaporation, and runoff determine its total availability and human decisions determine who gets what. Nearly every country in the world is experiencing water shortages during part of the year, and > 80 of them suffer from serious shortages. Most of the world's 37 major aquifers are being "mined" at rates exceeding natural replenishment and some are near exhaustion. Clean water resources per capita are declining rapidly as human population increases, more water is used to raise cattle/pig/chicken feed, and climate change causes more and bigger droughts. Pollution, erosion, runoff, and salinization associated with irrigation, plus habitually inefficient use of water, contribute to the decline in water resources. Allocation of increasingly scarce fresh water generates conflicts between and within countries (e.g., the "Arab Spring"'), industries, and individual communities with the majority everywhere being consumed by agriculture. Water shortages are also severely reducing biodiversity in aquatic and terrestrial ecosystems (Pimentel et al. 1997).

Africa's anticipated 4.5 billion (?) future inhabitants would not be able to feed themselves with ~60% or even all of its arable land unless they become able to irrigate it[96]. Because irrigated land almost always produces higher yields than do rain fed farms and also permit double and sometimes even triple cropping in warmer regions, such lands provide around 40% percent of global cereal supply (FAO 2011a). Currently only ~4% percent of Africa's cropland is irrigated due to prohibitive costs, insufficient water, and lack of commitment to infrastructure investment

[96] Irrigation is one of the keys to Professor Borlaug's Green Revolution.

in things like power plants and the fuels required to operate them. Consequently, it's unlikely that this book's cornucopian scenario could be implemented by either the African people themselves or the institutions/businesses/people that have traditionally provided most of their "aid"[97].

However, let's pretend that will somehow happen.

Pumping water onto approximately 10 percent of the world's total arable land (around 300 Mha) currently consumes around 0.225 EJ/yr. Another 0.05 EJ/year of indirect energy is devoted to the manufacture and delivery of irrigation equipment (Smil 2008). Around two-thirds of irrigation water currently used for irrigation is drawn from underground aquifers. Energy intensive electricity-powered deep well pumping accounts for about two-thirds of that and projections suggest that it will become ~90% by 2050 when shallow reserves everywhere are almost totally depleted. Additionally, global warming is simultaneously exacerbating droughts and melting the glaciers that feed the rivers providing much of the world's cheap-to-deliver irrigation water. Global warming has caused Mount Kilimanjaro's "snows" to disappear along with most of the USA's Glacier National Park's. Building more dams won't solve this problem because dams do not create water. Additionally, a comprehensive review of Nigeria's outside-funded dam projects (Tomlinson 2018) concluded that while they do make money for local promoters and the outsiders funding/supporting them, they decrease net agricultural productivity by turning once-fertile downstream flood plains into deserts. In addition to killing wetland-dependent wildlife[98], those dams have lowered not raised, the incomes of far more people than have benefitted. Most such dams also don't generate nearly as much electrical power as "promised" due to inadequate maintenance and low (water-limited) capacity factors. Finally, at best, dams represent a temporary fix for the problems that they are built to address because any dam's reservoir will eventually fill with mud.

Water shortages plus the current cost of desalination – primarily due to high energy costs – has led some countries rich enough to do so (e.g., China) to reduce their own crop production and

[97] It just boils down to human nature. Rich people usually have lots of options and choose the cheapest (to them) way of solving their problems whereas poor people without options must live with issues even if doing so will prematurely kill them (who cares? - most of 'em live" *in …thole countries*" and aren't the right color anyway). Building enough desalination facilities and their power sources to "save" the world's poor people will cost several $hundred billion & it's unlikely that today's venture-capitalist-dominated economic system will ever do anything that doesn't guarantee them a "reasonable" return on investment.

[98] Dams have almost destroyed salmon runs throughout most of the "developed" world including, of course, my long-time home state of Idaho. Its trout streams have been similarly impacted by too-warm water and the myriad of tiny dams and extra diversions built to take advantage of low head hydropower plant subsidies. Other things serving to devastate Idaho's trout fishing include the now almost universal use of neonicotinoid pesticides (Mason 2013) and steadfast refusal to enforce a law requiring irrigation canal companies to screen their headgates (Barker 2015).

rely more heavily upon imported grains. As of 2011, China was the world's largest producer and consumer of agricultural products. However, agricultural experts are predicting that its agricultural output will shrink by from 14 to 23% by 2050 due to water shortages and other impacts of climate change. Since 2000 the depletion of its main aquifers and several rivers has led to an overall decrease in grain production, turning China into a net importer. This trend is expected to accelerate as its water shortages worsen. Despite its potential, desalination finds relatively few customers because it is still cheaper to over-utilize rivers, lakes, and aquifers, even as they are becoming very much depleted (Watts 2011)

This situation is unsustainable which means that I'll next assume that about one half of the water irrigating Africa's future farmlands (and much of the rest of the world's too) would be generated by desalinating seawater – the Earth's only truly inexhaustible/sustainable water source. Wikipedia's description of Israel's solution to its water issues (Israel 2018), demonstrates how a responsibly managed and relatively "rich" future world could address its water woes. Israel's ~8.5 million people are fed by ~1.045E+9 m^3 of fresh water applied to its mostly irrigated farmland (Jewish 2016). This suggests that the rest of the even more water-stressed Middle East's mostly-poor ~101 million people, including the majority of those living in Palestine, Iraq, Jordan, Lebanon, Oman, Syria, and Yemen (Demographics 2018), could be equally well supported by irrigating their potentially arable land (assuming all of it) with 1.24E+10 m^3 of desalinated seawater. Assuming the ~3kWh/m^3 energy requirement of today's most popular approach to desalination, reverse osmosis (RO 2018), doing so would require an energy input of 1.34E+17 joules/a, which corresponds to the full-time output of ~4.2 one-GW_e nuclear reactors[99]. The volume of water corresponding to adding 0.51 meter (20") of it over 1.38E+8 ha of African farmland is 7.01E+11 m^3, which, if generated via RO, would require the full-time output of ~240 full-sized nuclear reactors (7.51E+18 Je/a). In principle at least, Siemen's electro dialysis-based desalination technology would require only about one-half that much power/reactors and is also less apt to be fouled by seawater's other-than-salt impurities (Hussain & Abolaban 2014).

To continue, Africa's average elevation is about 600 m (~2,000 feet) above sea level, roughly the same as that of both North and South America. If all of Africa's desalinated irrigation water would have to be pumped uphill that far, the energy needed to do so would be 4.12E+18 joules

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[9999] In many cases it's apt to be sensible to interface thermal desalination (e.g., multistage flash (MSF) distillation) with RO (Al-Mutaz 2003). The reason for this is that any sort of heat-to-electricity conversion system that the reactor's energy might power will require a cooling system for its working fluid (e.g., water, or carbon dioxide). Instead of being wasted as is generally the case now, the heat picked up by that coolant could "fuel" MSF desalination. Hybrid RO MSF desalination would combine the high desalting performance of distillation with the lower total energy requirement of membrane-based processes.

[7.07E+11m^3*1000 kg/m^3* 600 m*9.8 m/s] requiring another 131 full-sized nuclear power plants.

How much would Africa's desalination equipment cost? The contractual cost of the world's (Saudi Arabia's) biggest (~one million m^3/day), RO-based desalination plant is $1.89 billion (Desalination 2018). Collectively, these numbers suggest that building enough RO plants to irrigate Africa's future farmlands would require a one-time capital expenditure of $3.63 trillion] – under 15% of the USA's current national debt. Similarly addressing California's Central Valley's chronic irrigation water problems *should* cost about $280 billion[100].

As mentioned earlier, the Western World's recent Middle East military incursions will probably end up costing its citizens ~thirty times more ($4-6 trillion - 2.3 trillion for Afghanistan alone) than it would to have built enough nuclear-powered desalination plants to provide sufficient fresh water for everyone living there and thereby address a root cause of that region's almost perpetual turmoil. For example, a recent paper in the Proceedings of the (US) National Academy of Sciences (Kelly et al, 2014) points out that the chief driver for today's Syrian conflict/diaspora is the unrest/poverty generated by relentlessly worsening droughts and an already mined-out aquifer, not the desire for "regime change". The same thing has been driving hordes of Central America's people (especially Guatemala, El Salvador, Honduras and Nicaragua) to abandon their homes in the hope that they might somehow find places to live in the USA.

Another plus for desalination is that its product does not add additional salts to soil and also better at remediating already over-salinized soils than is ground water. A final plus is that because it doesn't already contain near-equilibrium levels of calcium, magnesium, carbonate/bicarbonate, silica, etc., it is a better rock solvent (more corrosive) than is ground water. The next section will reveal why that is important.

3.4 Green energy's not-so-little dirty secrets

If asked today about what should be done to "save the world" many people opine that we need more "renewable" energy. Throughout the western world, attempts to realize that aspiration have become the rationale behind governmental policies granting massive subsidies to the businessmen purveyors of politically correct energy technologies and an excuse for penalizing those that are not. It's the reason that several US states and other countries (e.g., California, Germany, and the UK) have spent billions on subsidizing windmills and solar panels, shut down

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[100] "Should" because doing anything "controversial" in California costs far more than it does anywhere else in the USA. I've assumed 34-million-acre ft of water/a & that the reactors would cost what they would now in South Korea, ~$4/watt.

already-paid-for much more reliable power plants, burdened their citizens with sky-high energy costs, and have yet to achieve more than modest greenhouse gas reductions.

"Renewables are not green. To reach the scale at which they would contribute importantly to meeting global energy demand, renewable sources of energy, such as wind, water, and biomass, cause serious environmental harm. Measuring renewables in watts per square meter that each source could produce smashes these environmental idols. Nuclear energy is green. However, in order to grow, the nuclear industry must extend out of its niche in baseload electric power generation, form alliances with the methane industry to introduce more hydrogen into energy markets and start making hydrogen itself. Technologies succeed when economies of scale form part of their conditions of evolution. Like computers, to grow larger, the energy system must now shrink in size and cost. Considered in watts per square meter, nuclear has astronomical advantages over its competitors."

(Jesse Ausable 2007)

Here's another expert's opinion.

A fundamental, generally implicit, assumption of the Intergovernmental Panel on Climate Change reports and many energy analysts is that each unit of energy supplied by non-fossil-fuel sources takes the place of a unit of energy supplied by fossil-fuel sources. However, owing to the complexity of economic systems and human behavior, it is often the case that changes aimed at reducing one type of resource consumption, either through improvements in efficiency of use or by developing substitutes; do not lead to the intended outcome when net effects are considered. Here, I show that the average pattern across most nations of the world over the past fifty years is one where each unit of total national energy use from non-fossil-fuel sources displaced less than one-quarter of a unit of fossil-fuel energy use and, focusing specifically on electricity, each unit of electricity generated by non-fossil-fuel sources displaced less than one-tenth of a unit of fossil-fuel-generated electricity. These results challenge conventional thinking in that they indicate that suppressing the use of fossil fuel will require changes other than simply technical ones such as expanding non-fossil-fuel energy production.

(Richard York–his Nature Climate Change paper's abstract (York 2012))

However, the folks currently professing that we must immediately embark upon their interpretation of a Green New Deal generally still believe that…

"*Since solar panels and wind turbines seem to keep getting cheaper, why should we bother with building anything else*?"

The reason is that, as more solar panels and wind turbines are added to a power supply system, their intermittency (unreliability) causes each facility's power to become less valuable[101] unless it's paid for, regardless of whether anyone can actually use it. While the cost of new solar panels and land based wind turbines has indeed become relatively low[102], when enough of them have been added, they impose large costs on the more reliable parts of the system because: 1) the system's reliable sources and transmission system must be capable of occasionally satisfying 100% of demand but won't be operated often enough to pay for themselves[103]; and 2) widely dispersed wind and solar power plants must be interconnected to and rendered compatible with the rest of the grid with vast amounts of relatively small scale equipment/wiring capable of handling their maximum, not average, outputs. In big systems like Texas's "Electric Reliability Council of Texas" (ERCOT), renewable source transmission/distribution systems costs about twice as much as do its photovoltaic panel (PV) and wind turbine sources (Gene Preston PhD, PE, personal communication 2020). In deregulated electricity markets like California or Texas, if the owner/operators of such sources have contract guaranteed production subsidies, they will bid energy prices near zero or even negative which eventually displaces reliable fossil-fueled, nuclear, and hydroelectric generators in any "privatized" power supply market that sells "energy", not reliable power.

Most of the USA's nuclear power plants were not designed to load follow and will "poison out" if shut down [104] causing 1-3 day 100% outage because they can't be quickly restarted . A few hours later when intermittent source power peters out, such reactors will not be able to resume

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[101] Wind and solar power plants are chaotic systems meaning that they are subject to nonlinearities and physical relationships that render their behavior neither random nor deterministic. They also require distribution systems capable of safely handing three to five times as much energy as they deliver to the grid.

[102] It's unlikely that windmills and solar panels will become much cheaper than they are now because both industries have become "mature".

[103] For instance, as this is being written (3Feb202)3 Texas is experiencing a repeat of the weather related "event" (Uri) that caused billions of dollars' worth of damage and killed several hundreds of people two years ago. Nearly 400k of its residents are without power again. While both wind and solar crapped out again, unlike the deadly mid-February 2021"Uri" winter storm that left about 4 million customers without electricity and gas, the real culprit this time around is its electricity transmission system. Virtually all of its current outages are due to breakdowns in its transmission and distribution system caused by ice on power lines or on nearby trees that fell and knocked down power lines.

[104] 92-hour half-life ^{135}Xe – the strongest known neutron-"poisoning" isotope - is primarily created by the beta decay (loss of an electron from its nucleus) of an abundant 6.7-hour half-life fission product, ^{135}I. During steady-state operation of a solid fueled reactor, such ^{135}Xe is "burned off" (transmuted) by absorbing (and thereby wasting) neutrons as quickly as it is created. When the reactor is suddenly shut down, no more fresh neutrons and produced and ^{135}Xe accumulates to a point that "poisons" the reactor until enough time has passed for it to decay away too.

operation meaning that either lots of inefficient natural gas fired "peaker plants"[105] must be fired up or the system's customers will have to put up with another brown/black out, i.e., involuntarily become "resilient" due to what their government's business-compliant regulators generally deem to be a "force majeure" or "Act of God"[106].

The consequence of the USA's most privatized electrical infrastructure (Texas' ERCOT) is a poorly designed, overly complex and expensive wholesale electricity market that generates high GHG emissions. Its economic business model rewards shortages by driving up prices instead of rewarding abundance which would work toward removing stressful times altogether.

One way to address such issues would be to specify more appropriate floor prices on bids from each fundamentally different generating source. If floor prices for intermittent sources were to be enough higher than those of more reliable ones, it would prevent short periods of high intermittent renewable output from forcing lengthy nuclear plant shut downs thereby reducing both the number and frequency of the system's customers' involuntary "load shedding".

Ontario implemented floor prices in 2013 and adjusted the curtailment[107] order (relative floor prices) in 2016 (Paul Acchione, personal communication Sept 2020). Those changes resulted in significant reduction in both CO_2 emissions and fuel costs.

However, all is not rosy. An August 2021 report [New Report – Electrification Pathways for Ontario to Reduce Emissions: Procuring Ontario's energy future – Strategic Policy Economics (strapolec.ca)] concludes that Ontario faces electricity supply shortage and reliability risks within the next eight years and won't meet Canada's net zero carbon emission objectives without building new nuclear generation starting as soon as possible.

Since 2013, Ontario's Independent Electricity System Operator (IESO) has been forecasting a significant gap in the province's electricity supply due to the anticipated closure of the Pickering Nuclear Generating Station, now scheduled for 2025 which will lose 3000 MW (15%) of

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105 Peaker plants (jet engines rather like those powering todays biggest airliners) are powered up when demand exceeds generation. However, their turbines are usually kept spinning (idling) to keep them warmed up and prevent rotor sag.

106 Another of Dr. Pavlak's ZOOM buddies, John Rudesill, recently came up with a third definition for the "Acts of God" that ERCOT's modelers cover their nethermost parts with: Act of God = force majeure = "farce manure"

107 "Curtailment" is shutting down a power plant because there's no demand for its power. That's one of the reasons that some of a wind farm turbines often don't run even when the wind is strong. Curtailment wouldn't be necessary if new/different policies were to reward consumers for building enough extra hot water heaters, desalination plants, and/or hydrogen electrolyzers to constructively use such "excess" power. The problem with that is that those technologies would have very low-capacity factors meaning that whatever they made/did would be pretty darn expensive per unit annually summed-up output even ft their energy were 'free".

Ontario's low-cost, low-carbon 24/7 electricity. Compounding the resulting supply gap, the IESO has been underestimating the amount of electricity required to meet Canadian transportation, building and industrial sectors emission reduction goals which would increase the province's electricity demand by 136%. The required new incremental baseload supply is equivalent to doubling Ontario's existing nuclear and hydro generation capacity. Consequently, Ontario's leadership has decided to support the development of SMRs along with the hydrogen-producing plants that more[108] nuclear power would render practical. They've realized that wind and solar power generated "green" hydrogen would be much more expensive because such power sources' unreliability would require building far more electrolyzers and storage capacity.

Undertaking power system analysis without understanding the underlying plant performance characteristics of each generation technology can lead to erroneous conclusions about the energy source mix that would satisfy emission limits at the lowest retail electricity cost.

Another issue with today's suite of renewables is that low energy density sources have high environmental impacts. For example, the U.S. Fish and Wildlife Service estimates that ,

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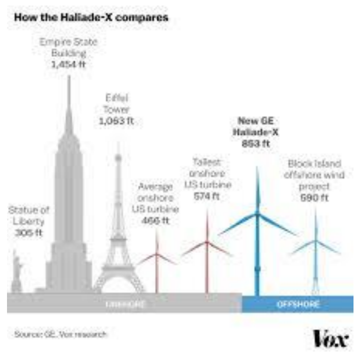

Figure 14 Wind turbine sizes

California's Ivanpah "concentrated solar power" (CSP) solar tower-type power plant[109] kills ~ 28,000 birds each year when they try to perch/land upon or catch the insects buzzing around the tops of the "receiver" towers at which its ~350,000 giant sun-tracking mirrors (heliostats) are focused.

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[108] Ontario's eight-reactor Bruce power plant is currently the world's largest fully operational nuclear power plant https://www.brucepower.com/2020/11/13/clean-energy-frontier-region-to-lead-canadas-next-generation-of-nuclear-technology/ - up until 2011, Fukushima was the biggest.

[109] Ivanpaw was built with the fervent support of the Sierra Club for $2.2 billion which included a $1.6 billion federal loan guarantee (that's a "super subsidy"). Just its build, not build+maintenance+profit margin, cost averaged over 20 years makes its solar energy cost 13.9cents/kWh – 4-5 times higher than that generated by today's nuclear reactors.

I suspect that we have no good way to accurately determine wind-turbine kills/injuries, because to dogs, foxes, raccoons, and other carnivores, dead/injured birds and bats represent easy-to-find lunches - they've got much better hearing and "sniffers" than we do. In most places wild carnivores are apt to locate/consume collision victims before our dogs do. In any case, to any of them, a big wind turbine represents an especially convenient feeding station that its owners don't want to talk about.

Wind turbines also kill millions of birds and bats/year (especially eagles - GOOGLE it) and bats every year because the tips of their giant propellers move much faster (~200 mph) than either can fly. **Error! Reference source not found.** depicts the sizes of state-of-the-art windmills along with some of the other man-made things that many of

It's highly likely that official survey kill-numbers are a fraction of a total that we are unlikely to ever know because the wind power industry's champions don't want us to know them. Idling wind turbines to reduce bird/bat deaths would decrease their reliability, reputation, and therefore their owners' profits. For as long as those folks are allowed to continue to claim that bird/bat mortality information is "proprietary", the real impact will remain unknown.

What we do know for sure is that our politicians don't reign in companies proposing new projects in regions where such impact is apt to be greatest. We also know that building enough windmills to affect a non-nuclear "green new deal" would have massive environmental impacts. Princeton University's studies assume that a third or more of Iowa and several other states would be covered with wind farms. By picking out pieces of land here or there for development or non-development, "renewable energy's" champions carefully avoid questions about the odds of migrating birds making it all the way north or south each year.

For instance, in 2019 the USA consumed 3.7 trillion kWh of electricity which figure represented about 13% of its total/raw energy consumption (~100 quads) of which ~37 quads went into to making that electricity. If we were to replace that electricity and the other 63 quads worth of non-electric energy with 33% CF, 2 MW- rated windmills (see **Error! Reference source not found.**) we'd have to build 4.06 million [(67+13)*1.055E+18/3600/24/365/2/1E+6] of them along with enough "batteries" (storage capacity) to render the whole system sufficiently reliable, & stick 'em up high where most migrating birds fly. That would "impact their diversity" in the same fashion as would marching blindfolded girl scouts down the center of a subway track during rush hour.

Because Ivanpah's CSP doesn't include the huge, heavily insulated heat energy storage "batteries" (molten salt tanks) that would enable it to generate some electricity when the sun isn't shining, solar energy actually provides only about 23% of its nominal 392 MWe "capacity". The rest is generated by burning natural gas which means that that nominally "solar" power plant dumps another ~560,000 tonnes of CO_2 into the atmosphere each year.

Like wind turbine-type “capacity”, CSP’s are often big natural gas consumers due to their modest overall solar heat-to-electric energy conversion efficiency (10-25%) and the need to usually “heat things up” before sunrise by burning gas (if Ivanpah’s optional storage system’s molten salts were to freeze up, the resulting volumetric change would damage its plumbing as did Texas’ recent “URI event” to thousands of Texan homeowners.). Since 2013, Ivanpah’s owners have twice sought permission to use even more gas than allowed by the plant’s certification agreement – 1.4 billion cubic feet in 2016 (Martin 2016*).

Like DOE’s Crescent Dunes CSP boondoggle (see my “CONCENTRATED SOLAR POWER” homework problem set), Chile’s Altacama desert-situated Cerro Dominador project (generally recognized to be the best possible place on Earth to site a solar power project) heats a molten salt used to then make superheated steam. Its solar salt storage tank batteries are big enough to maintain its nominal 110 MWe output for 17.5 hours. Unlike the USA’s Ivanpah CSP, 100% of its power is to be solar - no gas. Its build cost, $1.3 billion for a hoped-for 950 GWh/year, translates to a power-build cost of $12/watt. The good things about it are that, <u>if</u> there were no other costs, and <u>if</u> it were to work as promised, and <u>if</u> it were to last for 50 years, it could provide its customers with $0.03/kWh power throughout that entire period. However, based upon the performance of the US Crescent Dunes facility that Chili’s seems to be an almost exact copy of, that happy outcome seems unlikely (see this book’s “concentrated solar power” homework exercises) .

The world’s largest solar power plant featuring energy storage is Morocco’s Ouarzazate power station (https://en.wikipedia.org/wiki/Ouarzazate_Solar_Power_Station). Two of its three concentrated solar plant (CSP) facilities utilize somewhat over a half million parabolic trough-type mirrors that heat its molten salt working fluid flowing through pipes situated at the foci of each mirror. The third (“Noor 3”) utilizes 7400 huge (179 m^2 each) ”sun tracking” (heliostated) mirrors situated around a central “ tower of power” with a receiver at its top containing its molten salt working/storage fluid.

The entire system covers 2500 ha, has a nameplate rating of 510 MW, and is supposed to generate ~1470 GWh worth of useful energy per year (Noor 3 isn’t running yet) That corresponds to an average power output of 168 MW [147E+9*3600/3600/24/365] which suggests a capacity factor of 33% [168/510]. Its average output power/area is therefore 6.72 watts/m^2 [168E+6/2500/(100^2]. Since that part of Morocco’s “solar resource” is ~300 watts/m^2 (similar to southern California’s deserts), Morocco’s CSPs are very inefficient power sources (6.72/300 = 2.2%). Finally, a similar system scaled up to 1 GW_e would cover 149 km^2 of land – about 300 times that covered by a one 1 GW_e nuclear power plant.

The USA Crescent Dunes CSP’s current owners recently opined that, "*Today it makes no economic sense to generate with CSP during the day, because that's what photovoltaics are for and they are much cheaper*" (Ramos Miranda 2020). Not surprisingly, worldwide enthusiasm for CSP is fading.

A new study by a team of MIT researchers examines that trend and explains why they create an important role for both existing and new nuclear power plants in an affordable decarbonized energy system (Tapia-Ahumada 2019).

Here are its Summary and Abstract.

Summary: *This study shows that the U.S. electricity sector can meet projected electricity demand while reducing CO_2 emissions by 90% from 2005 levels. If nuclear generation costs remain at current levels as estimated by the U.S. Energy Information Administration, and renewable costs fall substantially, so that Levelized Cost Of Energy (LCOE) costs are well below natural gas generation costs, the authors project a considerable expansion, especially of wind, even without a CO_2 price (« carbon tax »). Given the low LCOE, one might expect a complete phase-out of carbon fuel-based electricity without a carbon price. However, the study finds that it takes a substantial carbon price to achieve deep decarbonization. Moreover, modest advances in lowering the cost of nuclear by about 2.5 cents per kilowatt hour create a substantial role for nuclear and reduce the needed carbon price by two-thirds. Continued focus on lowering the cost of baseload generation from low-carbon sources such as nuclear would make achieving deep reductions in carbon emissions much less costly.*

Abstract: *Continued improvements in wind turbine and solar PV technologies have reduced their costs to the point that they are nearly competitive with natural gas generation. This would seem to suggest there is little reason to look at other low carbon power sources such as nuclear, considering that the cost of building nuclear power plants, one of the main low carbon alternatives in the power sector, has remained high. However, simple cost metrics such as levelized cost of electricity are poor indicators of the full system cost and the competitiveness of different technologies. We use then an hourly electricity dispatch and capacity investment model, EleMod, to investigate whether nuclear power has a potential role in decarbonizing the US power sector, assuming that the cost of wind and solar continue to decline such that they become the least expensive of any generation option in terms of levelized cost.*

Daniel Yergin's book, "THE QUEST: Energy, Security, and the Remaking of the Modern World" (Yergin 2011), describes how tsunami damage to Japan's improperly sited nuclear power plant (Fukushima) caused Germany and several other European nations to declare a moratorium on new plants. Even France, the world's largest exporter of "nuclear" electricity, voiced some misgivings immediately after Japan's all-too-predicable tragedy.

3.4.1 Other countries' "green" plans and experiences

*"Had it not been so exceptionally calm in the run up to this autumn equinox, one could call the energy crisis a perfect storm. Wind farms stand idle for days on end, a fire interrupts a vital cable from **France**, a combination of post-Covid economic recovery and Russia tightening supply means the gas price has shot through the roof – and so the market price of both home heating and electricity is rocketing.*

But the root of the crisis lies in the monomaniacal way in which this government and its recent predecessors have pursued decarbonisation at the expense of other priorities including reliability and affordability of energy."

https://www.dailymail.co.uk/news/article-10010693/Power-mad-devastating-audit-lays-bare-costly-errors.html (Matt Ridley 20Sep2021)

Theoretically, assuming 100% fossil fuel backup, an electricity system primarily comprised of wind and solar renewables could function indefinitely but not cheaply because its consumers would be bearing the costs of redundant transmission and generating systems. Anybody who looks at most of the western world's madcap push toward increasing intermittent renewable source-type electricity should realize that it must eventually hit a wall **Renewable Energy Crunch Comes To The UK**, September 20, 2021/ Francis Menton. Since its politicians have been allowing their power suppliers to reduce their costs by first reducing and then eliminating reliable backup power plants, that wall is rapidly approaching and has begun to impact the UK in particular. Unfortunately for the Brits, this was happening on the eve of the next big "climate summit," COP26, set to kick off in Glasgow on November 1, 2021.

Power mad: This devastating audit lays bare the costly errors | Daily Mail Online

Unfortunately, mainstream US news sources are unlikely to say much about it because it's not politically correct to notice anything that might discourage us from "greenly" tackling the environmental issues that previous US administrations have been paying lip service to for several decades now. To get real information about such things, an excellent place for US readers to start is the (London-based) Global Warming Policy Foundation, which provides summaries and links to articles in the UK and other European press.

Like many other European countries, the UK has been in the thrall of both climate and nuclear hysteria for over two decades. When Boris Johnson, who had previously made some skeptical noises, became Prime Minister in 2019; he went after the climate dragon with the zeal of a fresh convert. His statutory commitment to reach "net zero" carbon emissions by 2050 was enacted while he was taking over from Theresa May.

Figure 15 appeared on page 88 of the 2020 "Digest of UK Energy Statistics" issued 29Jul2021. Great Britain's current electricity demand is about 30 GW in the summer and 50 GW in the winter (not much air conditioning is needed north of the 50th parallel).

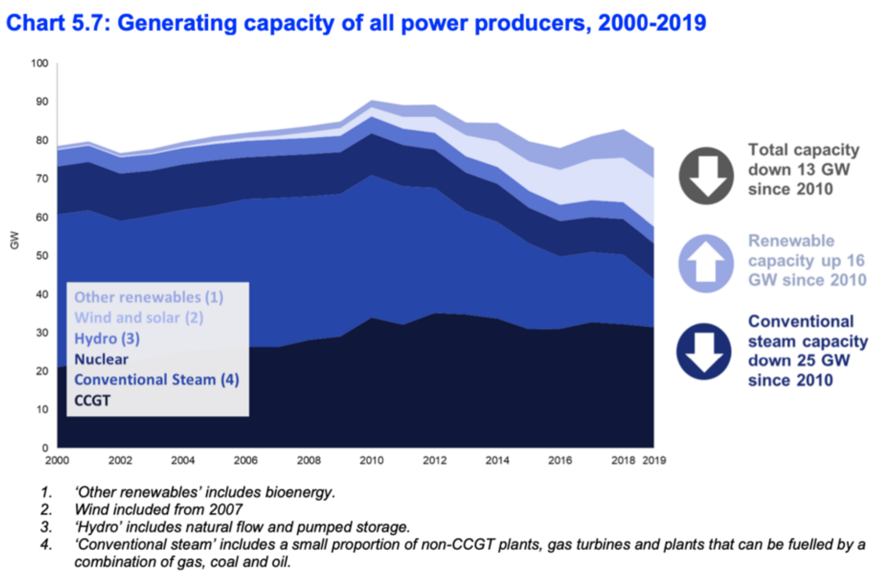

Figure 15 United Kingdom electricity sources

As recently as 2010, the UK had a very comfortable 80+ GW of dispatchable generation capacity of various sorts — Combined Cycle Gas Turbines (CCGT (i.e., natural gas)[110], "conventional steam" (almost 100% coal), nuclear, and hydro. But that year they started to reduce the amounts of all of them except natural gas. Today they're down to about 55 GW total of dispatchable capacity, with coal reduced from about 40 GW to ~15, and natural gas is up somewhat from about 20 GW to ~30 GW.

While it still may seem too soon for a crunch, a closer look reveals that natural gas is now critical - without it, coal, nuclear and hydro by themselves will not be sufficient when wind and solar output drop to zero as they often do. Even though the UK is sitting on top of a perfectly good gas shale formation, it has essentially banned fracking because its regulators accepted claims that fracking would cause earthquakes[111]. That's caused its "frackers" to throw in the towel even though its nearby North Sea field's gas output has been in serious decline for decades. When the wind and sun don't produce, the UK is now completely dependent on imported natural gas most of which is from relatively poor eastern bloc (ex-USSR but headed up

[110] A "combined cycle" gas-fired power plant directs the hot gasses coming out of its gas turbine through a tube-in-shell boiler to generate steam powering a close-coupled steam turbine. They are~50% more fuel-efficient than gas-fired peaker plants but cost much more and cannot load-follow rapidly changing system energy demand nearly as well.

[111] That's true but while they're detectable, they're generally too small to damage anything and may prevent "big" quakes by gradually relieving natural stress buildups.

by Russia) countries relishing the fact that they can now be come richer by bleeding their neighbors.

Exponential recent growth of the North and Baltic Sea offshore wind farms is a testament to the combined efforts of European countries' investing time, effort, and money in the decarbonization of their electricity grids. But just when Europe most needed such, the wind in the North Sea stopped blowing[112].

So, suddenly everybody in northern Europe had to crank up their remaining natural gas electricity generation capacity to 100%, with essentially no domestic supplies. Needless to say, gas spot prices spiked and supply shortages emerged just as another stormy winter (21-22) began to set in. Wholesale gas prices are up by~70% over the past month alone, and Bloomberg reported a 10% spike in gas prices in just the one day, as "*Russia is keeping a firm grip on supply*."

That crunch is particularly acute in the UK. In October 2021, The Daily Mail reported huge wholesale gas price increases and dozens of its utilities suddenly face bankruptcy unless they can either immediately raise consumer prices or get a prompt government bailout. On Nov 4 Reuters reported that a shortage of nitrogen fertilizer due to soaring natural gas prices is threatening to reduce global crop yields next year.

Consequently, UK taxpayers could be hit with a multibillion-pound bill when its energy Ministers try to keep its suppliers from collapsing.

Collateral consequences are rapidly spreading through the EU. After Fukushima, Germany's (where earthquakes are relatively rare, generally minor, and don't cause tsunamis) decision to shutter the nuclear power plants generating almost 30% of its electricity has raised its dependency upon Russia's natural gas despite its stepping up of wind, lignite/brown coal-fired, solar, and hydropower. In October 2021 Vladimir Putin's vowed to come to the rescue of European countries experiencing a severe energy pinch aggravated by continent -wide low wind levels. The EU's energy woes along with the Trump administration's policies are a gift to Putin, who has long dreamed of greater Kremlin influence over Western Europe and dividing it from

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[112] Britain's decision makers assumed that North Sea-sited wind farms "will not produce less than 10 percent of their potential electricity output on more than seven days per year. In 2021, there more than 65 such days." The Wind Turbine Failures Behind Europe's Energy Crisis Are a Warning for America (newsweek.com)

the United States. The decades-long political rift between Washington and Berlin over the Nord Stream pipelines which will soon bring gas from Russia to Germany, is the best-known example of this. Putin had a very good cardsto play and wasn't reluctant to do so[113].

As European energy prices go through the roof, factories are beginning to shut down and food is disappearing from store shelves. The closure of two fertilizer plants in northern England and others in Europe has left the food and drink industry facing a shortage of carbon dioxide -a byproduct of fertilizer manufacturing - critical to the production and transport of food products, from meat to bread, beer, and fizzy drinks. Emergency talks were being held between government officials and food producers, retailers, and the energy industry with warnings of a "black swan event"(a rare but increasingly likely blow with unpredictable consequences).

As the 2022-2023 's winter season begins (October 2022) a goodly number of northern European households have resorted to burning their garbage to stay warm ([Fanaticism Of The Apocalypse - Michael Shellenberger (substack.com)]). "*It's so bad this season that you can smell trash burning every day, which is completely new,*" said the 35-year-old mother of three from Jablonna, Poland, near Warsaw. "*Rarely can you smell a regular fuel. It's scary to think what happens when it really gets cold.*" Poland's government had already suspended quality regulations on coal burning for those who could still afford it which 60% of its citizens no longer could. Because of garbage burning, their government is soon apt to be handing out masks so its residents don't inhale the toxic fumes already causing an estimated 40,000 air pollution related premature deaths per year. In September one of Poland's most powerful politicians opined that, "*one needs to burn almost everything, except for tires and similarly harmful things.*"

Europe's forests are also being hammered. In Estonia and Finland, forests that had been set aside to capture carbon dioxide to reduce climate change are now being so heavily logged that they are net emitters. Hungary has lifted conservation regulations so old-growth forests could be logged and then banned the export of wood pellets.

Denmark has led the green energy revolution, having promoted wind energy since the oil crisis in the late 1970s. It gen erates over 40% of its electricity from wind power and dominates others in wind deployment per both capita and gross domestic product. Its wind industry is highly decentralized, with 88% of its ~3,000 producers operating no more than two turbines. There as is

[113] That's why Germany – the EU's biggest NATO member- is waffling about what "we" should do when Mr. Putin decides to reannex most or all of what remains of the Ukraine.

the case in many other countries, its wind turbines are approaching the end of their roughly 20-year lifetimes, making decisions about whether to scrap or upgrade them increasingly relevant.

Since the late 1970s Denmark has offered a feed-in tariff that guaranteed its producers a fixed price per kWh of wind energy generated, whether their turbines were new or old. Since 1999, additional replacement certificates have incentivized upgrades.

Both policies significantly impacted small producers' shutdown and upgrade decisions and accelerated the development of Denmark's wind industry. Without them, most of its small-scale wind producers would have left the industry by 2011, concentrating production in larger wind farms (Cook and Lawell 2020). Its government spent $3.5 billion on the feed-in tariff program from 1980-2011 and as much as $114 million on replacement certificates. Together, these programs reduced carbon emissions by 57.4 million metric tons of carbon dioxide.

For every metric ton of carbon dioxide avoided, the feed-in tariff costs Danish taxpayers $61.8, compared to $2.2 million or less for the replacement certificates. However, Cook and Lawell's study determined that replacement certificates were far more effective than the feed-in tariff in encouraging its small producers to stay in that business and thereby continue to help Denmark reduce its carbon emissions.

A video produced by Denmark's University of Aalborg suggests that its leadership is even more enthusiastic about renewables than is Germany's – its goal is to completely power itself with them by 2050 (Smart 2012). To accommodate wind & solar's unreliability, virtually everything will have to change including the need to devote much more land to producing biomass crops which in one way or another are supposed to supply about 50% of its total energy. All homes must become especially efficient energy-wise (e.g., super insulated) and mostly heated with "waste" heat generated with biofuel-fed centralized Combined Heat & Power (CHP) plants. More widely dispersed homes/businesses are to heated/cooled via heat pumps coupled to water within gigantic buried pipe arrays[114]. Electrified public transportation systems will largely replace POV s though some BEVs will be permitted , especially if better/cheaper batteries are developed . All light vehicles, trollies & trains are to be electrified. Heavy vehicles (trucks), airplanes, & ships are to be fueled with synfuels (e.g., methanol, DME, &"oils)" made from

[114] Air sourced heat pumps are pretty much useless when outdoor temperature is below ~ -10 degrees C. On the other hand, ~200 meter deep, ground-sourced heat pumps have a COP (coefficient of performance) of ~4 all year round. . They cost a lot more to install than do air sourced heat pumps which are themselves much more expensive than resistance-heated electric furnaces.

biomass-derived "green gas" & CO_2 reacted with H_2 generated via water electrolysis whenever the wind is blowing. As is also the case with the USA's Professor Mark Z. Jacobson's' lovely-sounding green scenarios, everything is to be accomplished without grid scale energy storage, any sort of fossil fuels, or nuclear power.

As does Germany's, Denmark's leadership tends to overreact to any sort of perceived threat. For example, during November 2020 its mink farmers were killing 17 million of their furry little charges because mink can catch Covid-19 from humans and are living under conditions employment that cause rapid disease spread like those of many of the USA's "essential" workers workplaces and thereby raised the probability of mutations that could render vaccines developed to fight the original virus useless. While scientists told Denmark's Berlingske Tidende newspaper that such viruses had not been detected since September, the head of Denmark's health authority, Soren Brostrom, said the risk was too great while the virus was spreading among the mink population & and therefore issued a nationwide culling order. However, after that order had been followed, the government then turned around and admitted that it lacked the legal framework for a nationwide order and only had jurisdiction to cull infected mink or herds within a safety radius. "*It is a mistake. It is a regrettable mistake*," said Prime Minister Mette Frederiksen as she apologized to parliament. https://www.bbc.com/news/world-europe-54890229

However, the USA has much to learn from Denmark with respect to the intelligent use of energy. Combining the production of electricity (combined heat and power) and heat for district heating is widely used throughout both Denmark and the rest of Scandinavia as are efforts to optimize their uses. Wise policies have rendered Danish homes much better insulated than are the USA's and its citizen's vehicles are more fuel efficient. Its Avedøre Power Station's combined heat and power station can cleanly burn coal, petroleum (oil, natural gas, and a wide variety of biomass fuels including straw, wood pellets , and (I'm just guessing here) miscellaneous wastes such as pelletized paper and plastics. Its off-gas cleaning system also produces a calcium sulfate plaster/plasterboard byproduct.

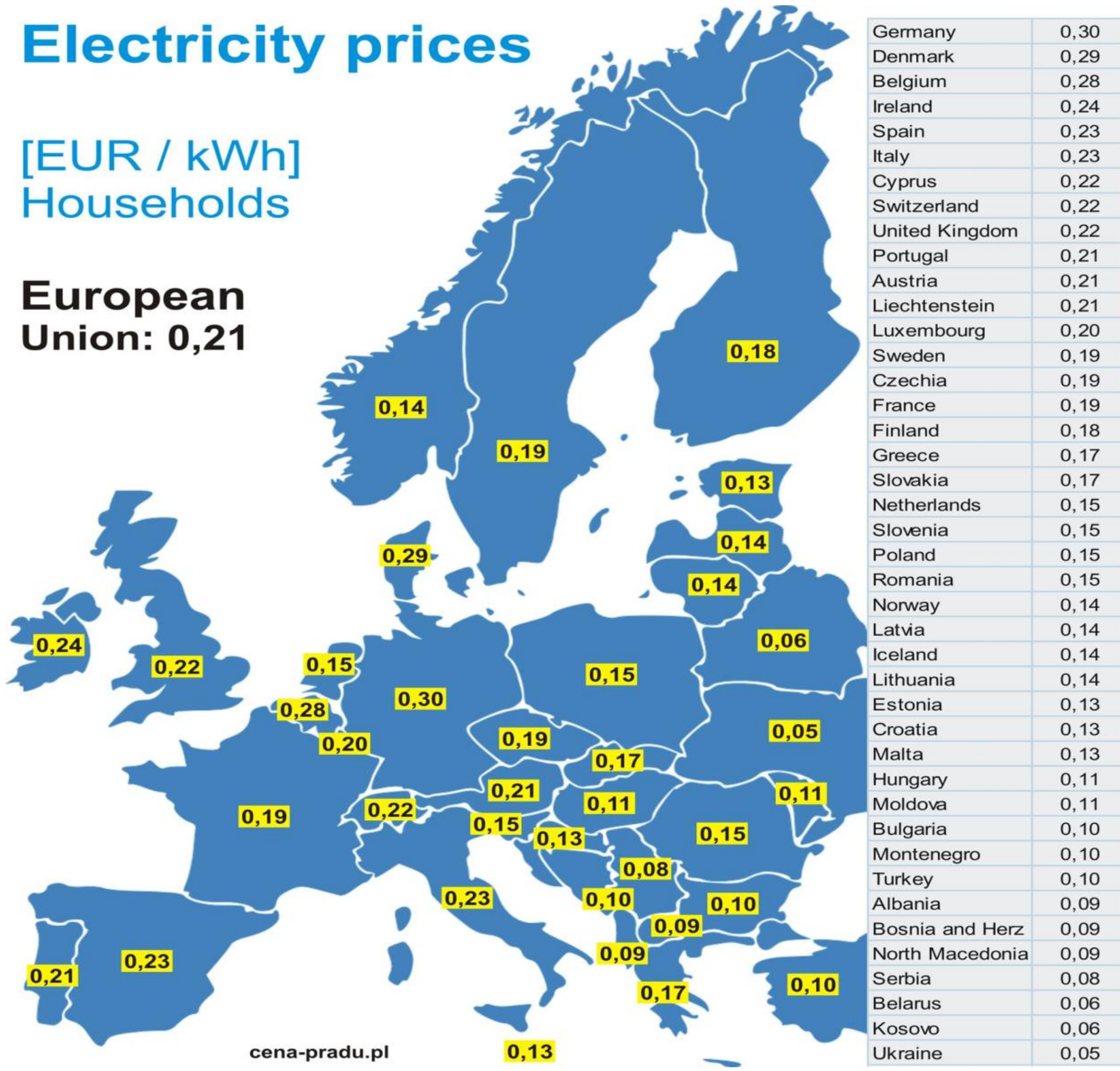

Figure 16 European Union Electricity Costs (1EU=$1.3)

It's no coincidence that Denmark's electricity now costs almost as much as Germany's.

[Macron 'disconnected from reality' as he snubs EU and launches project to counter Russia | Science | News | Express.co.uk]()

At COP 26 France joined nine other countries in a call for nuclear energy to be included in the framework of the European "taxonomy" before the end of 2021.

Its President Emmanuel Macron argued that nuclear power represents a key part of decarbonizing the world's energy supply and announced that France will build new nuclear power plants to ramp up its energy security. This was happening while the EU's energy prices were (and still are) spiraling out of control and its dependency upon Russian gas became more apparent after those supplies were cut back.

However, that didn't please other EU energy policymakers. [Five EU countries form anti-nuclear alliance at COP26 – EURACTIV.com] In the face of that French-led campaign, five other EU countries Germany, Denmark, Portugal, Luxembourg, and Austria banded together to urge the European Commission to keep nuclear out of the EU's green finance taxonomy. "*We are concerned that including nuclear power in the taxonomy would permanently damage its integrity, credibility and therefore its usefulness,*" their statement reads.

That issue is particularly sensitive for Germany which was without a government since its September election and public opinion still largely supports its planned 2022 nuclear exit, decided in the wake of the Fukushima disaster's "safety" issues. At COP 26, Germany's environmental Minister Svenja Schulze said: "*We don't want nuclear energy, we don't consider it sustainable, and we don't want the EU to support it either*." According to Schulze, nuclear power is not a solution in the fight against climate change because scaling it up to the required level would take too long and be far too expensive."

Unfortunately, there are several kernels of truth in her pronouncements because in the world that her like-minded allies' policies & actions have created (not Russia), nuclear power is indeed unsustainable, too expensive, and would take too long to expand sufficiently to address the EU's energy-related conundrums.

The EU's "Taxonomy" is a list of economic activities with performance criteria to assess the activities' contribution toward six environmental objectives — climate change mitigation; climate change adaptation; sustainable use and protection of water and marine resources; transition to a circular economy, water prevention and recycling; pollution prevention and control; and protection of healthy ecosystems. In other words, it describes what can be considered "green" by the EU's lenders and investors.

As of January 2022, the worldwide surge of interest in the electric-car industry continues to feed an even bigger surge of interest in financing the entire world's " green transition" - in 2020 Tesla's shares rose 50% and those of China's battery giant, CATL, rose by 68%. Unfortunately, Green-type fund management is rife with "green-washing", its sustainability-rating schemes are wildly inconsistent, and many of its fund managers are misleading investors about their LLC's green credentials. The rationale behind the EUs taxonomy" is that private funds and firms will employ its scheme to disclose what share of their proposed activities qualify as green, and that such clarity will help unleash a flood of voluntary capital. On December 3, 2021, the European Commission circulated its almost-current thinking. Its experts indicated that the world's movers & shakers are planning to be spending at least $2.5 trillion per year to 2050 to meet the promises they had just made at COP 26. The Economist 's main criticism is that it's likely that we'd have to spend at least twice that much (5 trillion/year) to succeed.

Of course, that shouldn't be necessary if the EU leadership's paradigm were to switch to another that's both much simpler and more likely to work.

(2050-2022) years times \$2.5T/year = \$70 Trillion which would/should be enough to buy 17,500 full sized (1 GW_e), genuinely "green" nuclear power plants (both So. Korea & China can build them now for ~\$4B/GWt – before it decided to hamstring itself, the US *used* to be able to build them for under \$2B/GW)

South Africa's energy futurists (Nuclear 2019*) predict that by 2050 its electrical sources will be as follows: 20.4 GWe of nuclear capacity (up from today's ~1.8 GWe) is to supply 30% of its electricity from 14% of the country's total anticipated generating capacity, coal will generate 31% from 18% of that total, wind 18% from 37.4 GWe capacity, and 6.5% from 17.6 GWe via solar PV. The rest of its electricity, about 14%, will primarily consist of imported hydropower. Combining those

Table 3 South Africa's anticipated power circa 2050

Nuclear (GEN II or III LWRs)	2.143	1
Coal fired thermal	1.891	0.88235
Wind	0.481	0.225
Solar PV	0.369	0.1723
(ref. World Nuclear 2019		

numbers translates to a total anticipated generating capacity of about 161 GW [20.4/.14/0.9 where 0.9 approximates a LWR's CF] – over three times today's - and suggests that the relative yearly capacity factors (reliability) of its electricity sources will be as depicted in Table 3's third column.

"Unfiltered" data like those of Figure 19 demonstrate why it is both irresponsible and callous for many of the "first world's" energy experts to persist in insisting/pretending that any affordable combination of intrinsically unreliable renewable energy sources – windmills, solar panels, etc. – could provide the energy required by 11.2 billion people each possessing a fair/equal share of a totally connected, cleaned-up, and "rich" technological civilization.

While it would indeed be possible for rich people in temperate climates to be comfortable during blackouts within their well-insulated, properly windowed/oriented homes equipped with especially efficient appliances and 12-20 thousand dollars' worth of "Power Walls" backed up by a \$10,000 "Home Standby Generator" & big fuel tank, the technological civilization that they would still depend upon for everything else they need (transportation, manufactured goods, and food) would still be requiring reliable, not intermittent, power to run effieicntly. Most folks, even some of our nation's energy experts don't seem to understand that a typical US daily work-commute consumes about as much energy as does that commuter's home.

3.4.2The lessons that Germany's Energiewende[115] should teach us

Germany's "Energiewende" (the energy transformation) calls for a nuclear-free and carbon-reduced economy through a vast deployment of renewable technologies to be mostly paid for with Feed In tariffs (FITs) guaranteeing long-term (usually for 20 years) fixed payments per unit of renewable energy produced. Its policies resulted in changes that have caused profound unintended consequences for Germany's stakeholders. While they did create an impressive roll-out of new renewable energy suppliers and nominal maximum power capacity, they also reduced the overall system's reliability, significantly increased energy prices to retail customers that weren't granted special rates because they were "too big to fail"", as well as value loss for other power consumers, both renewable and reliable energy producing companies, electric utilities, financial institutions, and investors (see germany_lessonslearned_final_071014.pdf (ourenergypolicy.org)).

US and German people have much in common both good and bad. A tendency to overly politicize technical issues and therefore believe in & do dumb things exemplifies the latter characteristic. That is the reason why neither country has recently supported the implementation a genuinely sustainable nuclear fuel cycle - one capable of cleanly "burning" either natural uranium or thorium and therefore able to adequately power themselves indefinitely. Worse, they've both embraced regulations and policies that discourage/foil their citizens from trying to do such things themselves.

Because its plethora of renewable sources & friendly neighbors often can't supply nearly enough power, Germany depends massively on imported natural gas primarily from Russia land-based (about 40%) & Norway's North/Norwegian/Barents seas gas fields (~35%). Russia's invasion of Ukraine will hopefully cause its decision makers to rethink their stance on nuclear power[116].

Germany is the world's sixth largest total energy consumer and Europe's largest electricity market. It is also the world's fifth-largest oil consumer which fuel accounted for "only" 34.3% of its total energy use in 2018 because gas provided another 23.7%. The majority of both of those fuels is imported – oil from Russia, Norway and the United Kingdom, and gas from the Netherlands, Norway, and Russia. Due to its own abundant "hard" (bituminous) coal deposits Germany had traditionally burned it to generate most of its power. However, domestic hard coal

[115] "Energiewende" translates to "energy transformation". According to some German intellectuals the underlying motivation for their country's renewables experiment, is to get over their guilt for the Holocaust and World War II. "*Germans would then at last feel that they have gone from being world-destroyers in the 20th century to world-saviors in the 21st*," noted a German reporter for Handelsblatt.

[116] Here's a brilliant explanation of how that invasion came to be Gravitas Plus | Explained: The Russia-Ukraine crisis - YouTube

mining has been almost phased out because: 1) it is now more expensive to deep-mine such coal in Germany than it is to import it from China and Australia, 2) the old power plants burning it were inefficient and grossly environmentally impactful.

Germany's green energy transition ("Energiewendie", usually acronymed EEG) was officially launched by its newly elected Green government in 2000. Back then, there was still talk about transitioning to a "competitive" energy supply system that wouldn't cost anyone more *"than an extra scoop of ice cream per month*". In the wake of Japan's tsunami-caused Fukushima disaster, in 2011, Germany declared that it would shut down all seventeen of its nuclear power plants by the end of 2022 and generate >80% of its electricity and >60% of its primary energy with politically correct renewables by 2050 (the Economist 2020). Ten years later (2021), its three remaining nuclear-fired power plants are still supplying 12% of its electricity.

Under its plans, those plants, with combined capacity of 4,200 gigawatts (GW), were to be totally shut down by the end of 2022. That hasn't happened yet (March 2022) because Russia's war on the West temporarily injected a degree of sanity into German politics.

Consequently, its people have since spent ~$600 billion on wind, solar and biofuel-type renewables and, with the help of its neighbors (primarily Sweden, Norway, and France), recently managed to achieve ~38% green electrical (not total) energy. However, it's also rendered its electricity nearly twice as expensive and ten times more carbon-intensive than is France's. Between 2011 and 2017 the shutdown of 10 of Germany's 17 nuclear reactors ballooned its retail electricity prices while its total carbon emissions stabilized[117] because more local & easier/safer to mine brown (lignite) coal and imported (mostly from Russia) natural gas was burned in lots of new thermal power plants (see Figure 18)[118].

Since 2000, electricity prices have more than doubled for Germany's private consumers and trebled for most of its industries. Accordingly, many of its industrial movers and shakers have threatened to shift their production, jobs, and tax revenues abroad.

In 2000, 6.6 percent of Germany's electricity came from renewable sources; in 2019, the share reached 41.1 percent. In 2000, Germany had an installed capacity of l2l gigawatts, generating 577 terawatt-hours, 54 percent as much as its suppliers theoretically could have generated

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117 "Stabilized" assumes that only the CO_2 generated by burning that coal is counted. In reality, it's likely that Germany's atmospheric impact has increased because coal strip mining always releases a great deal of coal bed methane which starts off as a ~150 times more impactful GHG than is CO_2 https://en.wikipedia.org/wiki/Coalbed_methane.

118 Similarly in 2014 the US state of Vermont shut down its only nuclear reactor and switched over to gas which brilliant move raised its per capita CO_2 emissions by ~5%. Iowa's energy geniuses have done the same things.

(nation-wide capacity factor = 54 %). In 2019, Germany produced just 5 percent more (607 TWh) electrical energy, but its installed capacity was 80 percent higher (218.1 GW) because its consumers must now support two generating systems one of which is intrinsically unreliable.

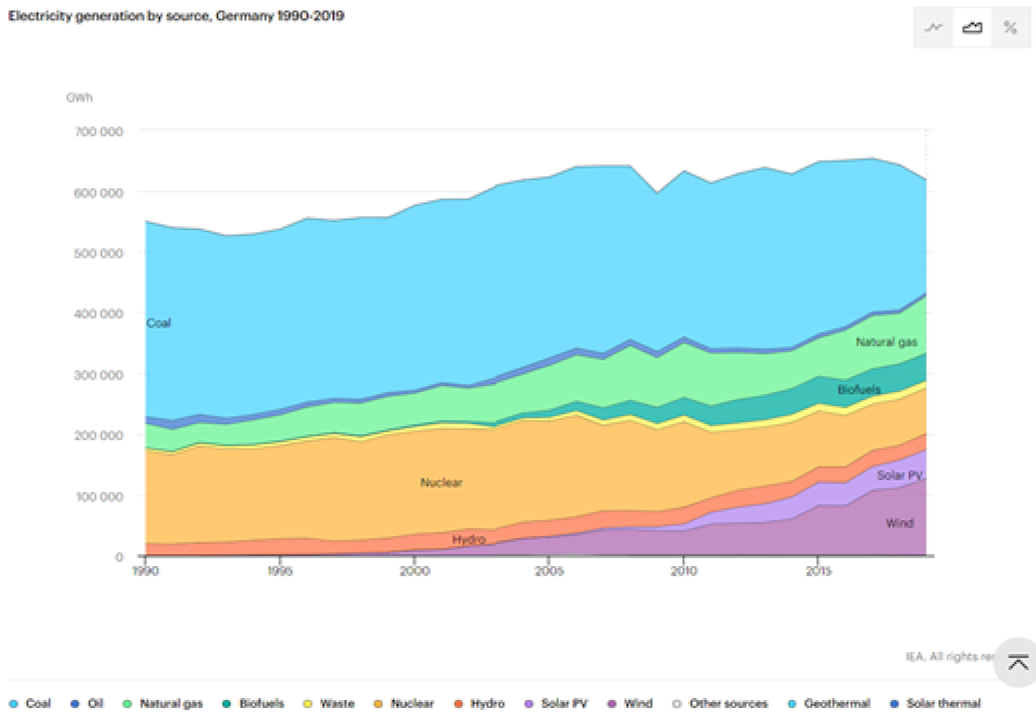

Figure 17 Germany's power generation (https://www.iea.org/regions/europe)

Its new system, based primarily upon unreliable wind and solar power, accounted for 110 GW, nearly 50 percent of Germany's total installed capacity in 2019, but operated with an average capacity factor of just 20 percent including ~10 percent for solar. The latter is not surprising given that large parts of that country are as cloudy as is the USA's city of Seattle. Size-wise its parallel, intrinsically reliable, and primarily fossil-fueled power system remains almost intact, retaining nearly 85 percent of 2000 AD's original net generating capacity. Germany must keep it going to satisfy nearly half of its average electrical energy demand and essentially 100% of it on cloudy and calm days. Consequently, its current reliable energy supply system's capacity factor is much lower than was its progenitor's.

It costs Germany's citizens a great deal to maintain such an excess of installed capacity. The average cost of electricity for German households has doubled since 2000. By 2019, its average citizens had to pay 34 U.S. cents per kilowatt-hour, compared to 22 cents per kilowatt-hour in France and 13 cents in the United States.

It’s not hard to measure how far the Energiewende has pushed Germany toward its ultimate decarbonization goal. In 2000, it got nearly 84 percent of its total primary energy from fossil fuels; that share fell to about 78 percent in 2019[119]. If extrapolated to 2050 , that rate of decline would have fossil fuels still providing nearly 70 percent of the country's primary energy supply. Meanwhile, the probability of large-scale blackouts is increasing because the scheduled shutdowns of Germany’s intrinsically reliable “dirty” fuel-burning and “clean” nuclear power plants continues apace. According to German think tank “Agora Energiewende” that country’s total GHG emissions from electricity generation increased by one-quarter (21 million tons) in the first half of 2021 Gas-fired power plants increased 15%, its new coal power plants by 36%, and hard coal power plants by 44%. Its experts say it was because Germany’s economy is growing more during its post-Covid recovery. "*Overall, the recovery in demand is by far the main factor behind the increase in fossil fuel generation*". However, that pollution increase was also due to a lack of wind which had generated just 46.8 terawatt hours during those months, well under the 59.4 TWh produced by the same wind farms during the first half of 2020. Offshore wind generation also dropped by 16%, to 11.7 TWh, during that period.

During the 1970’s Germany started carving out giant open pit mines for lignite (brown) coal, destroying down forests, farms, and villages along the way (Figure 18). The largest of these, the Hambach Mine, currently covering ~8000 ha and nearly 1,500 feet deep, is Europe’s biggest man-made hole. Everything about it is gigantic. The huge bucket-wheel, open pit mine, excavators crawling across its bottom are taller than the Statue of Liberty, longer than Madison Square Garden, and heavier than the Eiffel Tower. They hold aloft wheels 70 feet in diameter each with 18 massive buckets along its edges each capable of digging 6 1/2 tons of soil per revolution (Peters 2014). The local scenery featuring several of these ~14,000 tonne mechanical monsters crawling around within their devastated surroundings reminds visitors of the barren worlds depicted in apocalyptic science fiction movies. That mine produces 30-40 million tons of brown coal per year, and, since Germany has decided to junk its nuclear power plants, is expected to keep doing so for another 25-30 years although its leaders have solemnly promised to switch to 80% “clean” electricity and its strip-mined lignite is dustier (but cheaper) than was its deep-mined hard coal.

Germany’s current economics minister Peter Altmaier faces the “wicked” (unsolvable) problem of trying to work out a compromise between Germany’s green true believers and its rational energy experts. An English translation of the term used to describe what that compromise would

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[119] In the US, coal, natural gas, and nuclear fission generated approximately 88 percent of its electricity, with coal contributing almost 50 percent . By 2018, coal, natural gas and nuclear represented 82 percent of the total with 27% from coal and 36% from natural gas. In 2006, solar and wind supplied one percent of the total rising to ~8% by 2018. (*Electric Transmission Incentives Policy under Section 219 of the Federal Power Act,* Notice of Proposed Rulemaking,170 FERC ¶ 61,204.

entail would be ″top straightening″ - a soothing-sounding term for the involuntary dumping of consumers from the electrical grid whenever there is a shortage (here in the US, it’s called "load shedding" or “demand control”).

Localized blackouts (aka “demand control” or “load shedding”) have repeatedly been happening in recent years - but to date has mainly affected only Germany’s large industrial consumers such as its aluminum plants and steel rolling mills.

In the future, other industries and private end-users are to be subjected to preplanned load-shedding. Meanwhile as Germany’s eminently politically correct green energy transition continues, its total electricity consumption is to sharply increase and 100% of its nuclear power plants are to be mothballed.

A first attempt bill that was supposed to bring some order into Germany’s eminently foreseeable future blackouts was rejected by all parties involved in decision-making. That’s not surprising because who wants to be separated from the power grid, shortage of electricity or not? But in the end, it doesn't matter because neither wind nor sunshine - the sources of most of Germany’s imaginary 100% green future energy - obey Mankind’s laws/wishes and certainly won’t in the future. Laws formalizing Germany’s "top straightening ″ schedule would just be a sham anyway because where there is no electricity, you can't distribute electricity.

Figure 18 Germany's "new" substitute for its nuclear plants[120]

Germany's fundamental problem is that doesn't possess good wind or solar energy resources. The red line across the top of Figure 19 represents Germany's then still rapidly growing wind power "capacity" during 2011 – the blue spikes under it represent total power so produced. Its wind power system's mean yearly capacity factor was about 0.16 and there were many times with essentially no wind power anywhere across the entire country. This is consistent with Handschy et als' conclusions/observations (Handschy 2018), i.e., that it's *not* right or conservative, or safe, or…, to assume that strong winds will always be blowing somewhere within any such system. . Germany's wind electricity was 20%v lower during the first half of 2021 than the first half of 2020, resulting in a 24% higher use of fossil fuels and 28% greater GHG emissions from electricity [German Emissions From Electricity Rose 25% In First Half Of 2021 Due To The Lack Of Wind Power, Not Willpower (substack.com)] . Coal was again its number one electricity source in the first half of 2021, comprising 27% of the total.

Another "secret" that the US wind power industry keeps close to its chest is that wind turbines often "freeze up" when their power is most needed (Gao et al 2021)[121]. This uncomfortable truth

[120] nuclear and coal-fired power plants use the same "hyperbolic" evaporative cooling towers.

[121] "*Despite the high wind, iced-up wind turbines were found to rotate much slower and even shut down frequently during the icing event, with the icing-induced power loss being up to 80%.*". Because the Iowa State University

contributed to the severity of the power blackouts experienced from North Dakota to Texas during February 2021's "polar vortex".

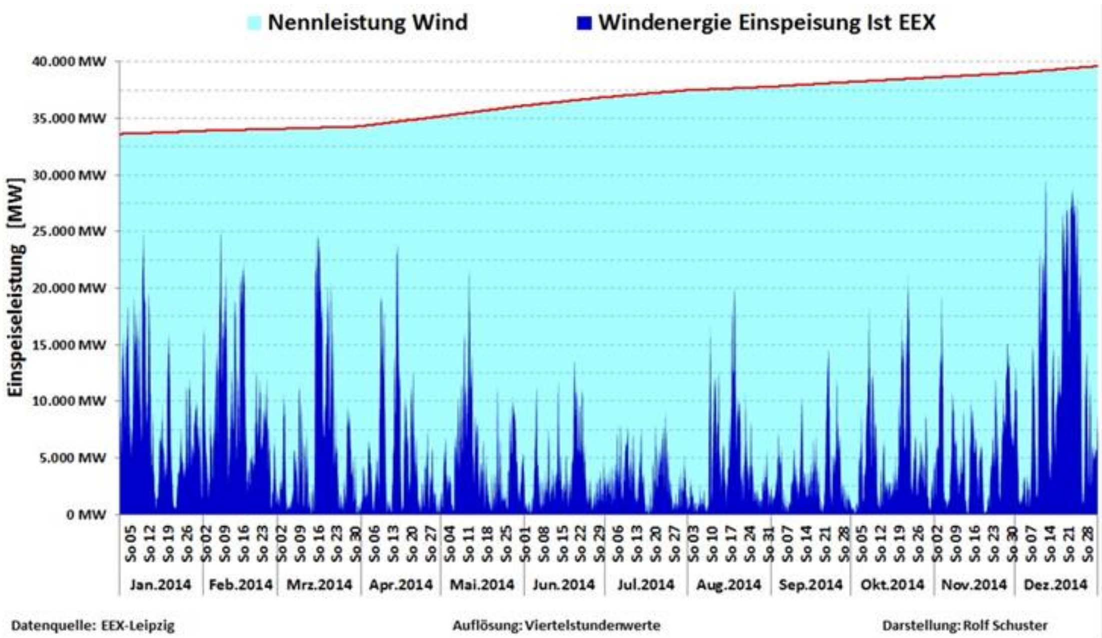

Figure 19. Germany's total real time wind power generation throughout 2014 Source: http://www.vernunftkraft.de/85-prozent-fehlzeit-windkraftanlagen-sind-faulpelze/ :

Germany's impressive "solar power capacity" figures are even more misleading. During 2011, its cumulative PV capacity of 29.7 GW provided only 18 TWh of electrical energy (https://en.wikipedia.org/wiki/Renewable_energy_in_Germany) corresponding to a yearly-averaged CF of under 7% [18*3.6E+15/(29.7E9*3600*24*365)=0.0693] – that's under one third of that achieved in places like northern Africa's or California's deserts. Production is considerably lower than that during Germany's notoriously cold and dark winters (see Figure 20).

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researchers drawing that conclusion had been denied access to Iowa's corporately owned/controlled ~6100 wind turbine fleet, they had to do their icing studies in China. Iowa's turbine owners apparently did not want the grid operator (MISO) or the public to see real data and there's no law forcing them to tell the truth, the whole truth, and nothing but the truth. In many jurisdictions wind power generators get credit/payments for "assured capacity"—usually a small fraction of its rated capacity. A study showing that turbine output is drastically reduced even when the wind is blowing would imply that such capacity is under that advertised and what its owners are currently being paid for. The other concern is liability. Ice thrown from a big turbine's blades can kill people up to about a half mile away. However, since such ice conveniently melts, unless such damage is immediately documented, courts won't award damages or impose limited operations during icing conditions. There are no easy fixes for this trans scientific issue – it's too "wicked" for legal minds to solve.

Figure 20 One of the Energiewende's great new jobs

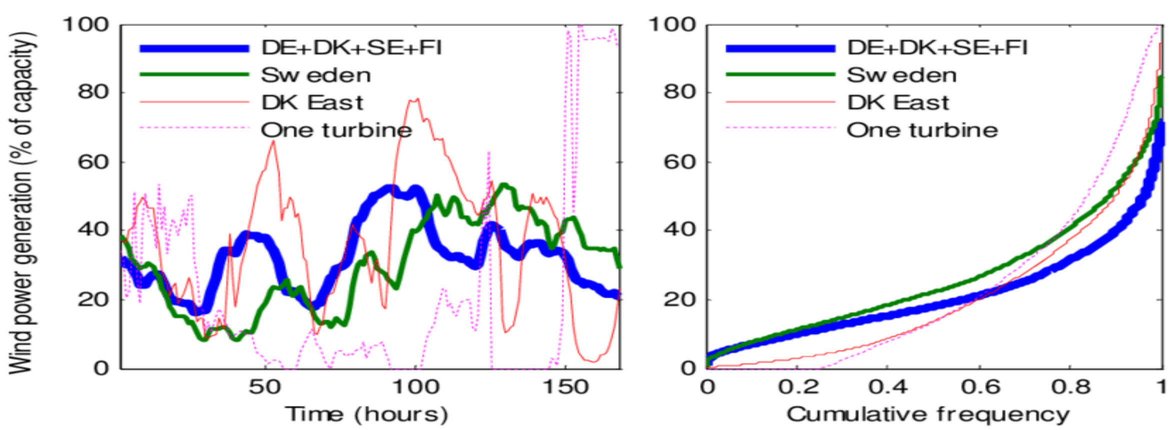

Figure 21: Typical variations in European wind power generation on different geographical scales (figure courtesy of Juha Kiviluoma)

Figure 21 displays one week's worth of Europe-wide wind power data during 2010. The leftmost figure depicts typical variations in wind power generation on different geographical scales (figure courtesy of   Juha Kiviluoma). The right shows two years (2010 and 2011) of hourly data sorted by generation level. The aggregated generation of four European countries was created by calculating a weighted average of capacity factors for each hour (Germany's weight was three because it is a bigger country demand-wise; the others were each assigned a weight of one).

Another problem is that Germany's nuclear plants are in its south and its wind is in its north. Closing its nuclear plants is causing a huge transmission flow problem meaning that it has had to halt its windfarm growth due to transmission constraints. Its solar energy is constrained by lots of cloudy weather, so its solar investments aren't looking good either. Because its wind is so variable Germany must rely upon imported Nordic hydropower to the maximum extent possible. What has everyone there worried is that closing its nuclear plants will force Germany to purchase even more Russian gas - to avoid that Germany has had to keep building new lignite coal-burning plants (Figure 18).

Other than its excessive costs, the main problem with Germany's post-Fukushima energy muddling is that it's encouraged many of the western world's other technically challenged political decision/rule makers to also assume that unreliable power sources can "back up" unreliable sources and therefore adopt policies that render "privatized" already-paid-for reliable power plants uneconomic and therefore a liability to their owners.

The conclusion of a recent independent professional engineering firm's analysis of Germany's much heralded "energy revolution" were as follows (Mckinsey 2019):

• Germany still generates only ~35% of its electricity with its renewables. If biomass burning, which is often dirtier than coal burning is excluded, Germany's wind, water, and solar electricity accounted for ~27% of its electricity generation in 2018.

• In 2018 – eight years after the Energiewende's Fukushima-inspired enabling legislation was passed – Germany was still generating 866 million metric tons of carbon dioxide per year, far short of cry from its 2020 ,750 million tonne, goal.

• Because many of its rural citizens are getting fed up with its ever-growing intrusive "wind parks", more Germans are protesting the building of even more — and often even taller — wind turbines in their neighborhoods. There is also steadfast resistance to building the massive new grid infrastructure required to transport their electricity from wherever it's generated to wherever it's needed. A 2014 study carried out for the Western Electricity Coordinating Council estimated a cost of nearly $3 million per mile for a typical high-tension line. Moreover, because transmission efficiency goes down linearly with distance and as the square of the current, losses for a typical high voltage line are 5% to 10% per 1,000 miles.

According to Germany's calculations, nearly 3,700 miles of new power lines would be required to make its Energiewende work. By the end of 2018, only ~93 miles of that network had been built[122].

• Its plan risks more than just supply shortfall because it could also prevent Germany from properly addressing climate change. By shutting down its nuclear plants faster than those burning coal, Germany is consigning itself to dependence upon both its own and imported fossil fuels.

• "Only short-term imports from neighboring countries were able to stabilize its electrical grid"

• "The ongoing phase-out of nuclear power by the end of 2022 and the planned coal withdrawal will successively shut down further secured capacity"

• "In the medium term, there is a risk that there will not be enough supply capacity within the EU's entire European network which could happen within five years and continue to worsen until 2030."d

• "It can be assumed that security of supply will continue to worsen in the future."

• "Due to energy supply shortages, the highest cost of the imported short-term (spot) "balancing energy" required to address short falls in renewables output skyrocketed from €64 in 2017 to €37,856 in 2019"

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[122] People almost everywhere would resist the building of sufficient new ultra-long distance power transmission capability to render a 100% intermittent-sourced green energy system workable. Aside from earthquakes, solar & ice storms, derechos and other natural events, all 100% renewable energy scenarios assume no seriously pissed-off land "stakeholders" because the driver of any big truck could take out their nation's biggest DC transmission line by simply ramming one of its towers. There are also all sorts of explosives and cutting tools—from cutting torches to abrasive wire cutters - available to anyone who really wants to raise heck. There are also many ways of shorting out a distribution system's wires – e.g., a bow and arrow could launch a light line attached to/followed by a stronger line followed by a conducting line. The Book "Powerline: The First Battle of America's Energy War", Barry M. Casper and Paul David Wellstone, Amherst, MA: The University of Massachusetts Press, 1981, ISBN 0-87023-321-1 and ISBN 0-87023-320-3, tells the story of how US corn belt farmers sabotaged the first HVDC line that was to be built through their region four decades ago. All they had to do to kill that project was blast its insulators with their deer rifles - insulators are relatively easy to replace but transformers are not (also see https://www.greentechmedia.com/articles/read/the-subtle-art-of-making-substatio-bulletproof) The recent shutdown of one of the USA's biggest oil pipelines due to Russian internet hostage-taking serves as a warning about big long-distance transmission systems. The bigger the system, the greater its security requirements must be if it is to remain "safe".

One of Germany's largest newspapers, Die Welt, summarized the conclusions of Mckinsey's report 2020 with a single word: "disastrous."

Germany's increasing energy insecurity is exacerbated by the fact that its neighbors Belgium and the Netherlands may also choose to shut down politically incorrect baseload power facilities, coal plants in the Netherlands and nuclear plants in Belgium.

The conclusions of the latest Fraunhofer Institute meta-analysis of Germany's efforts (Senkpiel et al 2018) were as follows:

"*Several conclusions can be drawn from this analysis: The current reduction in primary energy demand between 2005 and 2016 shows that the CO_2 emissions target of 80% reduction in the year 2050 may be met if the current reduction trend continues. However, the trend is very unstable, as data of the last three years even show an increase in CO_2 emissions. Higher emission reduction targets require an accelerated effort to decrease the primary energy demand. In addition, that development is dependent on a multitude of factors, including political decisions and socio-economic aspects. Wind energy and photovoltaics are mature technologies. If the historical trend is extrapolated, these technologies show a tendency to reach the installed capacities at the lower end necessary to meet the emission reduction targets of 80%. It is therefore questionable, whether this will be enough to reach the emission-reduction target. Biomass energy may not be expanded to a large extent due to limitations in the resources. Hydropower is a mature technology which will probably not be further exploited in the future due to the fact that the potential is almost fully exploited. Geothermal usage in Germany is promising, but there is no widespread use up to now. Wind energy and photovoltaics are mature technologies. If the historical trend is due to limitations in the resources. Hydropower is a mature extrapolated, these technologies show a tendency to reach the installed capacities at the lower end necessary to meet the emission reduction targets of 80%. It is therefore questionable, whether this will be enough to reach the emission-reduction target. Biomass energy may not be expanded to a large extent due to that resource's fundamental limitations. Hydropower represents a mature technology which will probably not be extensively expanded either because its potential is already almost fully exploited wherever it makes sense to do so. Geothermal usage in Germany is promising, but there is no widespread use up to now." … Pumped hydro storages are mature and well developed in Germany. Due to a limitation in available land and social acceptance, a further development of pumped hydro storage is not foreseen. All studies show a massive development of usage of batteries for electric vehicles. In the studies where stationary batteries are analyzed, a massive increase of installed capacities is proposed. Power-to-X technologies are at pilot project or demonstration project status and are expected to play a major role in the energy sector with high shares of renewable energy technologies. However, due to the currently small numbers of installed capacities the projection of future development comes with an even higher uncertainty*."

Another of the Energiewende's consequences is that between 2004 and 2011, ~ 2700 km² of Germany's natural grass and woodlands were ploughed up to plant 7000 km² of new maize-fields to meet biomass energy goals. This sort of "land use change" inevitably releases huge amounts of greenhouse gases (mostly CO_2) and severely impacts both biodiversity and groundwater recharge potential (Ukhanova 2018).

Consequently, another of the Energiewende's consequences is that it's likely that >1,000 additional Germans are dying every year due to the ~12% increase in local air pollution engendered by its bevy of new lignite-fired peaker power plants built to back up its windmills (Smith 2020). That point was also brought up in an excellent ~10 minute long British YouTube video entitled , "*How Many People Did Nuclear Energy Kill? Nuclear Death Toll*" https://www.youtube.com/watch?v=Jzfpyo-q-RM&feature=youtu.be .

The "technical" reason for Figure 18's environmental devastation is that coal has far less mass-wise energy density than does uranium. Some lignite coals contain over 400 ppm uranium see Uranium-bearing lignite in southwestern North Dakota (usgs.gov) meaning that far more power could be generated by "burning" it in a breeder reactor than by combusting the coal's combustibles. Since German brown coal is supposed to have a heat of combustion of ~16.9 kJ/gram and each atom of uranium "burned" in a breeder reactor generates ~3.1E-11 J, breeder reactors fed with a relatively "low grade" 100 ppm uranium bearing lignite coal would require mining of only ~ 0.2%[123] as much of it to satisfy Germany's energy demand (Figure 22 puts this into perspective).

[123] energy from 1 g coal combustion/1 g 100 ppm U coal = 16.9E+3/(100E-6*6.023E+23/238*3.2E-11)=0.0021

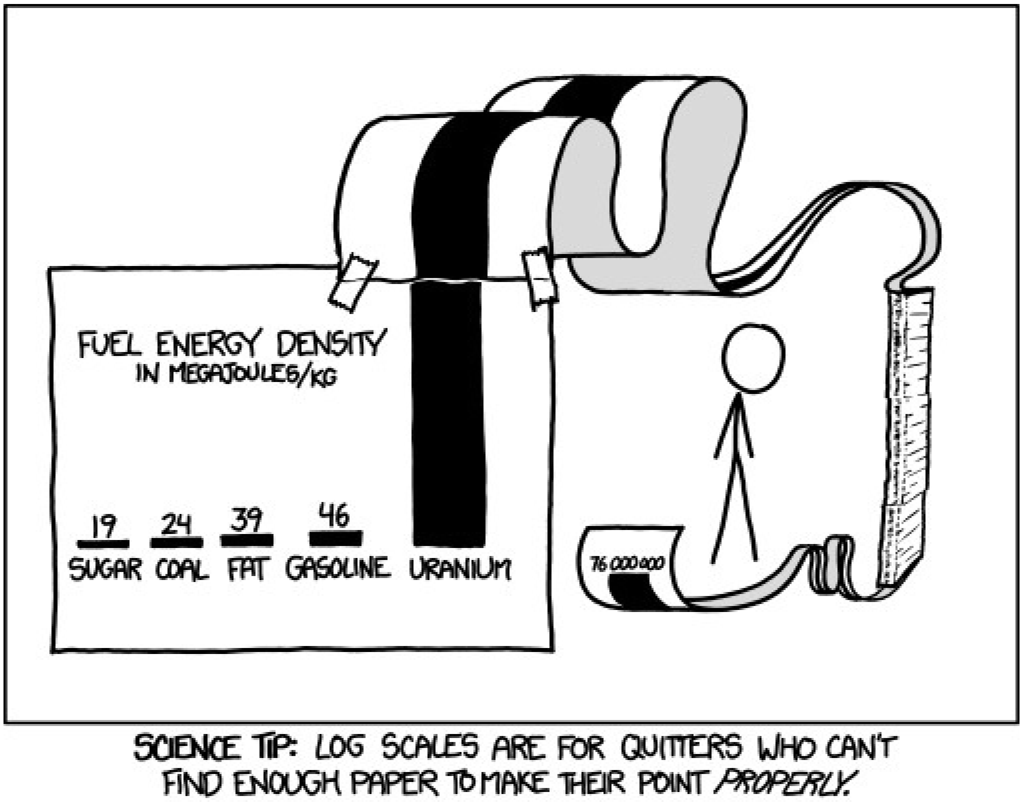

Figure 22 Comparing fuel energy densities

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3.4.3 Green power's cost issues

The electric energy sector is generally expected to be the linchpin of efforts to reduce greenhouse gas emissions. All credible pathways to climate (GHG) stabilization pose two challenges: cutting emissions to nearly zero (or even net negative) by mid-century and expanding the system to electrify and thereby decarbonize a much greater share of total energy use. Consequently, a flurry of studies has explored pathways to ''deep decarbonization'' of that energy sector. For

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[124] In light of almost everything else that Angela Merkel has done, this "question's" answer is surely "no". Despite earlier opining that closing nuclear was "a mistake", Chancellor Merkel had to join with another political party (the Greens) because she needed to form a government – her then-new job. However, the old saying, "The road to Hell is paved with good intentions." is mirrored by, "The road to redemption may lead back to Hell". In view of this coming winter's looming EU-wide energy crunch, with Mrs. Merkel finally off the stage, Germany is vulnerable to returning to another totalitarian dictatorship that promises to solve all the problems created by some of the last decade's "liberal" green agendas. Germany is especially prone to the sorts of bi-polar cultural swings that also happen elsewhere including right here in the good ol' USA.

that to happen in today's world, implementation must represent an attractive investment to whoever's funding the required new infrastructure. In today's mostly privatized "free" world, that translates to governmental subsidies sufficient to mitigate investor risk and guarantee profits.

"I *will do anything that is basically covered by the law to reduce Berkshire's*[125] *tax rate. For example, on wind energy, we get a tax credit if we build a lot of wind farms. That's the only reason to build them. They don't make sense without the tax credit*."

Warren Buffett:CEO Berkshire Hathaway

In the USA, subsidies typically comprise ~⅔ rds of a US wind farm's asset value – the rest is its product electricity's anticipated market value. Indirect subsidies comprise tax rebates implemented via loan interest and Modified Accelerated Cost Recovery System (MACRS) depreciation deductions from taxable income. Direct subsidies are up-front federal and state cash grants, total or partial waiving of state sales taxes, local property, municipal, and school taxes. (Sherlock 2019).

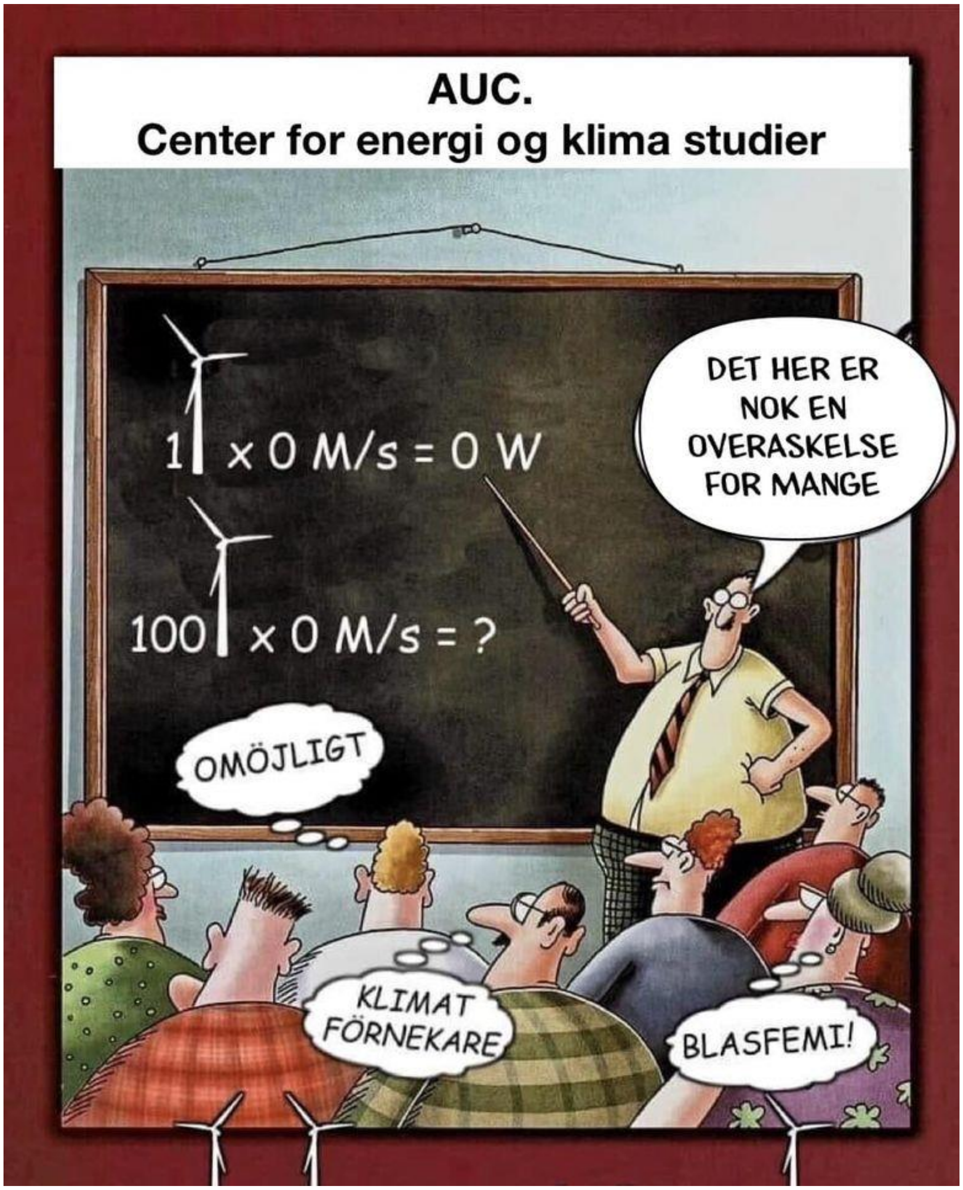
Here's a list of the subsidies that have attracted big money interests to wind energy (Schleede 2005).

1. Federal Accelerated Depreciation
2. Federal Production Tax Credit
3. Reductions in "wind farm" owners' state corporate income tax liability
4. Property, sales and other state and local tax reduction or elimination
5. "Public benefit funds"
6. Renewable Portfolio Standards" (RPS)
7. Mandated "green energy" purchases by distributors
8. "Voluntary" programs offering "green" electricity at a premium price
9. Other state utility commission actions that subsidize "wind farming"
10. Industrial Development Bonds to Finance privately owned wind farms
11. Curtailment fees (producers are paid for shutting down their facility when its energy can't be used by the grid's customers)

The thing that most decision makers, politicians, and "environmentally concerned" citizens don't seem to realize is that the cost of adding additional renewable energy sources to an existing power grid invariably adds to, not subtracts from, the cost of its electricity to consumers but not

[125] Berkshire Hathaway is the parent organization of MidAmerican Energy 's 1.6 million billed customers. Believe billionaires like misters Buffet & Gates-- they've no need to lie.

to its distributors (Figure 21). It's most harmful in already-renewables-saturated power systems like those of Denmark, Germany, and California.



The true cost of electricity from wind is much higher than wind advocates admit. Wind energy advocates ignore key elements of the true cost of wind electricity, including…

:•The cost of tax breaks and subsidies which shift tax burden and costs from "wind farm" owners to ordinary taxpayers and customers.

•The cost of providing backup power to balance the intermittent and volatile output from wind turbines. China's statistics during its summer and winter high-demand periods, indicate that the combined output of wind and solar sources is generally below 15% of their nominal capacity 60% of the time. During Hunan Province's winter of 2020, the electric load was historically high due to heating loads, while more than 80% of its wind turbines were frozen and unable to serve the grid. As also happened during Texas's February "polar vortex", Hunan's wind output was under 2% of its wind farms' nominal capacity, contributing little to resource adequacy.

•The full, true, cost of transmitting electricity from wind farms to electric customers and the extra burden on grid management.

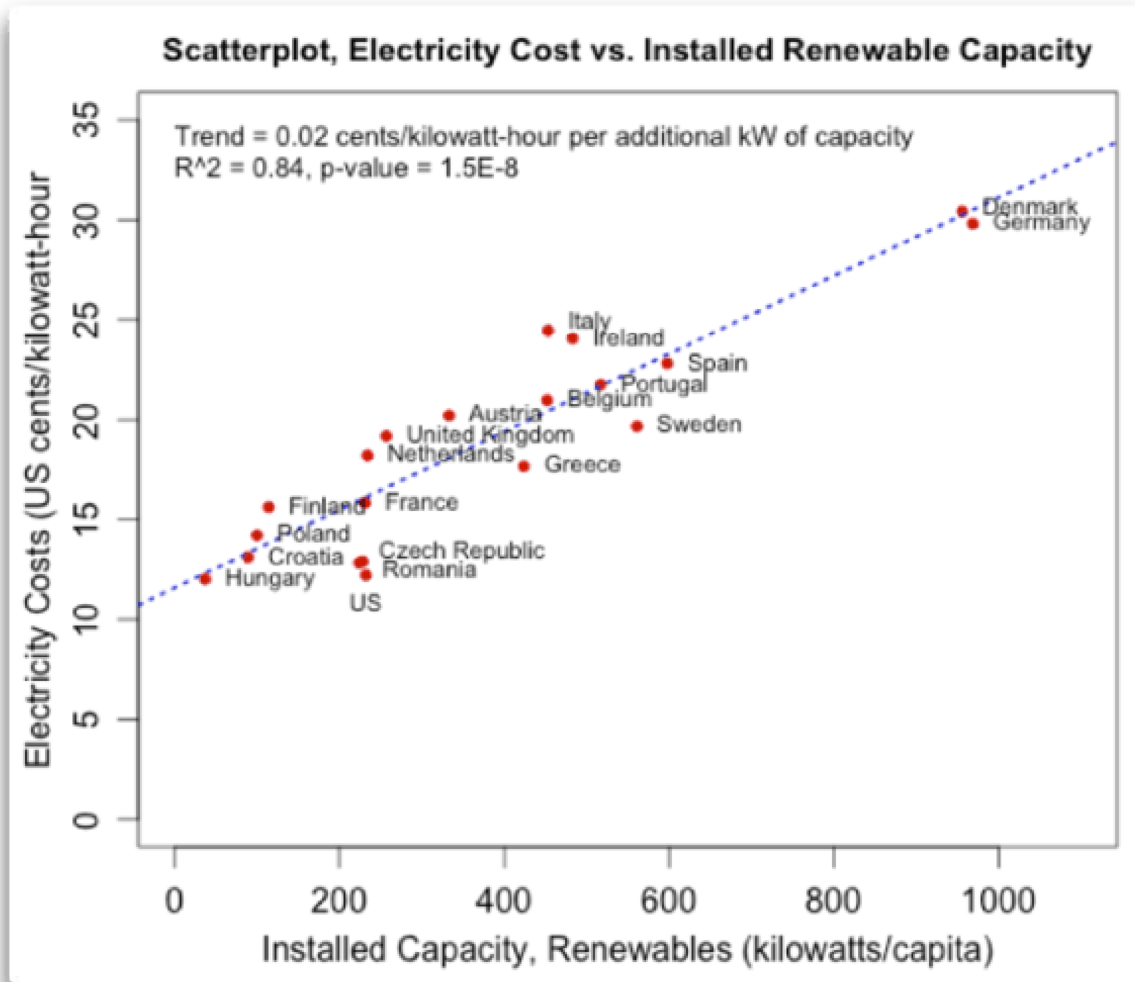


Figure 23 Costs of adding additional renewable power

Just over the border in Ontario the average contractual cost of generation (does not include unreliable source system integration costs) in Canadian cents (~0.75 US cent) /kWh, as forecasted by the Ontario Energy Board for 2020 is:

Hydro 6.3 cents) /kWh 36.4 TWh, (includes about 10% curtailment)

8.7 cents/kWh for Nuclear 90.4 TWh

11.8 cents/kWh for Natural Gas 9.5 TWh

14.7 cents/kWh for Wind 11 TWh

47.9 cents/kWh for Solar 0.7 TWh (behind the meter (rooftop) solar ~ 6 TWh)

26.8 cents/kWh for Bioenergy 0.4 TWh

The table below summarizes these figures and reveals the cost differences between sources.

Table 4 Ontarios' data

Type of energy generation	Cost per kWh (cents)	Total Output (TWh)	Cost per TWh (cents per TWh)
Hydroelectric	6.3	36.4	6.3×10^9
Nuclear	8.7	90.4	8.7×10^9
Natural Gas	11.8	9.5	1.18×10^{10}
Wind	14.7	11	1.47×10^{10}
Solar	47.9	0.7	4.79×10^{10}
Bio-energy	26.8	0.4	2.68×10^{10}

If we sum the cost per TWh for nuclear and natural gas together (2.05×10^{10} cents/TWh) and compare it to the sum for wind, solar and bio-energy (8.94×10^{10} cents/TWh), the cost is almost 4.5 times higher per TWh for renewables. This is a powerful illustration of the massive costs associated with those "clean" but unreliable energy sources.

These numbers show that substituting wind, solar and bioenergy for a combination of base-load nuclear and "peaker" natural gas would severely impact that Province's ratepayers. The majority of Ontario's already-built new wind farms' output is 1) either totally wasted or causes its run-of-the-river-type hydropower energy to be wasted, or 2) is sold to the USA for few percent of what its own utility ratepayers are billed for their electricity.

MISO the USA's "Midcontinent Independent System Operator" (one of the USA's three biggest ISOs with a tie-in connection to Ontario via Michigan and Minnesota) has just published (February 2021) a study of what the impact of adding more renewables to its grid would be. Its 217 page report can be downloaded at https://www.misoenergy.org/planning/policy-studies/Renewable-integration-impact-assessment/#t=10&p=0&s=&sd=

That "Renewable Integration Impact Assessment" (RIIA) points out that as renewable energy penetration increases, so does the variety and magnitude of the bulk electric system's needs and risks. It concluded that managing the system under such conditions, particularly beyond the 30% system-wide renewable level "*is not insurmountable but will require transformational changes* *in planning, markets, and operations"*. Through coordinated action with MISO's stakeholders, its authors also concluded that renewable penetration beyond 50% would be "possible".

Those changes represent the additional "system integration" costs that intermittent renewables impose upon an electrical grid. Those costs are rarely considered or included in the contractual energy costs that the proponents of such sources use to claim that their growth scenario would be cheaper per kWh than would adding more of the traditional and more dependable, thermal-type power plants. The latter "old fashioned" technologies inherently provide the reliability and dynamic stability which is neither recognized nor compensated for in fully privatized electricity markets like Texas's ERCOT.

The real issue with even well-conducted modeling exercises like MISO's is that its experts were paid to study the wrong scenario, i.e., determine how much more of today's most-favored renewable energy sources could be added to its system before its costs became intolerable rather than come up with the most affordable way to power a world that no longer burns fossil fuels and must also somehow reduce the amount of CO_2 already in the atmosphere, not just the rate at which it continues to be dumped while those resources still exist.

Studies should focus upon ultimate goals, not just upon the most affordable/attractive next incremental step in a predetermined direction. In particular, modeling conclusions based upon extrapolations of cost trends aren't worth much. Things & services do and will likely continue to cost whatever the market will bear. This article https://www.zerohedge.com/energy/wind-energy-becoming-too-expensive points out that today's (2022) supply chain disruptions are reversing the trend of decreasing costs for wind and solar. In our leaders' zeal to collapse fossil fuels for climate change mitigation, producers have seized an opportunity to curtail supply and force prices up. This of course rolls through the entire economy raising prices (inflation) resulting in increased costs for everything. Increasing the cost of energy is a self-multiplying recursive dynamic and if we do not include that in capital cost modelling we are under projecting future costs of everything.

Any country's political leaders, environmentalists, and system planners should be more transparent with its citizens about the total system integrated costs of all their proposed "greener" energy generation schemes. If its decision makers continue to ignore integration costs, its retail electricity rates will rise faster than in countries that choose to retain traditional generation technologies and/or develop equally reliable new & better breeder reactors. Higher retail electricity rates will disadvantage domestic manufacturers in international trade and lower that country's citizens' living standards.

3.4.4 Green energy's waste and resource issues

Today's most popular renewable energy sources – wind turbines and solar panels – generate far more environment-impacting waste than do nuclear reactors per unit output.

Waste. An energy-related issue raised by today's increasingly extreme weather is that wind turbines shut down when the wind gets too strong and destroyed if it gets totally out of hand.

For instance, Typhoon Usagi was a violent tropical cyclone which affected Taiwan, the Philippines, China, and Hong Kong in September 2013. One third of the Honghaiwan wind farm's Vestas V47 600KW turbines (located ~130 kilometers northeast of Hong Kong) were blown down and another third lost their blades. It had also been hit by another typhoon ten years earlier damaging 13 out of its then-25 turbine system causing a loss of 10 million yuan.

Solar photovoltaic panels gradually lose productivity and are expected to have useful lifetimes of ~20 years. Natural (& now becoming both unnatural and more common) events like severe hailstorms, tornadoes, hurricanes, derecho[126]s, etc. also routinely damage solar panels. For example, in 2015, a tornado destroyed 200,000 solar modules at southern California's "Desert Sunlight solar farm". More recently, Puerto Rico's second largest solar farm, usually generating 40 percent of that island's electricity, was severely damaged by Hurricane Maria   much of which still hasn't been repaired four years four years later.

Figure 24 Post hurricane solar farm

[126] An unprecedented four derechos have swept across where I'm living now (Iowa) in the past two years, flattening crops, sheering off roofs and siding, and toppling utility poles. One of them was accompanied by a massive dust storm ("haboob"), the first in this state since the 1930s Dust Bowl days.

Also see https://energyskeptic.com/2019/wind/

The International Renewable Energy Agency estimated that there was about 250,000 metric tons of solar panel waste in the world at the end of 2016 and that the figure could reach 78 million metric tons by 2050. Solar panels contain lead, cadmium, tellurium, and other toxic chemicals that cannot be removed without breaking them completely up & "digesting" the detritus in strong acids. While their disposal often takes place in regular landfills, it is not recommended because buried modules will eventually break and their toxic constituents leach into the soil, compromising both drinking water and agriculture if such land were to be reclaimed and repurposed. Solar panels can be recycled but doing so is generally more costly than is the economic value of the materials recovered which means that it's unlikely to happen in a privatized economy. Considering that the ~1.8 million solar panels of a proposed 6,350-acre solar farm in Virginia contain about 100,000 pounds of cadmium, such disposal is a genuine cause for concern. Furthermore, even rainwater can slowly flush cadmium out of intact solar panels. Washington is currently the only U.S. state jurisdiction requiring a panel's manufacturer to develop a recycling plan, but its requirements do not address ultimate disposal costs. Adding a disposal fee to solar panel purchase costs would increase the probability that that issue is addressed if/when the manufacturers go bankrupt. However, because such guarantees would likely render solar panels no longer "cheap" and therefore less apt to be purchased, it's also unlikely to happen. Since 2016, at least seven solar panel manufacturers (Sungevity, Beamreach, Verengo Solar, SunEdison, Yingli Green Energy, Solar World, and Suniva) have gone bankrupt (IER 2018) which of course means that any promises made by their managers won't be honored.

Wind turbine energy also isn't as "green" as its champions claim (American Experiment 2019). The average lifespan of a wind farm's turbine is expected to be 20 - 25 years[127] after which its owners should/could (but may not) repurpose and recycle 90 percent of its materials (copper, steel, etc.) except for its gigantic blades. About 2,700 wind turbines have been decommissioned

[127] There are two reasons that most turbines are unlikely to last even 20 years. The first is that, to keep their weight and cost down, their blades are made of fiberglass which material does not hold up well to severe weather exposure. The tips of their blades move so quickly (typ. >180 mph) that their leading edges are often destroyed within a few years by rain, snow, ice, and dust impact. Cycles of heat and cold plus constant vibration damage structural integrity. In short, they wear out quite quickly. Offshore turbines wear out even sooner and cost far more to both build and maintain. The second is that a wind turbine is a highly complex mechanical and electrical device. It has a huge gearbox connecting the blades to the generator that serves to feather (twist) the blades to control speed and provide braking. All of this stuff is very heavy and in constant motion which grinds gears and bearings. In some regions, generators last only a few years due to external temperature extremes (heat and cold) and internally generated mechanical heat, magnetic forces and lubrication issues. Consequently, thousands of wind turbines have already been burned up, broken up, or otherwise destroyed. Some wind farms requires so much maintenance that they are not cost-efficient even with today's high subsidies. There are lots of spectacular YouTube videos of wind turbine failures that the industry's champions downplay. They want us to think of them as gently and gracefully turning "forever" without repairs or concerns.

since the USA's first (1970's) alternative energy boom. Each of today's modern turbine blades occupies between 30 and 45 m^3 of landfill space and landfills in Wyoming, Texas, and Oklahoma are being inundated with them. Bloomberg New Energy Finance (Bloomberg 2019) predicted that 2 gigawatts worth of turbines would be refitted that year meaning that there will be a lot more blades destined for the dumps.

However, an "anti renewables" argument based upon wind turbine blade disposal costs is pretty weak. If/when we here in the good 'ol USA ever decide to adopt rational policies, worn-out blades will become valuable enough to be worth shipping to a recycling and/or cement plant https://cen.acs.org/articles/100/i27/companies-recycle-wind-turbine-blades.html . Even if our leaders don't decide to properly incentivize wind energy entrepreneurs, continuing to bury those blades isn't a big deal either. For instance, https://www.wind-watch.org/news/2022/02/28/graveyard-of-the-green-giants/ informs us that Sweetwater Texas's wind turbine blade graveyard contains "4000 blades covering an area of almost acres". Let's assume wind farms comprised of 2 MW- rated turbines with a lifetime of 20 years and an average CF of 35%. Each of their turbines would generate 2E+6*0.35*3.15e7*20/3.6E6 or 1.23E+8 kWh worth of energy and eventually require 3/4000*25 or 0.0188 acres of blade-burial plot land. Since "undeveloped" land in the USA's mostly desert-like & otherwise useless West (most of the Permian Basin or almost all of Wyoming) currently goes for about $1000 acre, enough land to bury each such turbine's blades would cost about $19 which translates to an energy cost increment of $1.53E-7/kWh. (A reasonable-sounding analysis of wind energy economics https://www.semprius.com/how-long-does-it-take-a-wind-turbine-to-pay-for-itself/ suggests that producing energy with non-subsidized wind turbines costs ~$0.037 kWh.)

In November 2020, the University of Edinburgh's Professor Gorden Hughes, presented a paper entitled, "Wind Power Economics –Rhetoric and Reality", from which Figure 25 has been excerpted.

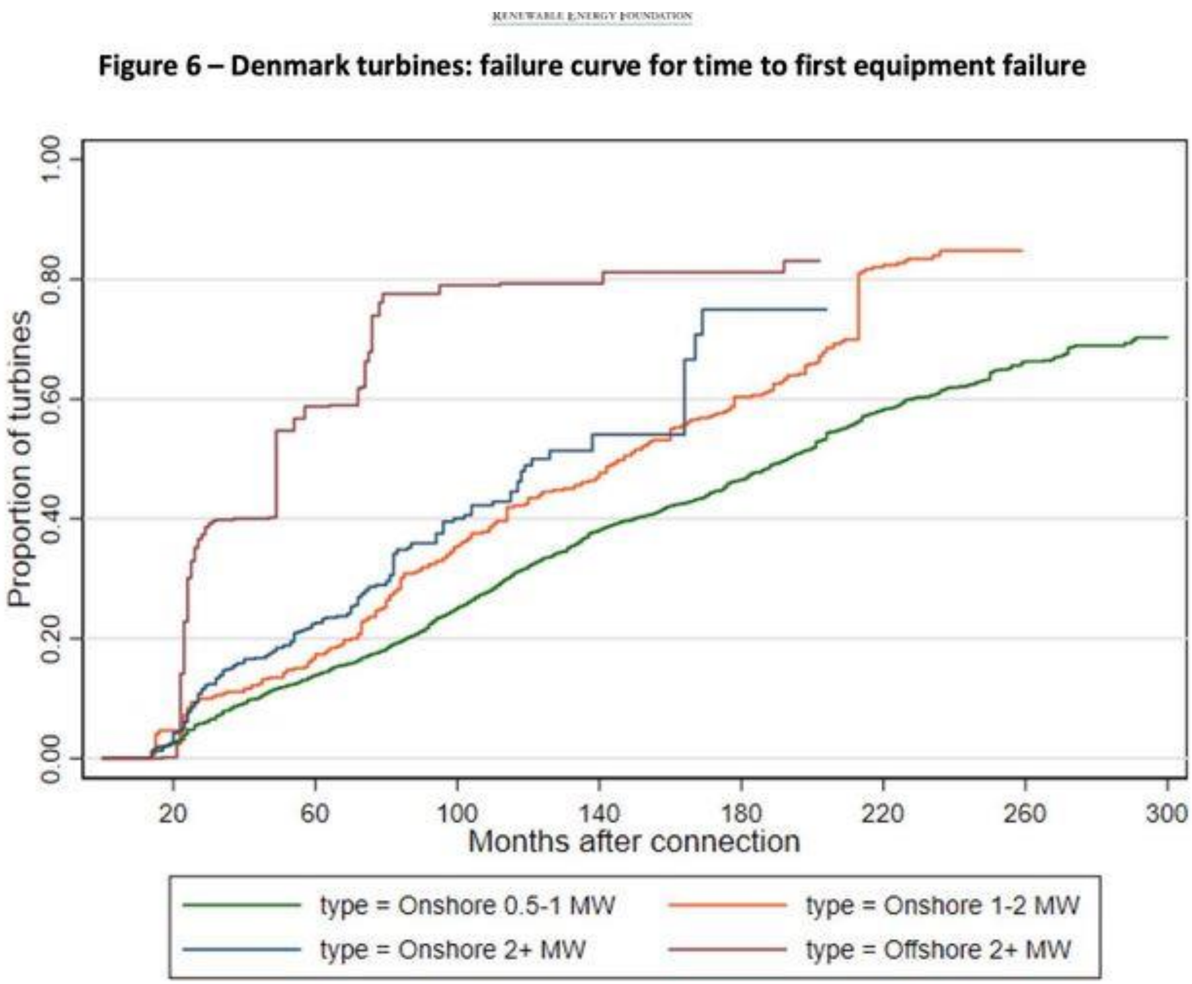


Figure 25 Real-world wind turbine reliability/maintenance issues (from Hughes 2020)

Professor Hughes' presentation begins with….

"It is difficult to make predictions, especially about the future. [Attributed variously to Niels Bohr (Nobel Prize in Physics) and SamGoldwyn (movie mogul)]. The theme of my talk is the disparity between predictions about the future costs and performance of wind power (especially offshore wind)"

It should become apparent to anyone who professes to "follow the science" that deciding to go whole-hog on any combination of wind and solar power-sourced technologies will cost a lot more than most of both them and the rest of us have been led to expect.

An aging wind farm poses questions about who is responsible for "decommissioning" its worn-out turbines and reclaiming the land that they stood on. To head off the possibility of abandoned, decaying, wind farms, the state of Wyoming now requires companies to provide bonds to cover the cost of their decommissioning and disposal when they are taken out of service or abandoned.

While it is relatively easy to recycle a wind turbine's steel and copper, the number of blades requiring disposal will only continue to grow unless the USA's decision makers bite the bullet and enact legislation mandating that they either end up becoming just another feed/fuel (like plastic bags, etc.) for the Future's cement plants[128] or that turbine owners must purchase bonds to pay whoever eventually does bury them[129].

Green energy campaigners are infatuated with China's now relatively "cheap" wind turbines[130], but making their permanent magnets is environmentally impactful – to China (Hurst 2010,). China currently meets about 96% of the world's demand for rare earths, and most of the so-required mining, separation and extraction is done there[131]. Every ton of rare earth element (REE) produced purportedly generates 9,600 to 12,000 cubic meters of dusty waste gases containing hydrofluoric acid, sulfur dioxide, and sulfuric acid, ~ 75 cubic meters of acidic wastewater, and ~one ton of relatively concentrated radioactive waste residue. China's Baotou region produces approximately ten million tons of such wastewater every year most of which is dumped without effective treatment and thereby contaminates both potable and irrigation water. Disposal of the approximately 2000 tonnes of mildly radioactive mine tailings generated per tonne REE is also problematic. Generally, tailings are placed into large open impoundments whereas in the U.S. permits are required and such waste piles must be tightly covered or remediated in some other fashion (see [The dystopian lake filled by the world's tech lust - BBC Future]). .

A Chinese-made 2 MW wind generator's permanent magnets require about 930 pounds (~0.4 tonnes) of REE which means that building a wind farm with an average CF of 0.3 capable of providing as much energy per year as a 1 GW_e molten salt breeder reactor (MSR) would require about 700 tonnes of rare earths - mostly neodymium (Stover 2011).

To quantify this in terms of environmental impact, let's assume Hurst's contention that the mining/processing of one ton of rare earth minerals produces about one ton of a concentrated toxic/rad "mixed" waste. In 2012, the U.S. added about 13.1 GW of wind power capacity which

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[128] Their blades consist of a burnable plastic (epoxy or material reinforced with calcia/alumina/silica glass fibers – consequently they could comprise both the feed and fuel of a Portland Cement plant - just add some clay, iron ore, and limestone (Miceli 2019 also see [How can companies recycle wind turbine blades? (acs.org)]).

[130] To learn why China's wind turbines are "better" in some respects than are those utilizing electromagnets see https://www.renewableenergyworld.com/2012/10/05/which-wind-turbine-generator-will-win/#gref .

[131] The USA's Mt. Pass, Calif. rare earth mining and processing operation sends its concentrated ore to China to be refined to metals, compounds, and anything else containing REEs.

figure means that about 2770 tonnes of rare earths were used in the wind turbines installed here that year. It also suggests that about 2770 tonnes of the above-mentioned radioactive waste was created to make them.

To put that number into perspective, America's nuclear power industry produces about 2000 tonnes of spent LWR fuel "waste" each year. This means that the U.S. wind energy industry may very well have created more tonnes of "radioactive waste" (in somebody else's back yard, of course) than did its nuclear power industry. In that sense too, the USA's nuclear industry is relatively clean because its reactors supplied about 20% of its electrical energy that year whereas wind accounted for just 3.5 %.

Mineral Resources: In a report published earlier this year, the International Energy Agency found that achieving net-zero emissions by 2050 is apt to require six times more of certain minerals by 2040 than are being mined today. Deep-sea speculators contend that ocean-floor nodules[132] represent a critical part of filling that need, with estimates that they may contain six times as much cobalt and triple the amount of nickel as there is on land — and at a higher grade. Mining nodules, they say, will help the world to shift away from the biodiversity loss, toxic pollution, and exploitive labor practices that often come with terrestrial mining.

However, other equally smart but less invested people say that harvesting them could put one of the world's last pristine ecosystems at risk of irreversible damage, affect whale and tuna migration, extinguish newly discovered species, and even accelerate climate change by kicking up long-undisturbed carbon stores.

The most recent analysis (**Mining Of Minerals And The Limits To Growth**) published by a Finland-based Australian Professor of Mineral Processing, Simon Michaux, makes the point that minerals have been declining in both availability and quantity pretty much as predicted by the original analysis's "Standard Run"[133].

Those reports as well as what's proven to be an uncommonly sensible assumption (i.e., that the world's mineral resources are finite) indicate that our descendants' civilization must be powered

[132] These nodules are potato-sized mineral chunks containing elements vital to the renewable-technologies anticipated for the world's transition away from fossil fuels, particularly lithium-ion batteries, solar panels, and wind turbines The lumps are formed when something like a shark's tooth falls to the ocean floor and mineralized metals build up slowly on its surface over the eons. They dot the ocean bottom around the world, but they are most plentiful in the Clarion-Clipperton Zone (CCZ), a 1.7 million-square-mile expanse of international waters in the Pacific Ocean. They mainly contain manganese and iron, but also lots of cobalt, nickel, copper, along with traces of rare earth elements.

[133] His other conclusions were that today's "Linear Economy" is seriously unbalanced, not remotely sustainable, and that the industrial ecosystem and society it currently supports will radically change and may soon contract in size.

in a way that's more land, money, and mineral resource-efficient than any realistic combination of batteries, windmills, solar panels, and biofuels would be.

Section 7.3.1.1 of this book will discuss the environmental and economic consequences of the fact that producing a joules worth of solar/wind power requires far more other building materials (steel, concrete, etc.), land, and water than does nuclear energy.

2.1.4.2 Green Energy's "Job" scam

Another of green energy's wasteful characteristics as far as its consumers/customers are concerned is that energy generation (especially with solar power) requires far more labor than does coal or nuclear power per joule – in other words, its workforce is less productive (see Figure 26). While this fact is often touted as an advantage (creates jobs), most green jobs are either temporary construction/installation gigs or have more to do with increasing the system's overhead (assessing the efficiency of lighting/heating/ ventilation, air conditioning (HVAC) systems, other appliances, ENERGY STAR ratings, software development, etc.) than with generating either useful services or energy. The bottom line is that the majority of today's green jobs really don't have much to offer most of us.

Besides, our Greenies have gotten it backwards: it's not the new jobs in energy-generation that count but those created/enabled by energy's use. The provision of cheap, reliable energy would enable the private sector to create "free" jobs as far as society's taxpayers are concerned

Lesser returns from bigger investments of energy and money would make any country poorer, not richer.

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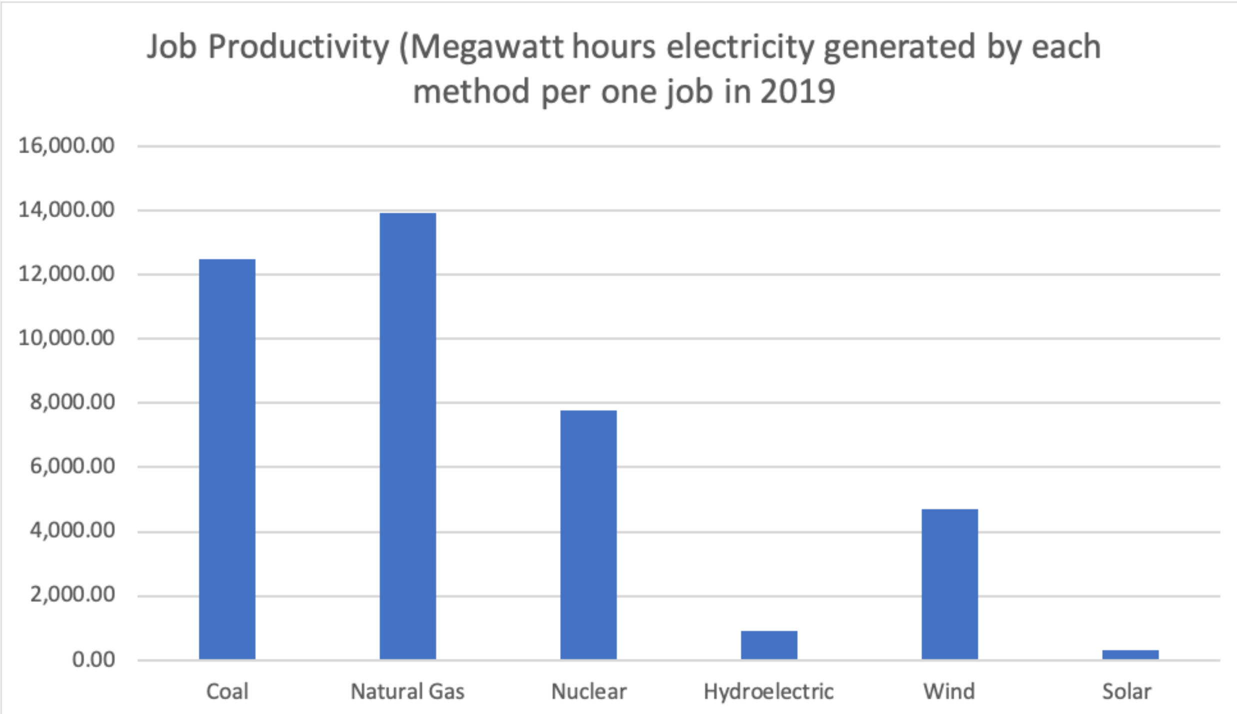


Figure 26 Energy generated per job

Mandating the use of horse-drawn machinery for farming would also create lots of jobs. It would also cause a huge drop in agricultural productivity which would leave most of us worse off and some of us starving. Mandating the use of less productive energy sources in the energy sector would have the same effect. Inefficiency won't grow the economy. It makes no sense to use job number projections to justify renewable energy mandates that will serve to drive up the cost of electricity and destroy more jobs than they create.

3.4.5 Storage:– "renewable" energy's biggest technical issue

Electrical energy storage becomes more important as the share (degree of "penetration") of intermittent generation technologies, mostly wind and solar, in a region's power mix increases.

Today's fossil fuels are remarkable in several ways. They are (1) inexpensive, (2) cheap to store and (3) economic to transport globally. The storage challenge is what makes getting off of them so difficult. Unlike them, wind and solar photovoltaic power have no storage reserves. Here in the USA our energy system (all forms) provides about 100 quads of energy per year with about 6 weeks of storage - more in winter and less in summer. Storage addresses daily to seasonal changes in energy demand and provides assured energy in the face of hurricanes, earthquakes, and multi-week weather events. Without it an energy system has no resilience, meaning that people can die during those events.

At that scale six weeks of storage is 3.4 million GWhs . To put that into proper perspective, let's consider options capable of providing just one million gigawatt hours of "green" electricity storage. As of August 2021, the U.S. Energy Information Agency reports that the installed costs of utility-scale storage battery systems at $589/kWh. Equally important to consider is the fact that a plot of cost/MWe storage as a function of time suggests that their costs will level off at about $500/kWh (2021 dollars) as the cost of raw materials make up a larger fraction of the total cost. . If we somehow manage to reduce the capital cost ofsuch systems to $200/kWh, the necessary investment cost would still come to ~ $200 trillion—or about 8 times the U.S.A's GNP. While large-scale battery installations have been growing rapidly, their *absolute* scale is tiny—about 0.5 GWh of added storage capacity per year. That's why 99% of U.S. electricity storage is still hydroelectric pumped storage—553 GWh (DOE 2021).

There are three ways to create short term reliability

1. Building enough baseload-type power sources to supply 100% of maximum demand all day, every day.
2. Providing less such source capacity but back it up with redundant sources capable of being cranked up on a moment's notice if something fails or demand shoots up, and having those sources close enough to their customers to avoid transmission-related issues
3. Building several times as much "intermittent" source capacity as maximum anticipated load and back it/them up with enough storage to keep things running for at least several days' worth of bad weather across the entire country.

In the third scenario, the following illustrates how difficult its 100% renewables plus batteries scheme would be to implement.

After a recent expansion, Panasonic's total annual North American battery production capacity rose to 38-39 gigawatt hours". To run the USA's electrical grid solely with wind and solar, we'd need battery backup for at least 4 days (~100 hours) of cloudy, windless weather. That's ~500 GW x 100 hours or 1300 years' worth of Panasonic's battery production."

Coal, natural gas, biomass, nuclear and reservoir-type (not run of the river) hydroelectric dams are baseload-type suppliers The further a power source is from its customer the more likely service is apt to interrupted by weather, accidents, negligence, etc. and the more it will cost.

The people managing several of the USA's regional transmission organizations (RTO , an acronym for an electricity supply/distribution system - another acronym for essentially the same thing is ISO) are currently trying to reassure their customers and, more importantly, the politicians representing them that it'd be perfectly "safe" to shut down nuclear and coal-fired power plants because building more wind farms and solar panels would serve the same purpose (i.e., to their subject matter "experts", two dead horses could pull more than one dead horse).

The Carnegie Mellon Electricity Industry Center's examination of ERCOT's (the USA's largest) wind power system (Katzenstein 2010) formally tested that assertion. Its conclusions were that:

" *when there is wind, there is wind everywhere.*

- *when there is no wind there is no wind everywhere*."

Here are some less formal opinions.

Let's begin with an old quotation from the "good book"[134]

"The wind bloweth where it listeth, and thou hearest the sound thereof, but canst not tell whence it cometh, and whither it goeth." John 3:8

Here's a 110-year-old quote from one of USA's first official "Professional Engineers"

.."*The problem of the commercial utilization, for the production of power, of the energy of solar radiation, the wind and other intermittent natural sources is a double one. The energy of the sources must first be changed so as to be suitable in form; it must next be stored so as to be available in time."* (Fessenden 1910)

Here's another written a year ago by one of Canada's senior-most Professional engineers:

"*Wind's production characteristics means that wind energy is best used to supply interruptible electricity demand, NOT dependable electricity demand. It's good for charging electric cars but bad for running industrial or commercial operations." With the exception of "special" areas (e.g., the Sahara Desert), real solar power tends to be less reliable than wind power.*

*During the early 1960s I lived in North Vancouver, which is at about 50 degrees north latitude. During one memorable winter there were 52 successive days with no direct sunligh*t."

Charles Rhodes, PhD, P. Eng.

& finally, a poet's opinion

"*If the sun we do not store, we have no power after four*."
(After a couplet by Nathan S. Lewis)

Of course, in today's world, obvious conclusions/opinions like these examples don't matter much if there's big money to be made acting in ways inconsistent with their message.

2.4.5.1 The problem

[134] I love the King James version of that tome because you can rationalize almost anything you might want to say or do by quoting something within it. This, of course, includes "iconic" but terribly awkward phrasing/writing.

The main problem with most of today's renewable energy sources is not their headline cost per kWh, but that they're a bad match for a modern civilization's demand-driven energy needs[135]. ~80% of US energy use (after conversions) is non-electric. With the exception of wood-burning and the world's already nearly maxed-out hydroelectric dams, renewables are non-dispatchable electric. In a low-carbon world, the total source capacity required to serve the load would depend upon the reliability of the individual sources comprising "*all of the above*". Solar/wind power dominated systems are currently dependent upon natural gas turbine "peaker plant" backup which wouldn't be an option in that low carbon world scenario.

Table 5 lists California's consumption and source data. Note that it generated about 68% (22.2/32.6) its own electricity and that its total within-state generating "capacity" was almost three times its average demand. That's because its hydro, wind, and solar power sources exhibited low yearly-averaged CFs (~25% for its severely water-limited hydro plants & ~27% for its windmills and solar panels).

Table 5 California's electricity

California Electricity 2018

Source	GWe
total in state capacity	80
total solar	13.5
total wind	6
other renewables	7.6
total hydro	12
nuclear	2.4
gas	41

tot consumption= 2.855E+6 GWh, Av power=32.6 GWe
tot in state generation =1.948E+6 GWh, Av.power= 22.2 GWe
2018 http//ww2energy.gov/almanac/electricity data/total system power.html

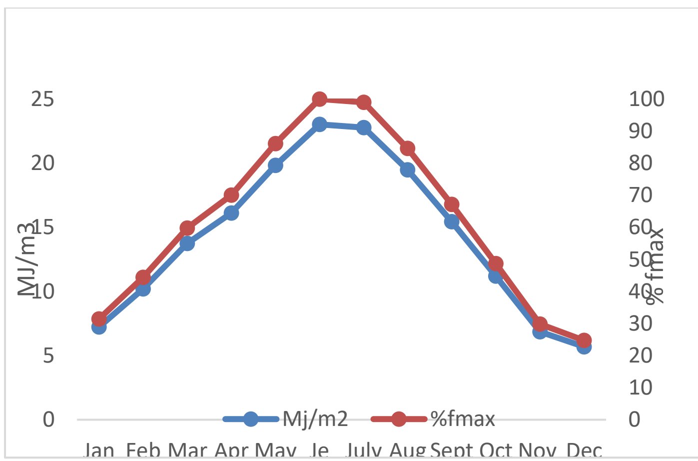
Two inexorable energy trends are underway in California: soaring electricity prices and ever-worsening reliability both of which bode especially ill for its low- and middle-income workers and consumers.

[135] We expect trains, mail, planes, things, and people to be able to go almost anywhere both cheaply and on time. That's why today's few remaining sailing "ships" are just toys.

Its California Independent System Operator (CAISO) is now (written Summer 2021) issuing lots of “flex alerts” asking consumers to reduce their power use “*to reduce stress on the grid and avoid power outages*.” CAISO’s warnings herald another blackout-riddled summer at the same time California’s electricity prices are skyrocketing. Its burgeoning spate of brown/blackouts have been the subject of lots of well publicized handwringing.

In 2020, California’s electricity prices jumped 7.5%, the biggest price increase of any state in the country that year and nearly seven times that of the United States as a whole. According to the USA’s Energy Information Administration, the all-sector price of electricity in California last year jumped to 18.15 cents per kilowatt-hour, which means that its people now must pay ~70% more for their electricity than the U.S. mean all-sector rate ($0.01066/ kWh). Even more worrisome is the fact that California’s electricity rates are expected to soar over the next decade.

Figure 27 depicts weekly-smoothed[136] Californian electricity demand and total renewables (wind, solar, & hydro) output throughout 2018. It demonstrates what would happen if its



Average Ames Iowa solar irradiance (energy/m^2/day) throughout one year

decision makers decided to meet demand with a nominally equivalent (i.e., yearly CF-corrected) amount of wind and solar energy. The problem is that the capacity factors (CFs) of both of those sources vary with the seasons as do peak power demands which means that the winter’s high heating loads occur when there’s low renewables output. Trying to compensate for a seasonal

[136] Cherry picking & “smoothing” data hides short term extremes – both techniques are widely utilized to “sell” renewables. Real world total wind/solar source power generation in many places often drops to almost zero for extended periods – especially during winters.

mismatch with energy storage systems is far more difficult/expensive than is buffering short term (hour-to-hour or day-to-day) renewables output randomness.

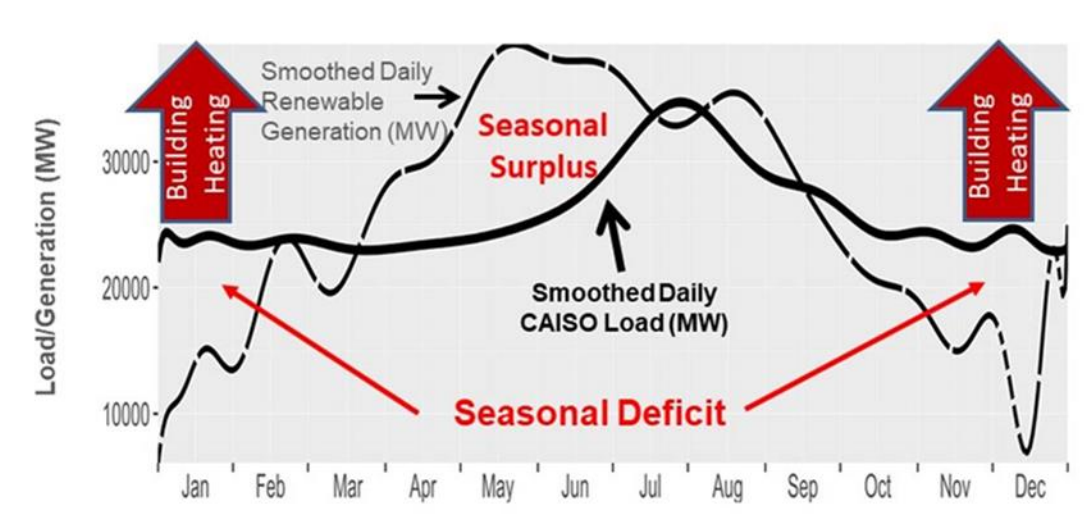


Figure 27 California's "100% renewables" conundrum (fig. courtesy of Charles Forsberg)

U.S. Energy Info Admin. put an average 2018 installed battery cost in California at $1,522/kWh. Let's see what that figure translates to if we were to try to power that state with currently politically correct energy sources and real-world batteries.

Annual California electricity consumption: 259,500,000,000 kWh

Average daily consumption: 259,500,000,000 / 365 = 710,959,000 kWh

Cost for sufficient battery capacity to power California for one day if cloudy, calm weather renders those renewables unavailable):

710,959,000 kWh x $1,522 / kWh = $1,082,079,598,000 = $1.08 trillion

Consequently, one day's worth of battery capacity would cost its citizens the equivalent of over four years of their state's total budget (~$230 billion/a). Of course, any such power system's storage batteries would have to be replaced every 7-10 years which translates to additional maintenance costs boosting retail power costs by another 50%.

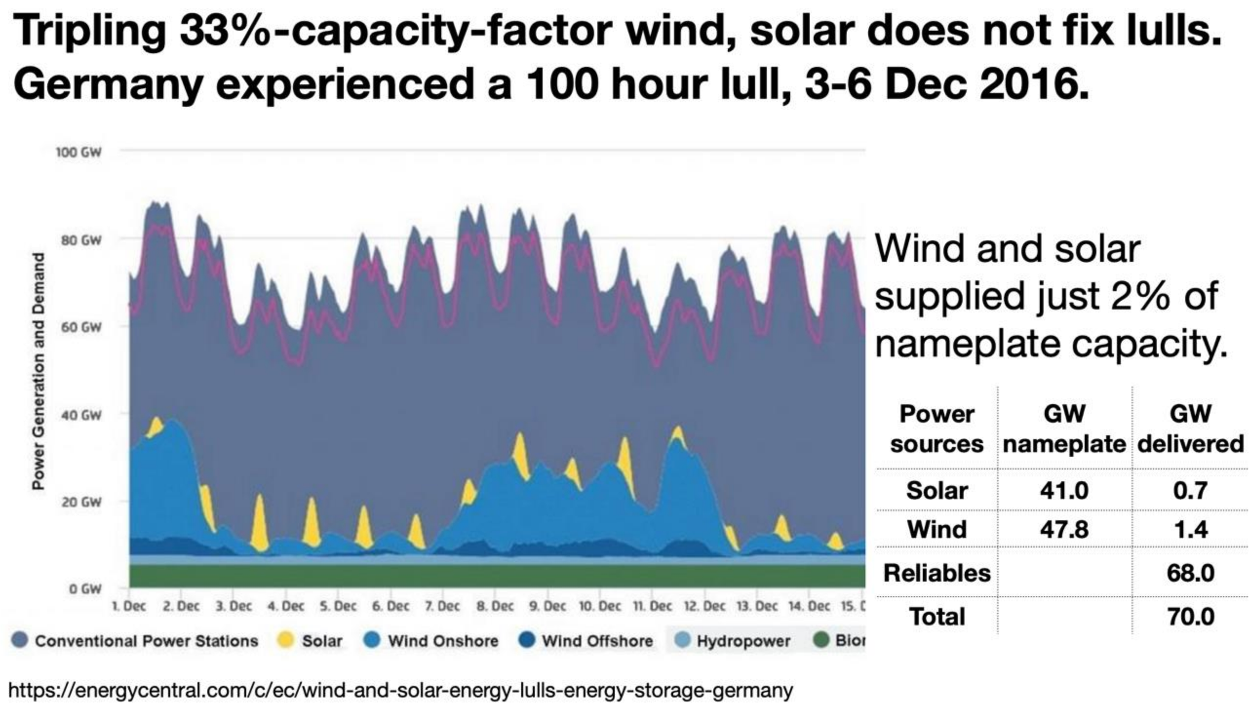


Figure 28 The WHYs of Storage (figure courtesy of Robert Hargraves[137])

Finally, let's base a storage calculation upon a very well-documented German "dunkleflaute" (extended period with little wind or sunlight over a large area - see Figure 28). Germany's situation is more relevant than is California's both because it's an entire country and over twice as many people are being subjected to Mother Nature's increasingly common "extreme" weather events.

In this example, the installation of a total of 88.8 GW worth of wind and solar "capacity" to help meet an average power demand of ~75 GW (peak demand = 88.8) would have satisfied just 2% of total demand for 100 hrs. That means that avoiding a blackout would have required (1-0.02* 88.8/75)*100 hr*3600 s/hr*88.8E9 J/s/3.6E+6 J/kWh or 8.7E+9 kWhs worth of batteries. That's about 4.3 trillion dollars' worth of Mr. Musk's grid scale Li-ion battery storage systems.

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[137] Robert Hargraves is a Brown physics PhD and honors AB in mathematics from Dartmouth College who then went on to teach mathematics and initiate its computer science program. He founded a software company, was a VP at Met Life, an IT consultant at AD Little, then VP of medical device firm Boston Scientific. He is the author of both *THORIUM: Energy Cheaper Than Coal* and *Electrifying Our World*, and cofounder of the MSR startup ThorCon. He's also currently teaching Dartmouth's "Osher Institute's Spring 2022 "Fission is in Fashion" class.

The problem is even worse than that. Dowling et al 2020 looked at 40 years' worth of US weather data asking how much storage would be required. They modeled 1-year increments, 2-year increments ... 6-year increments. The longer the time series, the more storage capacity was required. It appears that .their conclusion was that the intermittent generators plus storage problem does not have a bounded solution – in other words, any of today's affordable storage systems would eventually be totally discharged.

[Homework problem 40 demonstrates how a quantitative (numerical) conclusion about energy storage requirement can be drawn from figures like this. In that exercise's scenario, about $18 trillion worth of TESLA "Power Walls" would be required to compensate for anemic winter season renewable energy source outputs.]

Depending upon the time of year, The USA's current primary energy system includes between 45 and 90-days' worth of energy storage — primarily in the form of recently refueled nuclear reactors, tanked petroleum, coal piles, and, for natural gas, hollowed-out salt domes or deep underground porous underground rock/sand storage sites some of which have sprung spectacular leaks when viewed with infrared cameras able to "see" methane. It's important to understand that the bulk of that energy is used to generate heat and that only a fraction of that heat will then be converted to the electricity representing ~13% of the USA's primary energy consumption (Figure 40).

Such storage addre**sses** seasonal energy demand swings and disruptive events like hurricanes or winter cold spells. Annual U.S. energy consumption is about 29,000 Terrawatt hours (100 quads/year) which means that one month's worth of its energy storage comes to about 2.4 million gigawatt hours. Consequently, a zero GHG emissions USA's energy storage requirements would likely be <u>several million-gigawatt hours</u>. We can quibble about that figure's exact size but not about its order of magnitude.

If the capital cost of such a US-wide storage system were just $1/kWh (~one half of one percent of what today's grid scale lithium battery banks cost), purchasing one million gigawatt-hours' worth of battery backup would require one trillion dollars. Consequently, it should be obvious (but apparently isn't) that the USA's citizens couldn't afford large-scale deployment of Mr. Musk's ~$500/kWh grid scale. Li-ion battery-based, storage systems because doing so would cost them 25 to 100 times its/their nation's gross national product.

A recent analysis of grid-scale US "unsubsidized and levelized electricity storage" costs (Lazard 2017) for various sorts of storage systems concluded that if lithium-ion batteries were to replace today's gas-fired "peaker plants", the overall system's Levelized Costs of Storage (LCOS) would be about $0.282/kWh .

A subsequent analysis performed by MIT researchers concluded that energy storage would have to cost $10 to $20/kWh for a wind/solar plus storage system to be competitive with one in which nuclear power provided baseload electricity. Competing with a natural gas peaker plant backed-up system would require a storage cost of ~$5/kWh (Patel 2018).

Those figures assume scenarios in which solar/wind/storage must satisfy power demand 100 percent of the time. If other sources (moonbeams from Mars?) could satisfy demand 5 percent of the time, such scenarios could work at a storage price of $150/kWh.

Which technologies could hit that target?

2.4.5.2 Gravity-type storage "batteries

In September 2021, China's National Energy Administration released the middle- and long-term development plans for pumped storage hydropower from 2021 to 2035 (Sills 2021). The plan aims to expand China's pumped storage hydropower capacity to about 120 GWh by 2030, as part of its efforts to boost renewable energy and achieve carbon emission reduction goals. As of 2021 pumped storage hydropower accounts for 93% of the United States' utility-scale energy storage and over 10% of worldwide total hydropower capacity. The Tennessee Valley Authority's (TVA) Raccoon Mountain hydroelectric power station just west of Chattanooga TN is the closest thing to an ideal GW-day-scale energy battery that we have. Its construction was started in 1970 and completed within eight years. Water is pumped from Nickajack Lake on the Tennessee River at the base of Raccoon Mountain to a storage reservoir built about a thousand feet above it at that mountain's top. When filled, its upper reservoir contains about 47 million m^3 of water. The 70-meter-high dam on one end of it is the largest rock-fill dam ever built by the TVA. During periods of high-power demand, water is released from the upper reservoir through a tunnel drilled through the center of the mountain to drive reversible turbo generators in its underground hydroelectric plant. That plant has a maximum power output of 1,652 megawatts which it can generate for up to 22 hours. (i.e., it has a ~1.5 GWday energy storage capacity). During low demand periods, its power plant's turbo pumps are reversed, and the water is pumped back up into its upper reservoir.

California has several such facilities in its Sierra Mountain Range drainage, the largest of which is its Helms Facility -1.2 GWe maximum power capacity and theoretical storage capacity 5.6 times that of Racoon Mountain (204 GWh). Unfortunately, California is now experiencing its worst drought in the last thousand years. That means that its pumped hydro batteries likely won't work in the summer just when they are needed the most. During droughts, its residents are apt to be drinking its pumped storage water leaving nothing to recharge those batteries with.

Wherever there's a reasonably sized pair of nearby lakes with sufficient elevation difference plus an adequate source of make-up water, pumped storage will work if we don't mind sacrificing local lakeside environments due to water-level thrashing. Along coastlines, the lower such lake could be an ocean which of course would also represent that storage battery's drought-proof "electrolyte" (water) supply . The reason that California doesn't have such facilities is because its coastline is "protected" – no private ownership and all uses subject to Fish

& Wildlife, The Coastal Commission, the Water Resources Control Board, and "concerned citizen" protests/regulation/lawsuits/etc. The point seems to be that its government's experts and decision makers want a slot for both 'renewables' and gas-generated power in spite of the fact that the first can't do what must be done & the second represents another source of the same anthropogenic GHG problem facing the whole planet.

Collectively, pumped-storage facilities are the USA's largest electrical energy storage resource accounting for a total of ~23 gigawatts (GW) of power capacity representing about 5% of its average electricity demand[138] and ~92% of its electrical energy storage capacity (~250 GWh as

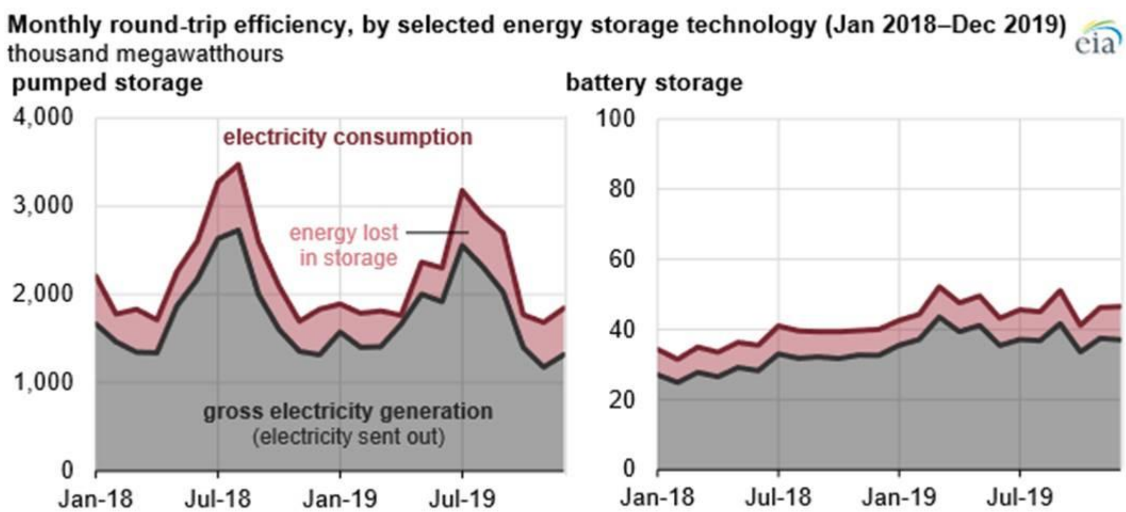

Figure 29 US electrical energy storage (EIA 2019)

of November 2020). Although lithium-ion batteries have slightly higher round-trip efficiency (82 vs 79%) than pumped storage, the latter typically operate at utilization factors twice as high as those of batteries and will last much longer.

That and the fact that the TVA was able to build Raccoon Mountain for only 310 million 1978-type dollars is pretty darn impressive. However, a little more ballparking indicates that we'd need to build another 1600 of them to provide just one day's worth of backup energy storage for an all-renewables-powered "green" US. Most of them would be far more expensive than was the TVA's facility because their builders would first have to build mountains to put them upon.

Where I am living now, central Iowa, there aren't any natural mountain tops to perch a pumped-water storage battery's upper reservoir upon. However, if someone were to propose building a

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[138] After subtracting out that required to make its electricity, the USA currently consumes about 60 quads worth of primary energy year. 60 quads energy/year ≈ 2000 GW steady-state power. [60*1.055E+18/3.15E+7/1E+9 ≈ 2009].

big-enough corn cob or cattle/pig crap mountain along either side of the state where there's always been plenty of river water to pump, something like that might excite its politicians and renewable power investors[139].

I wonder if the companies currently doing the USA's mountain-scalping type coal mining could build us lots of >1000 ft high pumped-hydro renewable energy storage facilities? If they could figure out how to power their bulldozers, etc. with windmills, it could morph into a really fine-sounding "Green New Deal" infrastructure-building jobs project[140].

Oh well.

2.4.5.3 Chemical batteries

At the end of 2018, the USA possessed 869 megawatts (MW) of battery-type power storage capacity representing 1.2 gigawatt hours (GWh) of energy storage capacity.

- Over 90% of large-scale battery storage power capacity in the United States was provided by systems based on lithium-ion chemistries.

- About 73% of large-scale battery storage power capacity in the Unites States, representing 70% of energy capacity, was installed in states covered by independent system operators (ISOs) or regional transmission organizations (RTOs).

- Alaska and Hawaii, with comparatively small electrical systems rep representing ~1% of the USA's total grid capacity, accounted for 12% of the power capacity[141] in 2018, or 14% of large-scale battery energy capacity.

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[139] Iowa's businesspersons, farmers, and politicians currently prefer to store solar energy in the form of corn ethanol which green-sounding activity features an overall sunlight-to-liquid fuel to electrical energy storage/conversion efficiency of ~0.04%. They currently don't even pretend to store Iowa's excess ("curtailed") wind power.

[140] Texas has purportedly already amassed "mountains" of cow poo upon which its most adventurous entrepreneurs could perch a Raccoon Mountain-like wind energy storage system's upper reservoir upon. It's funny that I haven't heard about that yet.

[141] The first large-scale US battery storage installation still operating in 2019 had entered service in 2003. Only 50 MW of battery storage power capacity was installed between 2003 and 2010. By the end of 2019, 163 large-scale US-sited battery storage systems were operating with a power capacity of 1.02 GW and 1.69 GWh energy capacity. The cost/kWh of those systems (not just their batteries) dropped a lot between 2003 and 2016 but recently appears to be asymptoting off at about $500/kWh. The initial rapid price drop in any manufactured product is due to larger manufacturing scales and learning by doing. At some point, costs stop dropping. There has been a great deal of debate about when that would happen and at what price point. The evidence is piling up that chemical battery-based electricity storage won't get much cheaper than somewhere between $400 and 500/kWh electric (2020-type dollars). Note that is for the entire AC in, AC out "battery system", not just its "naked" batteries. This and several other reports suggest that further rapid decreases in battery-type storage cost won't occur. See www.eia.gov/pressroom/releases/press483.php).

- Historically, most of the USA's annual battery installations have occurred within the California Independent System Operator's (CAISO) and the PJM Interconnection (PJM) territories[142]. However, in 2018, over 58% (130 MW) of power capacity additions, representing 69% (337 MWh) of energy capacity additions, were installed in states outside of those areas.

I will begin this section with a few words about chemical storage batteries in general. All batteries convert chemical potential energy into usable electrical energy. Any chemical battery has three main components: its positive electrode (cathode), its negative electrode (anode) and the cation- conducting electrolyte in between. If its cathode and anode are connected via an external circuit ("load"), it will spontaneously discharge its stored energy; i.e., the "charged" anode's accumulation of active metal's (e.g., lithium) electrons will leave the battery through a wire connected to its "load" & return to it through a wire connected to its cathode. The active metal's electrolyte soluble cations (e.g., Li+) leave the anode, move through the electrolyte and then bury themselves in the cathode material which maintains electrical neutrality by changing the oxidation state of one of its components: e.g., the electron returning to the battery's cathode reduces its Co^{+3} to Co^{+2} or its Fe^{+3} to Fe^{+2}. Many anode/cathode/electrolyte combinations are possible and thousands of reports have been written about them.

Solid state batteries store energy via three mechanisms. First, alloying reactions can take place with metal anodes like Si or Sn. Second, conversion reactions can take place at the cathode of air batteries and metal fluorides, as well as certain oxide and sulfide anode materials (e.g., Fe_3O_4 and MoS_2). Both of those mechanisms permit very high capacities, but also exhibit large volume changes which limits long-term reversibility and therefore practical application. Consequently, most of today's battery development work focuses upon a third mechanism, "intercalation", whereby a mobile ion or molecule is reversibly incorporated into vacant sites within a solid crystal lattice; e.g., olivine-structured $LiFePO_4$, $LiCoO_2$ or spinel $LiMn_2O_4$. Despite relatively modest storage capacities (max ~300 Wh/kg), intercalation minimizes volume changes/mechanical strains during repeated insertions/extractions of the active cation (e.g., Li^+) thereby favoring reversibility - a key characteristic of any useful energy storage system. Consequently, that mechanism governs the operation of today's Li-ion battery electrodes regardless of their chemistry.

Every intercalation-type cathode (the electrode storing the active metal's cation (oxidized form)) is based upon a crystal structure which includes one or more redox-active transition metals in (usually) an oxide matrix. This is also true for anode materials, with the exception of graphite and other carbon-based materials.

[142] PJM manages the grid powering the District of Columbia and 13 eastern and Midwestern states.

For every M^{+n} ion (e.g. Li^{+} or Mg^{+2}) inserted into the cathode host mineral's porous structure, n electrons must also be injected to maintain electroneutrality. In general, this means reversible redox of that mineral's transition metal (Co, Ni, Fe, Mn, etc).

Vanadium flow liquid state batteries are often touted as ideal for large-scale, long-duration storage because they can store large amounts of energy using scalable tanks of a relatively cheap electrolyte. One tank contains a solution of highly oxidized vanadium (V^{iv} and V^{v}) ions and the other it's reduced forms (V^{II} & V^{III}). Those solutions are pumped past each other on the opposite sides of a membrane within a cell where useful work is done - reversible charging and discharging - by moving electrons back and forth through it. Because flow batteries employ heterogeneous electron transfer rather than solid-state diffusion or intercalation they are more appropriately called fuel cells rather than batteries. Its champions are saying that it should be possible to drop their cost to ~$100/ KWh.

In March 2019, QY Research Group predicted the global redox flow battery market would be worth $370 million by 2025, based on a roughly 14 percent compound annual growth rate (CAGR) from 2018.

However, their main competitors, lithium-ion batteries, are acing ahead thanks to the burgeoning electric car industry. A May 2019 study by Prescient & Strategic Intelligence estimated the solid-state lithium-ion battery market would be worth close to $107 billion by 2024, with a CAGR (compound annual growth rate) of 22 percent.

However, there are other flow battery concepts championed by the slew of hyper secretive startup companies competing for Green New Deal investment dollars. The technology that's currently most "promising"[143] is Form Energy's mysterious "aqueous air/sulfur" battery about which no details have been revealed other than those intrinsic to its name and the identities of some of the terribly important people championing or investing in it.

In response to government-mandated (regions, states & sometimes even cities) increase in the proportion of distributed power subject to the whims of Mother Nature (esp. wind and solar), several US utilities are installing megawatt-scale battery systems to mitigate the effects of the inevitable fluctuations. Utilities in Hawaii, California, and Arizona (APS) have been early adopters and have installed a few multimegawatt-scale lithium-ion "Super Powerwalls" in regions with lots of windmills and solar panels.

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[143] :"Most promising" primarily because Bill Gates has invested in it.

In April 2018 a fire and explosion at a one-year-old, 2 MW/2-MWh (just barely "grid-scale"[144]) batteries installed west of Phoenix AZ highlighted some of special challenges posed by a battery backed-up wind/solar based power supply system grid. That explosion sent eight firefighters and a police officer to the hospital. The root cause of that and other such incidents, both large and small (in airplanes, cars, cell phones, etc.), is that upon recharge, the lithium within their anodes tends to form metallic dendrites that may penetrate the electrolyte separating their electrodes and thereby short-circuit them. The resulting heat spike ruptures the battery case and its flammable metallic lithium and organic electrolyte (an organo-carbonate compound) quickly ignite & everything immediately goes up in a cloud of toxic smoke.

Today's electricity storage batteries couldn't render a zero GHG system comprised of an "optimal" mix of wind and solar energy sources practical unless it was tremendously over-built (capacity >10x mean demand) or backed up with power magically imported from far enough away (China?) to not be simultaneously affected by Mother Nature's whims.

As is the case with the light water reactors on the supply side of this ledger, for grid-scale energy storage, today's lithium-ion storage batteries represent a prematurely locked-in technology poorly suited to the problem it is now being called upon to address. Faced with diminishing returns on Li-ion materials research, alternative metallic (sodium, magnesium, potassium, or calcium) intercalation chemistries have recently received a great deal of attention. Sodium-ion batteries, now being deployed by Aquion Energy, are the most mature of these alternatives. The main advantages of Na-ion batteries relative to lithium-ion batteries include similar (but not identical) electrochemistry and lower cost. However, their energy density is generally lower and the larger Na^+ cation tends to do more damage to the host lattice upon long-term cycling. The periodic table's next alkali metal, potassium, has received some attention, albeit limited because its even-larger K^+ ion is apt to cause more damage than does Na^+ without offering sufficient additional advantages.

However, there are several other possibilities. For example, liquid metal batteries can't fail the same way that today's lithium-ion batteries can/do and are also apt to be much cheaper because they feature liquid (molten), not solid, cheap, not expensive, metallic electrodes separated by a cheap molten salt electrolyte. Their operation relies upon density/SPG differences: a high density (e.g., antimony) molten metal electrode lies on the bottom of the cell. Immediately above it is an intermediate density molten salt electrolyte (e.g., a low melting mix of lithium and potassium chloride salts), and a low-density liquid metal (e.g., lithium or calcium electrode floats on top. Like oil & vinegar those fluids naturally self-segregate and charging/discharging the battery doesn't generate the sorts of irreversible physical changes that eventually cause any solid

[144] 2MWh is enough energy to power Arizona's utility rate payers for ~7 seconds.

electrode-based battery system to fail (lithium-ion batteries are unlikely to last more than ten years in such applications).

Global solutions must be based on globally abundant materials because nothing else works at scale. That's the point behind MIT Professor Donald Sadoway's battery research program. His teams have looked into a plurality of cheap metal (e.g., sodium, calcium, aluminum, magnesium…) battery chemistries the latest of which utilizes a metallic aluminum negative electrode, an elemental sulfur + graphite positive electrode, a safely low melting molten salt electrolyte (about 90°C) - mixture of sodium, potassium, and aluminum chloride salts, and a spacer that looks like a thin layer of fiber glass matting – see [Fast-charging aluminium-chalcogen batteries resistant to dendritic shorting - PubMed (nih.gov)]

To me this seems to be the breakthrough that could render an almost totally electrified transportation system including even farm tractors practical. All of its components are dirt cheap and neither particularly flammable nor apt to create much smoke if something surrounding the battery catches fire. Its voltage per cell is about 1.05 volts which along with the fact that both of its electrode materials have low equivalent weights suggests a theoretical electrode energy storage capacity of about 96500*1.05/(27/3+32/2)/3.6E6 or 0.001126 kWh/gram[145]1. Professor Sadoway estimated that his entire Al/S batteries will eventually cost about $8.99/kWh and have capacities of about 300 milliamp-hours/gram . At a voltage of 1.05 volts, that's 1.05 volts*0.3 amp*3600 s/ 3.6E+6 J/kWh or about 0.0003 kWh per gram. For a premium Tesla BEV-sized battery (90 kWh) that totals up to 300 kg (90/0.0003 grams) of battery costing 90*8.99 or about $810. If you drive it 15,000 miles per year & its Al/S battery lasts for 5 years[146], & TESLAs really can go 300 miles/full charge, that's a battery (not electricity) driving cost of 1.08 cents/mile ($810/(15000*5).

If our government were to also become willing to mandate that the configuration of such batteries be standardized so that they could be quickly/cheaply exchanged at "filling" stations[147], happy days could be here again!!

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145 96500=one Faraday = number of coulombs/of electricity per equivalent of charge. The oxidation of one gram mole of aluminum (27 grams) generates three Faraday's worth of electrons & reduction of one gram mole (32 g) of sulfur to sulfide sucks up 2 Faradays

146 Since the car's battery would be undergoing only 50 full charge-discharge cycles/annum (15000/300 =50), it's quite likely to be able to last at least five years.

147 That's what Edison proposed for his electric cars over 110 years ago – car owners don't need to own their car's battery too.

Unfortunately, enough of even such “cheap” batteries to store just one day's worth of 22 TWe power (approximate world demand circa 2100 AD) would cost ~39.6 trillion of today’s US dollars.

In the real world, Edison’s ~120-year-old nickel-iron (Ni Fe) battery has proven to be the most durable solid electrode-based storage battery. It’s extremely robust, tolerant of abuse, (overcharge, over discharge, and short-circuiting) and often exhibits very long life even if so abused. However, due to its low specific energy/power (energy/power per kilogram), relatively poor charge retention, and high cost of manufacture (retail cost per kWh is currently about 60% higher than a TESLA Powerwall’s), other types of rechargeable batteries have largely displaced them. However, it’s experiencing resurgence in some quarters (GOOGLE “Battolyser”) because overcharging them generates hydrogen which can be stored and/or used for a host of purposes including backup energy generation via combustion or fuel cells. In that manner, they could accomplish both short-term and long-term energy storage. However, even if these batteries were to last for 30 years, their relatively high up-front cost (currently about $800/kWh) translates to a LCOS of $7638/MWh.

A report in the 25Aug21 edition of Nature. (Zhu et al 2021) suggests that a group from Stanford University may have hit upon another technology that could render battery-powered cars & trucks genuinely affordable.

It’s a rechargeable version of the lithium thionyl ($SOCl_2$) battery utilizing a microporous carbon positive electrode, a starting electrolyte composed of aluminum chloride in $SOCl_2$ with fluoride-based additives, and either metallic sodium or lithium as its negative electrode. It operates via redox between mainly Cl_2/Cl^- in the carbon’s micropores and either Na/Na^+ or Li/Li^+ redox on sodium or lithium metal. The reversible redox reactions $Cl_2/NaCl$ or $Cl_2/LiCl$ occurring within in microporous carbon affords rechargeability at the positive electrode side and the thin alkali-fluoride-doped alkali-chloride solid electrolyte interface stabilizes the negative electrode.

Its key advantages are that all its components are cheap – either sodium or lithium, sulfur, carbon, oxygen, and chlorine - & it is apparently also considerably lighter/kWh.

Another outfit has apparently optimized its relatively cheap iron phosphate cathode-based lithium-ion battery which enables its same-sized battery pack to more than double the driving range of Tesla’s iconic Model S to over 800 miles https://www.motortrend.com/news/one-gemini-battery-tesla-model-s-range-test .

Other groups are convinced that lithium sulfur batteries will prove to be better. It’s a “cheap” rechargeable system notable for its high specific energy due to the low atomic weights of both lithium and sulfur. Its reactions involve metallic lithium dissolution from the anode surface and its incorporation into an elemental sulfur/carbon cathode as a lithium polysulfide salt during discharge and reversing that reaction - lithium replating back onto the metallic anode while charging. In most of today's electric vehicle batteries, their cathode materials (typically nickel/manganese/cobalt-oxide molecules) can only host 0.5 to 0.7 lithium ions each, whereas a single sulfur atom can host two lithium ions. Consequently, gravimetric energy storage densities jump from 150 -260 Wh/kg to over 500 enabling it to triple your car's range or get by with a much smaller/lighter/cheaper battery [Lyten Promises Big Things for EVs From Its Lithium-Sulfur Battery (motortrend.com)]

One of them has apparently come up with a "gamma" sulfur cathode material /carbonate electrolyte combination that enables their battery to maintain its reversibility through 4000 charge/discharge cycles. – at least ten years' worth of typical commuter-type driving [Stabilization of gamma sulfur at room temperature to enable the use of carbonate electrolyte in Li-S batteries (nature.com)].

Another advance that I just learned about today (6March2022) by watching ay CGTN's technically oriented weekly news show ("RAZOR") had to do with Chinese work on developing better EV batteries. The "breakthrough" in question involved replacing the alkali metal intercalation-based graphite anodes in Li ion batteries with ones made of a "black phosphorous"/graphite composite material. It should more than double the capacity (energy/kg) of that sort of battery because, in principle, each phosphorus atom can replace over six times as many carbon atoms. That concept was of course first described/published here in the USA but not actually reduced to commercial practice, see Bridging Covalently Functionalized Black Phosphorus on Graphene for High-Performance Sodium-Ion Battery | ACS Applied Materials & Interfaces

At this stage of the game, it's impossible to predict what's going to be powering our automobiles twenty-five years from now but I wouldn't be surprised if it's a solid-state battery based upon magnesium, aluminum, or sodium rather than lithium. I'd also guess that Elon Musk will own most of the factories making them.

Again, to really solve the electrified POV "range anxiety" problem, our political leaders must eventually become willing to insist that the configurations of any such batteries be standardized to render their switch-out quick/simple.

Those leaders should also be reminded that their/our world doesn't need another "perfect" car built to both impress & sell to millionaires - it needs lots of good-enough, cheap, and reliable cars .supported by governmental policies that assure their owners that they won't be haunted by range anxieties (i.e., financially incentivize other businessperson to build lots of "filling (battery change-out) stations".)

Here's another calculation that puts these figures into perspective: A bit of GOOGLEing reveals that the average US household currently consumes ~10.4 MWh per year of electricity costing (retail) about 12 cents per KWh– a total of $1282/a. If 100% of that power were to be produced with wind turbines and solar panels possessing capacity factors of ~30% and 15%

respectively, it seems likely that at least half of the power going into the average US home at any given time is apt to be coming from some sort of storage system – not directly from such unpredictable sources. If that proportion happens to be 50%, with today's lithium-ion battery-based storage gadgets, that home's annual power bill would increase by $1644 [50/100*10.4*282] meaning that their electricity would then be costing its residents >26 cents/kWh[148]. Since the average US wholesale cost of nuclear power is now only about 3.4 cents/kWh, it would make a lot more sense to satisfy 100% of its citizens' power needs with reliable nuclear reactors than to cover their world with windmills and solar panels supported with enough new transmission lines and batteries to render the latter scenario workable.

2.4.5.4 Thermal energy storage "batteries"

Why don't we just use the same hot salt-type energy storage batteries that the world's concentrated solar plants (CSPs) have been employing?

Existing commercial CSP heat-storage systems use tanks of hot and cold nitrate salts with capital costs of $20-30/KWh of heat energy over 85% of which cost is associated with the tanks and the salt.

Let's go through another calculation to see how that scenario would scale.

Let's assume that we're trying to supply a regional power demand of 3 GW_e (that's about what Idaho's populace currently requires) with 2 MW turbine-based windmill farms. Assume also that their average CF is 33% but that there are periods of up to one day long when the wind doesn't blow at all.

First, how many windmills are we talking about? That's easy – 3E+9/2E+6/0.33 = 4545 windmills (~120 typical-sized US wind farms).

Storing one day's worth of 3 GW electricity means that collectively those farms' heat batteries would have to reversibly store/release heat sufficient to generate 3 GWe days' worth of electricity.

How much hot salt would that require? Well, if we assume…

- A solar salt Cp (heat capacity) of 1.56 J/degree/gram (a reasonable figure)

[148] This figure assumes only the added costs of battery storage. "Correcting" it by adding-in guesses about the relative costs of nuclear vs solar vs wind vs etc., battery charging is apt to increase the retail consumer's cost differential.

•	That the temperature of the salt would be cycled between 600 and 300 degrees C (also reasonable), &

•	That the gas turbines associated with it can convert 45% of heat energy to electricity (probably a bit optimistic)

… the amount of heat required would be 1.73E+15 Joules [3E+9*24*3*3600/0.45] and the amount of solar salt needed would be 3.73E+6 tonnes [1.73E+15/1.56/(570-270)/1E+6] or about ~2.07 billion gallons[149].

Since solar salt currently costs about $520/tonne, 3 GW_e days worth of heat storage salt would cost about $2 billion.

That might be possible but not simple or cheap.

It becomes impossible if scaled up to something apable of supplying a week's worth of Idaho's energy needs.

A group of MIT, INL, and EPRI nuclear engineers has pointed out that the above-ballparked

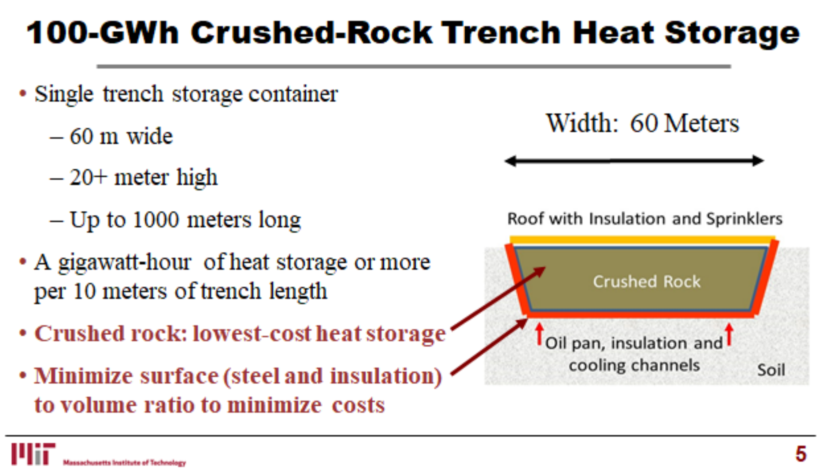

Figure 30 MIT's hot rock/molten salt heat "battery" (Forsberg, 2020)

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149 That's probably enough man-made nitrate to fight both of the last century's world wars (it's a key ingredient of most explosives). We're smarter than that now – just one of our modern military's medium sized "hydrogen" bombs can generate that much "boom" (question for California's lawmakers: "*now that you 'know' about this, are you now gonna be warning people about hydrogen too*?").

heat storage scenario's salt cost issue could be addressed by filling the tanks with chunks of rock to/from which heat would be transferred by a relatively small amount of fluid trickled down through them - the "CRUSH concept. Rocks are cheap & some types could likely withstand thousands of several-hundred-degree temperature cycles

Their system (depicted in Figure 30) reduces costs by (1) storing heat in crushed rock, not a liquid, (2) transferring heat to and from the rock chunks with a liquid trickled through them, and (3) replacing expensive tanks with huge low-cost buildings similar to aircraft hangars with both internal and external insulation. The trick of course is to engineer a cheap-enough system that would actually work. For the storage of the low-grade (~300°C) heat generated by water cooled nuclear reactors , a silicone oil could serve as the heat transfer fluid and almost any kind of rock would work. For the ~525°C heat generated by a liquid sodium-cooled reactor, a 60/40 by weight mix of sodium and potassium nitrate salts ("solar salt") would likely work with basaltic or quartzite-type rocks (Bonk 2017). The 650 to 900°C heat generated by gas-cooled and molten salt type reactors would rapidly decompose "solar salt" meaning that a different heat transfer medium must be used – perhaps a sodium/potassium/lithium chloride salt eutectic?

Gene Preston recently modeled (21Mar2022) a "clean" (no fossil fuel) power system for the USA's biggest Regional Transmission Organization (PJM's 165 GW peak load RTO).It features that region's current wind (12.5 GW) and solar (3.45 GW) renewable source capacities plus 112 GW's worth of Natrium's sodium-cooled fast reactors close-coupled to a 7283 GWh CRUSH battery (i.e., 52 GW for 150 hours or big enough to ride through another URI-type "polar vortex"). The costs were 2 to 4$/kWh for hot rock storage s and $1000/kW for the power generating turbogenerators. Assuming PV, wind, and reactor build costs of $1.8,0.82 and 6.6 per watt, energy cost to the RTO'S customers would be s 9.25 cents per kWh. The system's nuclear plants would run all of the time and always be charging/heating that battery.

Siemens is currently pilot-planting another potentially GWhr-scale *really* hot rock heat storage system utilizing air rather than a liquid (oil or molten salt) as its heat transfer medium. When electricity is cheap (i.e., lots of wind/sun & more than enough windmills/solar panels to meet immediate demand) air is heated and blown through the rock pile to heat it to about 650°C. When the wind dies down and/or the clouds roll in thereby rendering electricity sufficiently valuable, cold air is blown through that pile to a boiler/turbine that generates electricity. Siemens' tests will generate information about the effects of repeated thermal cycling of various sorts of rocks. The downsides of any such system include:

a. huge pumping energy losses because gases have very low heat capacities relative to their viscosities
b. from a purely thermodynamic point of view, converting renewable sourced electricity to heat and then back to electricity again will be wasteful - at best 50% & more likely under 30% efficient

A link recently sent to me by Professor Forsberg (2Apr22), describes a new “heat battery” developed by Rondo Energy, Inc which features drop-in modules that purportedly can provide affordable, high temperature and therefore more useful process heart (up to 1000°C - much higher than the ~570°C max provided by a solar salt-based heat storage system. Such “green” (decarbonized) stored heat energy could either replace an aging fuel-fed boiler or complement those still in operation.

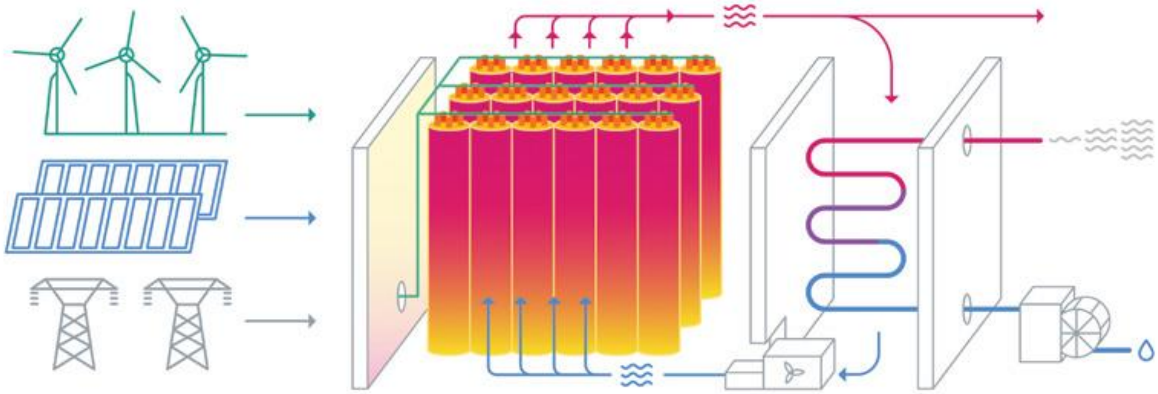

Figure 31 Rondo Energy's process solid state heat "battery”

According to its developers , “*it uses well-proven materials to build a heat battery that uses renewable electricity to deliver high temperature heat by circulating air through a solid material to deliver hot air or high-pressure steam at any condition. the standard unit delivers 20 MW of steam, which is like a boiler that’s burning 85 million Btu/h,”*

Rondo’s “battery” sound like s a real step forward because it represents a relatively cheap compared to lithium battery way of storing the heat-type energy comprising approximately 80% of that which modern civilization’s industries now generate with fossil fuels. However, I suspect that it cannot compete with crushed rock-based systems for grid-scale energy storage.

Finally, Chinese researchers have just published [A performance analysis of the spray-type packed bed thermal energy storage for concentrating solar power generation - ScienceDirect]() describing how their country’s alumina “rock”/silicone oil pilot plant-scaled experimental system has actually worked. To this old US-based experimentalist, that’s justmore evidence that China is apt to devise practical solutions to the world’s energy issues before we do.

Finally, to put things into better perspective, I’ve done some ball parking with the numbers in a report having to do with another real world system that works in basically the same fashion https://www.911metallurgist.com/blog/heap-leaching .

The USA's biggest heap leach gold mine (it's in Nevada) processes 150 thousand tonnes of crushed rock/day – it sprays acid down through a rockpile situated on a rubber pad on a gentle slope – its leachate is collected in a ditch

If it's got a typical-for-gold 45- day leachate residence time (see WIKIPEDIA) , it weighs 45*150,000 tonnes or 6.75E+12 grams.

If its rock's density is 2.7/cc (like granite's) & the pile has 35% void volume, its volume is 3.85E+6 m^3 or about 1.5 times that of the Giza plateau's "great pyramid".

If its rock's heat capacity is 0.79 J/g (again, like granite's), the temp of a CRUSH-type battery made from it is to cycle up/down 100 C, & the overall system's 's heat to electricity eff = 30%, that battery's electrical capacity rating would be 44.4 GWh - under two days' worth of one of today's average power reactor's useful output (we now typically discard 2/3's of its heat energy).

If the total volume of "leachate" (heat transfer fluid) within our giant rock pile CRUSH battery's , pipes, ditch, & heat exchangers is 2/3's of its void volume, that's 9E+5 m^3 or 1.6e+6 tonnes of solar salt

Next, how much salt are we going to have to pump?

Since an "average-sized power reactor" is one GWe and we're assuming SMRs one third that powerful instead , let's start by estimating what it'd take in terms of heat exchanger (HX) surface area to transfer one third of one of todays " average sized"" reactor's heat output to a 44.4 GWh "CRUSH' battery's heat transfer fluid.

According to Mr GOOGLE (Shell and Tube Heat Exchanger: Top 7 Reasons Not to Purchase (csidesigns.com)) "plate & frame" type HX's are the best/most efficient ones out there (can transfer about 2500 J's worth of heat/m2/degree'

Let's also assume that the salts on both side of its "plates" are like FLiBe; i.e., possess densities of about 2 g/cc at the system's working temp and heat capacities of ~2.4 J/s/cc (Mr. GOOGLE says that FLIBe's heat capacity is 2414.17 kJ/kg/ K)

Let's also assume that the temperatures of the molten salt on both sides of each HX plate change 100C during their passage through it

If so, each of our huge heat battery's-charging system's three 1000 MWt SMRs would require HXs possessing surface areas of about 1E9 j/s /2500 J/s/m^2/degree/100 degrees or ~4000 m^2

(that's a total of ~12,000 m2 's worth of super-efficient HX area for all three of 'em)

Next, how much salt would we be pumping?

To transfer each SMR's 1E9J/s's worth of heat energy with a 100-degree temp differential with its respective HX, we' d have to be pumping 1e9/2.414/100 or 4.125 tonnes of salt past each of its two sides per second)

(that's pumping a total of 24.4 tonnes or ~12.4 m^3 of molten salt/second through our hypothetical close-coupled, 3 reactor/ CRUSH battery system)

Accomplishing something that isn't apt to be trivially easy or cheap. Especially on the almost inevitably y "dirty" hot- rock side of its HX's)

Finally, since several more of Mr. GOOGLE's hits suggested that "solar salt" typically costs about $1500/tonne, that battery's heat transfer salt alone would cost 2.5 billion dollars - which figure is likely much too low because of the recent greater-than doubling of nitrogen fertilizer cost

Wouldn't it make more sense to just concentrate upon building enough of the right sort of reactors, not generating/protecting "novel" IP .

This is just some more ball parking suggesting that trying to do "all of the above" in every possible way rather than focusing upon the best option (100% nuke) isn't likely to work.

2.4.5.5 Synfuel-type energy storage "batteries"

Another storage idea (Yolcular 2007) that's gotten some traction invokes reversible conversion of toluene (aka methyl benzene, an unsaturated compound) to its fully saturated chemical analog, methyl cyclohexane (MCH), via hydrogenation with renewable power-generated hydrogen.

$$3H_2 + CH_3\text{-}C_6H_5 \leftrightarrow CH_3\text{-}C_6H_{11}$$

When electricity demand exceeds production, that reaction is to be reversed via the use of a "proprietary" catalyst to regenerate the hydrogen for use in fuel cells, engines, etc.

That sounds great but has some practical drawbacks. First, the energy value of the hydrogen involved (3-gram moles per mole of methyl toluene) is far less than that of its toluene "carrier" (a good motor fuel in itself), which means that that system could not replace a car or truck's fuel tank. Second, the huge amount of toluene required to so-fuel those factories, homes, and industries requiring reliable power in a 100% non-nuclear renewables-powered world would be impractically huge and pose serious safety issues. That energy's storage medium, some combination of MCH and toluene, and the reversible hydro/dehydrogenation system required to use it, is unlikely to be approved for operation in homes or even in most commercial settings. That reaction requires heating MCH sufficiently to undergo endothermic dehydrogenation to release its hydrogen thereby leaving toluene as an empty/spent hydrogen carrier - essentially what some of an oil refinery's "reformers" do. That reaction is unlikely to affect 100% conversion in either direction. The subsequent rehydrogenation step to convert the "spent" toluene back to MCH requires both some heat and pressurized hydrogen. Overall, however, that step is exothermic meaning that the system must be designed to either utilize or safely waste such heat. This brainstorm poses too many control issues to be applicable to anything outside of a dedicated refinery-type industrial site. Shuttling both the storage medium and hydrogen around anywhere else would pose too many safety issues.

Here's another "battery" brainstorm (mine).

At some time in the future, it might be possible to utilize the USA's already-paid-for natural gas "trunk lines" as chemical (hydrogen gas or ammonia) "batteries" to back up its intermittent (wind & solar) renewable power plants.   That network apparently consists of about 278,000 miles worth of 24-to-36-inch diameter pipes typically operating at 1000-1500 psi.

Assuming a pressure of 1250 psi, a pipe diameter of 30 inches, & that high-pressure hydrogen behaves like an ideal gas, that system could store ~7.74E+11 gram moles of hydrogen. At a combustion energy of 286 kJ/mole, that works out to 2.21E+17 J or about three fourths of one day's worth of the USA's current primary/raw energy demand (~100 quads/365 days/yr…Homework – check my calculation).

The same trunk lines could probably also both store & transport pressure-liquefied "nuclear ammonia" instead of hydrogen. It's a lot more energy-dense (liquid ammonia ~12x higher than 1250 psi H_2) and much less apt to go boom if/when someone screws up.

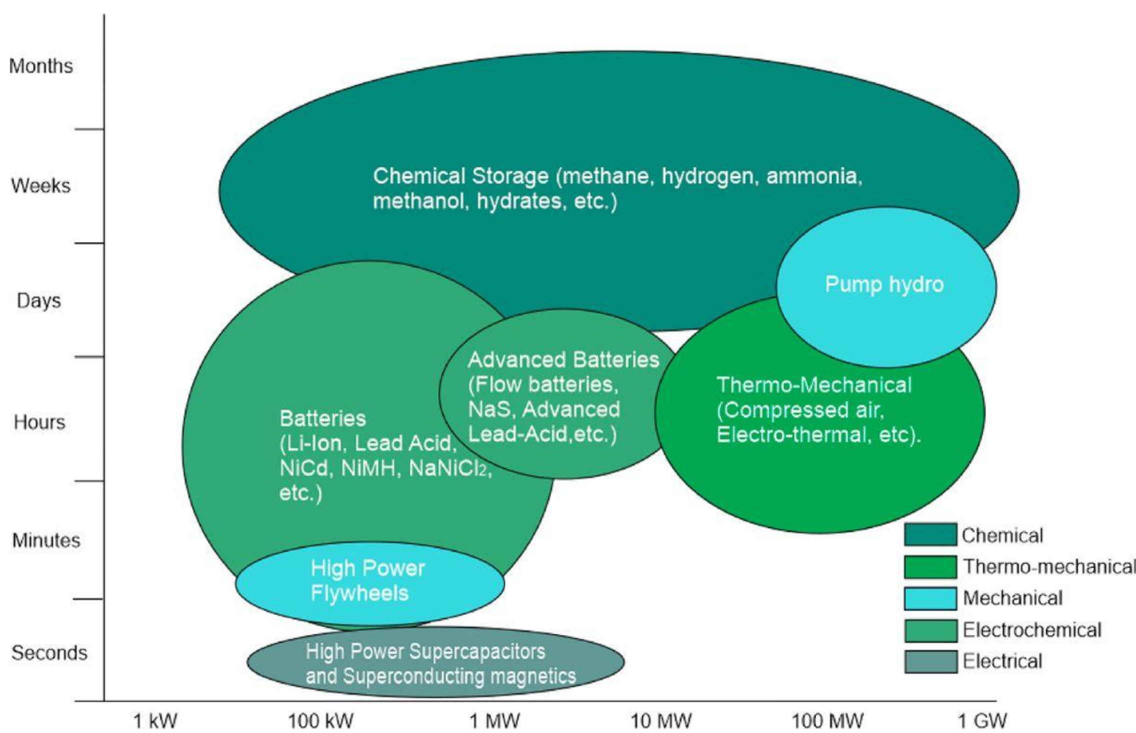

Figure 32 Energy storage technology regimes (Valera Medina et al 2021)

Our decision makers should be thinking about what's apt to be happening circa 2100AD after oil, natural gas, and coal have all "peaked out", not about what's currently most profitable/sensible or represents the cheapest immediate next step in moving towards a cleaner, greener future. The USA's current competitive market designs do not allow producers to either pay for spare capacity to deal with contingencies like 2021's "URI event" or prepare for a future subject to different constraints. Thanks to that drive, its entire economy is headed toward scarcity pricing. It's a terrible way for humans to live because it puts us always on the edge of another disaster.

By 2100 AD there won't be any cheap natural gas left to frack meaning that whatever fuel replaces it must be human made. Hydrogen can be made with "excess" renewable electricity whether it be nuclear, wind, or solar & would be a good fuel for stationary equipment but not so good for cars, motorcycles, etc. Today's natural gas trunk lines, pipes, etc. could both store & deliver it cheaply.

Another reason for adopting a synfuel-based storage scheme is that it's much cheaper to move huge amounts of energy from one region to another via a pipeline than it is via any sort of wire-based distribution system. For example, due to what's been going on along the Ukraine/Russia border recently (winter 2021-2022) one of the most controversial (trans scientific) international technical issues is what's to become of the Nordstream-2 pipeline. Germany desperately wanted it to be completed because one consequence of its Energiewende is that the shutdown of its nuclear power plants rendered its citizens/industries even more dependent upon Russia's natural gas. Nordstream-2 is an already built 1,230-kilometer-long (764-mile-long) natural gas pipeline under the Baltic Sea, running from Russia to Germany's Baltic coast. If it ever actually does run, it would double the capacity of its/their earlier Nord Stream pipeline to 110 billion cubic meters of gas/year and sidestep Ukraine and Poland both of which would lose lucrative transit fees being collected because Russian gas now flows to the EU through what's become too small and too vulnerable pipelines.

How much power transmission capacity would such a pipeline represent?

That's easy to ballpark. Since burning one cubic meter of natural gas generates 38.3 megajoules and there are 31.5 million seconds in one year, 110 billion cubic meters of gas per year corresponds to a heat-type energy transfer rate of 117 gigawatts. A modern gas fired electricity generator is about 50% efficient which means that that pipeline could easily move about 60 GW's worth of electricity - about 50 times greater than that of one of today's "bigger" electricity transmission systems (see Electric power transmission - Wikipedia).

To me it seems that something like that represents a better grid-scale "battery" (~61 GWh's worth for H_2, ~730 GWh for "green" ammonia) than does anything else we've been hearing about.

Homework problems 78-82 have to do with such a scenario.

Over the long haul a hydrogen economy would have to be implemented with "green hydrogen" generated via electrolysis of water with carbon-free electricity and much is riding on that scenario's success. Green hydrogen's three key requirements are water along with the renewable energy and electrolyzer that splits it into hydrogen and oxygen. It's morphed from being a niche climate-change solution three or four years ago, into something that could power everything from shipping, aviation, and large trucks to industrial processes like making steel and fertilizer. The International Renewable Energy Agency (IRENA) estimates that it could account for almost a tenth of global final energy use by 2050 According to the Hydrogen Council that project there are ~680 large-scale hydrogen projects under consideration around the world requiring an estimated $700 billion of investments to hits the world's already-announced 2030 net-zero emissions targets. Other companies including BP , Fortescue Metals (FMG.AX) and Reliance Industries (RELI.NS) are leading the charge into green hydrogen.

One issue is the cost of the non-performing assets associated with employing intermittent 'renewable' power to make clean H_2. This would mean that few people are apt to be able to afford renewables-generated green hydrogen because electrolysis plants are expensive to build —if operated only 25% of the time, the value of the energy required to power them would be under their financial charges.

People who have operated real chemical plants, would put the chances of successfully operating a hydrogen plant that stops and starts both often and randomly as low. Chemical plants run differently than do most manufacturing plants. In the latter, both startup and shutdown are quick and easy —that is why many of them can operate one, two, or even three work shifts depending upon demand. On the other hand, chemical plants often run continuously for over a year due both to startup difficulties and high equipment failure rates during startup and shutdown. The state of New York was recently supporting PV manufacturing—it did not go well. One of the biggest problems is that it has industrial (manufacturing) unions with rules that do not work in the process industry.

Another issue with current plans is water availability. A search for "water" in those companies' statements, generally yields nothing which suggests that their prospectus writers are either ignoring the risks, underestimating how much is needed, the challenges of securing it, and how much it will cost [150]

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[150] One issue is that generating the required power usually would mean building factories in areas where either industry, agriculture and households are already heavily competing for water, or in the hot, dry, sun-drenched deserted most suitable for solar panels. Estimates on how much water will be needed vary wildly and problematic because ~85% of the planned facilities are in regions already suffering from water stress. In May 2022, Australia's Kallis Energy Investments cancelled plans to build a 6-gigawatt green hydrogen facility in South Australia because getting enough water to run it proved to be an insurmountable problem.

These factors will likely drive canny investors and customers away because they would greatly increase the price of its system's product. Any governmental subsidies associated with such hydrogen's use would also have to grow if such schemes are to remain viable and there's no assurance that that would happen.

On August 31, 2021, President Biden's Secretary of Energy Jennifer M. Granholm and U.S. Senator Joe Manchin (D-WV) joined with Deputy Secretary of Energy David Turk, Special Presidential Envoy for Climate John Kerry and Breakthrough Energy founder Bill Gates for the opening session of the U.S. Department of Energy's (DOE's) first ever Hydrogen Shot Summit, a virtual gathering of leaders from around the world to map out strategies for achieving DOE's goal of driving down the cost of clean hydrogen by 80% (from~$5 to $1 per kilogram) within this decade[151]. In my opinion, what makes it good news is the fact that Bill Gates was invited to participate - he's both willing and able to come up with realistic solutions to technical problems – not just bloviate about them.

Most of today's hydrogen is "gray" meaning that it's made via the steam reforming of natural gas or coal — a process which produces carbon dioxide that usually ends up in the atmosphere but makes hydrogen more cheaply than does electrolytic cells powered with today's electricity.

The hydrogen rainbow

Researchers use colors to distinguish

between dlfferent kinds of hydrogen.

Gray hydrogen Made from fossil

fuels, which release carbon dioxide and

add to global warming.

I Blue hydrogen Sameasgray

hydrogen, but the carbon is captured

and sequestered.

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151 Hydrogen Shot is the first in a series of DOE's new Energy Earthshots to support President Biden's goals of transitioning the USA's economy to clean energy and addressing the climate crisis. Earthshots are aimed at driving the major breakthroughs needed to dramatically reduce costs of critical clean energy technologies by 2030, scale deployment to reach the goal of a net-zero economy by 2050 and create clean energy jobs.

{$ Green hydrogen Made without carbon

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vehicles that are ill-suited to

However, since we still don't have reliable cheap, clean, and renewable power, for as long as it lasts, natural gas could either be converted to clean "blue hydrogen" by merging steam reforming with carbon capture and storage (CCS) or to "turquoise" hydrogen- (a merge of blue and green) via pyrolysis which converts the methane's carbon to elemental "carbon black". One of the outfits (C-Zero) proposing to make that shade of it plans to do so by bubbling methane through a molten nickel bath which is supposed to generate tiny carbon particles entrained in its H_2 gas product are then separated with a bag house and/or cyclone. Other companies propose to use iron and/ or iron ore. Another scheme would bubble the methane through a molten tin bath where its carbon ends up floating on the top where it can be skimmed off.

These concepts' carbon black byproducts could either be utilized for doing useful things like making rubber tires or simply buried & thereby becoming "fossil char" (aka manmade coal).

Finally, to complete the rainbow, there's "orange" hydrogen stimulated by pumping water into deep source rocks containing elemental iron or basaltic minerals which upon hydration generate hydrogen via "serpentinization" and "gold" hydrogen tapped from so-generated natural subsurface accumulations.

In any case, here's a great idea that would eliminate the "*where's all that water going to come from*" issue. (from John Rudesill see https://www.chemistryworld.com/news/seawater-splitting-system-could-scale-up-renewable-hydrogen-production/4013332.article). It invokes an electrolysis cell containing the anode and cathode and, initially, pure water plus a pure salt electrolyte. The bottom and sides of the cell would be covered with a semipermeable membrane (Nafion?) that only lets water[152] through. That cell is immersed in naturally "dirty" seawater or some other readily available water source . As the cell operates, its water content decreases which increases its electrolyte's concentration until the resulting osmotic gradient favors permeation of water from the surrounding brine to into the cell. The pure water feed from such water resources is therefore cheap and essentially limtless.

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[152] Nafion is also permeable to the hydrogen cations (H^+ aka protons) generated by splitting up water but not to its solutes other cations or anions.

Finally, here's a note from MIT's Charles Forsberg.

"*Green hydrogen based on electricity from the grid is unlikely to be economically viable. Hydrogen plants have very high capital costs and are chemical plants. Even if zero-price electricity, can't afford a hydrogen plant operating 25% of the time. Economics requires 24/7 operation. Chemical plants do not like cycling as equipment and seals fail—that can result in very bad days. I am giving a talk at the AIChE Solar conference later this week (* AiChE 2021 Solar Crush PV.pdf *) on what may be required to produce base-load electricity from PV that is the starting point of green hydrogen. The PV is coupled to 100-GW$_t$ heat storage. Use DC from PV to heat nitrate salt that transfers heat to the Crushed Rock Ultra-large Stored Heat (CRUSH) system. The problem with the grid is that it is a third of the cost of delivered electricity so want to avoid that cost. Do not want to convert DC to AC and the grid to send to some storage system. There are some other implications. Minimum size is somewhere between 100 and 300 square kilometers.*

If hydrogen production goal using PV electricity, use CRUSH and more efficient lower-capital-cost high-temperature electrolysis that requires steam and electric input. Ship hydrogen by pipeline.

People are under the false impression of small-is-beautiful renewables. Economically affordable renewables will likely be 100 square mile solar systems and 200-meter-high wind towers. The Chinese have figured this out. "

2.1.5.6 Couldn't Mr. Musk's "Virtual Power Plants" fix everything?

Virtual power plants (VPP) are mostly imaginary cloud-based distributed power plants that aggregate the capacities of heterogeneous distributed energy resources (e.g., roof mounted solar panels) and storage systems (e.g., Powerwalls and/or plugged-in BEVs) to either enhance power generation or (more commonly) to trade/sell power on the electricity market. Real examples of virtual power plants currently exist in the United States, Europe, and Australia.

GOOGLing "VPP" brings up some facts about an Australian program that Mr. Musk is heavily involved with (https://www.ny-engineers.com/blog/virtual-power-plant)

It's supposed to eventually involve 50,000 homes each of which is to have 5KW's worth of solar panel generation capacity and one 13 kWh TESLA Powerwall. The total money already invested on the first 1100 such homes is ~ 32 million AUS dollars which works out to a bit over 18,600 $US per household.

If we assume that each of its Powerwall batteries requires 20% more lithium than is suggested by a purely stoichiometric calculation (~0.094 kWh/gram mole Li), the total amount of that metal required for Mr. Musk's 50,000 homes project would be about 57 tonnes.

Extrapolating to the USA's 330 million people assuming 3 persons/house and that each home also has a 75 kWh TESLA car to run around in, the total lithium required to do the same thing on this side of the Pacific would be ~80,000 tonnes – about one year's worth of current world Li consumption. In principle that's doable/possible too.

Finally, assuming the same $18,600 per home for the Powerwall/solar panel combos & that the cars' 75 kWh batteries cost $200/kWh (about one half of what they do now), outfitting the entire system that way would cost about $3.7 trillion. In view of what's happening today in response to the Covid-19 pandemic & Putin's madness, that figure is also not unimaginable.

So far, this all sounds great but there are some issues. First, most homes require much more energy than 5 kW's worth of solar panels could provide, (mine certainly does), especially during the winter Charging up its residents' car batteries as well would make that situation worse. Most important is the fact that their home & cars represent only a fraction of the total energy required to provide them or their descendants with everything needed to live as well as we do now.

It's fun to think about though. If I were still an academic or actively consulting, someone might even pay me to "study" it for a few more years.

2.1.5.7 Electricity storage business issues (much help from Paul Achionne)

There are four problems to solve before you can make a viable business (not political) case for seasonal energy storage:[153]

(1) Duty Cycle

Battery storage is affordable if storage is completely cycled every hour or so. Pumped hydroelectric storage is affordable if you fully cycle it at least once every week. Any sort of storage cycled only twice a year would be outrageously expensive. The reason for this is that the

[153]….The rest of this section reflects the experience, words, and opinions of Paul Acchione – one of Canada's senior-most Professional Engineers.

storage system's capital investment must be paid for by its energy flow. If you fill and empty a "battery" every hour, you have 8760 opportunities per year to pay for it. That is not the case for seasonal hydroelectric storage filled in the spring and discharged during the summer/fall/winter. In most of the world, both electricity supply and demand is highly seasonal.

(2) Energy Losses

All forms of storage have significant losses that must be paid for by producing additional energy. State of the art batteries and their associated electronics are the most efficient (~90%) for ~one hour cycles but much less so on a seasonal cycle as anyone who has ever left his car in storage over the winter knows. Pumped hydroelectric is likely the cheapest storage if you happen to be in the right place[154] but only 70 to 80% efficient due to inevitable pump, turbine, and generator losses. Round trip compressed gas and hydrogen electrolysis efficiencies are smaller yet. On a seasonal basis, round trip efficiency of compressed air storage[155] is terribly low unless fossil fuel is burned and then not counted to replace the heat energy lost to the earth or whatever else that air is stored in.

(3) Price Arbitrage

Many proponents of storage facilities assume arbitrage (price difference between daytime and nighttime) to pay for the system. That only works for storage systems too small to affect the supply-demand bid price stack. Large storage facilities do affect that price stack. When they consume power at night, they use so much of it that they drive up demand and market price. During the day they generate so much power that they push the market price down. The result is that once a large storage facility starts to operate there will be too little daily price difference to generate sufficient arbitrage earnings to pay for itself. Therefore, you must find a way to finance it as a common system service financed like a transmission system; as either a *surcharge on consumer energy use* or consumer peak power demand.

(4) Supply-Demand Hourly Misalignment

Storage requirements are determined by supply-demand "power" imbalance over a period of time. . It must be sufficient to absorb the supply-demand energy imbalance over the complete duty cycle. If only short term hourly, daily, weekly or even monthly unbalances are considered, the facility will not be large enough to address peak hourly power imbalances throughout the

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[154] This means a big river or lake situated close to a mountain with a big reservoir at its top.

[155] This is typically done by pumping air (which of course heats it) into underground cavities created by the "solution mining" of salt (NaCl) from rock salt formations. That heat energy gradually bleeds off into the surrounding salt.

entire year. For example, a seasonal storage system capable of absorbing Ontario's (Canadian province) surplus energy over one season would be enormous.

The following figures for Ontario's ~25,000 MW power system assume three different generation technologies. A mix of generation technologies would require less storage but nevertheless unaffordable.

- a 100% nuclear power system needs a storage system with 9,000 MW of "power" capacity with 2,600,000 MWh of "energy" capacity.

- a 100% wind power system needs a storage system with 40,500 MW of "power" capacity with 22,000,000 MWh of "energy" capacity.

- a 100% solar power system would require a system featuring 115,000 MW of "power" capacity and 29,000,000 MWh of "energy" capacity.

That much storage would drastically increase electricity rates. Ontario's electricity rate numbers based upon the 2013 OSPE study using the cheapest storage technology (pumped hydroelectric) will frighten you. OSPE did not "study" chemical batteries because seasonal storage cost would be over 20x higher than is pumped hydroelectric.

TESLA's recently installed/commissioned grid-qualified electrical storage battery cost Australia $66 million for a 100 MW/129 MWh system or about $511/kWh in 2017-type dollars[156]. At those prices a seasonal battery storage system for Ontario's power grid would cost $1.3 trillion for a 100% nuclear power system, $11 trillion dollars for a 100% wind system and $14.5 trillion for a 100% solar system. That's well beyond Ontario citizen's ability to fund anything.

The Ontario Society of Professional Engineers (OSPE) has been recommending a different approach. Retail rates should change so that consumers could buy surplus electricity at its low wholesale energy price and use it to displace the higher cost fossil fuels currently satisfying their heating needs utilizing hybrid (dual fuel) heating systems for hot water, space heating and steam. They should also use the low-cost surplus power to charge electric cars and/ to make hydrogen gas for industry and the transportation sector[157].

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[156] Let's try to put that "big" number (129 MWh) into perspective. Because GOOGLE says that Australia makes about 1.63 million tonnes of aluminum per year and making one tonne of it requires~17,000 kWh of electricity, its then "*world largest*" grid backup battery could power the aluminum factories consuming ~10% of its power for ~2.45 minutes ***if*** it were fully charged and able to dump its energy quickly enough (it couldn't).

[157] "The Environment Plan is evolving to address the environmental priorities of Ontarians as new information, ideas and innovations emerge. Although not a new idea, hydrogen has re-emerged as an exciting and potential long-term way to address climate change and air quality while creating opportunities for industry to grow. Depending on how

The mass deployment of storage could overcome one of the biggest obstacles to renewable energy – it's cycling between oversupply when the sun shines or the wind blows, and shortage when the Sun sets or the wind drops and thereby replace the fossil fueled "peaker" plants that must be built if/when today's "market forces" (selfishness) substitute unreliable energy sources for reliable ones.

California is currently the global leader in the effort to balance the intermittency of renewable energy in electric grids.

A few years ago, Power Magazine published a description of the CASIO system's new pony-motor powered, "synchronous condensers" – another of the expensive/complicated crutches added to address some of the problems caused by substituting intermittent power sources for more reliable coal/gas/nuclear ones https://www.powermag.com/aes-uses-synchronous-condensers-for-grid-balancing/

A synchronous "condenser" is a huge/heavy DC-excited synchronous DC motor/generator whose shaft spins freely and isn't connected to anything. Its purpose is to optimize the grid's short-term characteristics, not convert mechanical power to electric power or vice versa. Its field current/power is regulated to either generate or absorb AC reactive power as needed to maintain/adjust the grid's voltage (flywheel effect) or improve its power factor. It cannot increase the grid's capacity for more than a minute or so.

Another crutch would be to install lots of big, expensive, utility-scale batteries.

In December 2020 Vistra Energy began to operate its Phase I 300-MW/1,200-MWh lithium-ion battery storage system at its Moss Landing CA, combined cycle gas power plant. It is currently the world's largest grid-scale battery storage system comprising 4,500 stacked battery racks, each containing 22 individual battery modules in a building that used to house the turbines of one of that facility's two gas fired power plants[158]. No cost information was released but based upon that of Australia's recently "world's-largest" 129 MWh battery pack, it is likely to be on the

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it is produced, hydrogen has the potential to be low carbon, for example, hydrogen that is produced from Ontario's electricity grid. Together with other actions, hydrogen can help decarbonize our economy and reduce our reliance on fuels that have a larger carbon footprint like coal, natural gas, diesel, and gasoline. Considering opportunities to support this sector could help Ontario's longer-term economic recovery in all regions of the province as businesses rethink how they operate and grow. This is especially important since about 80 per cent of Ontario's 2018 greenhouse gas emissions came from transportation, buildings and industry – all areas where hydrogen can be used" .(Ontario Low Carbon 2020)

[158] Moss Landing used to be California's largest power plant, 2560 MW, before one of its two politically incorrect gas-fired units was shut down. Its current generating capacity is 1.3 GW to which its batteries if fully charged can temporarily add 0.3 GW.

order of $600 million. That's to provide about one third of the Moss Landing's power plant's nominal output for ~3.5 ***hours*** (not days, weeks, or months).

As far as that company's investors are concerned, it sounded like a great deal because it will enable its owners to make money via daily time-shift electricity arbitrage (load the battery from CASIO's precariously over loaded grid when the spot price is low & sell it back when it's high). They've been given that opportunity because California's retail utility ratepayers apparently don't mind writing big checks for good-sounding causes. The resulting pain is their own fault because they've not only been willing to put up with too-high utility bills & taxes, overly intrusive/special interest driven government, but also insist upon re-electing the politicians responsible for it.

It may not seem like such a good deal now because it had to be shut down eight months later (4Sep21) when it experienced its first fire. First responders found scorched battery racks and melted wires. It experienced another meltdown five months later on 13February2022 -that time its fire fighters discovered that another ten battery packs had melted.

South Korea had bit into the grid scale battery apple before the USA and Australia and thusly became the world's largest market for them before a rash of fires halted further deployments. In early 2019 South Korean government officials largely stopped deployment of new lithium-ion battery systems and urged operators to curtail operations of existing ones after twenty-three battery fires had broken out. Many owners continued operating, however, and more battery fires have been reported both there and elsewhere (see Figure 34).

By June 2021 South Korea's Ministry of Trade, Industry and Energy completed a several months-long investigation concluding that the fires were caused by a range of issues including lack of protection against shocks, faulty installation practices and control systems incompatible with other components.

More broadly, though, investigators at DNV GL—a global engineering standards firm contracted to investigate the root cause of one of the fires—said the common (most profitable) practice of cycling those lithium-ion batteries from close to zero to 100 percent and then back down again daily was the underlying cause. That hard-driving cycling pattern is common with storage systems co-located with wind and solar farms in order to make money via arbitrage.

"*If we start cycling those batteries as aggressively as we do in Korea, we will likely see similar failure rates*," George Garabandic, DNV GL's energy storage leader for the Asia-Pacific region, told The Energy Daily. "*It should be expected that a higher component stress will result in higher levels of random component failures. In other, more developed energy storage system (ESS) markets, the batteries are providing services similar to frequency regulation, and the* *component stress is relatively milder*." https://ihsmarkit.com/research-analysis/aggressive-loadshifting-could-increase-battery-fire-risk-inves.html

That assessment could/should but didn't prove problematic for the U.S. utility-scale battery developers currently planning to co-locate storage with solar generation for the same purpose as did their south Korean colleagues.

Batteries are great "insurance" if you don't actually use them. In that respect they are rather like INL's reactor research facilities - there's lots of big, shiny, expensive stuff to impress important-enough "tourists" (especially politicians) but not much really going on because doing that would be "too risky".

This subchapter's bottom line is that regardless of how good any sort of energy storage system's "battery" might be, its economics would be terrible with respect to seasonal - not just hourly, daily, or weekly energy shifting.

Consequently, I conclude that the best address these issues without resorting to genetic modification[159] to would be to power the grid with clusters of sustainable nuclear reactors (e.g., GE Hitachi's already developed S Prism) that wouldn't require other backup and could also provide both electricity and process heat needed to make the green hydrogen, ammonia, and liquid synfuel(s) required to keep the other sectors of our economy going too.

3.3.4 The reasons why politically correct renewables couldn't "save the world"

Nuclear power is the world's safest and lowest cost of humanity's simultaneously reliable and clean electrical power sources. In terms of documented, not hypothesized, deaths per kWh, official statistics say that nuclear power is 24 times safer than solar PV; 178 times safer than onshore wind; 850 times safer than offshore wind; 7,190 times safer than natural gas; 10,000 times safer than oil; and 12,000 times safer than coal. Its relatively low cost is evidenced by the fact that the world's biggest low GHG emission power systems (France, Quebec, Ontario, Sweden, Norway, British Columbia, Paraguay, and Switzerland) all employ some combination of nuclear and hydro for over 80% of their power (Figure 33).While hydro is even cheaper than nuclear, it is an already nearly maxed-out geographic blessing with many environmental constraints.

[159] Of course, another way to address this issue would be to genetically modify us humans so that our descendants could comfortably either estivate (summers) or /hibernate (winters) when &where ever Mother Nature wasn't providing enough "renewables". Also of course, the downside of that is that then we'd all be GMOs which would therefore deprive our already too-sensitive & much put upon cannibal-type citizen minority of "natural" food.

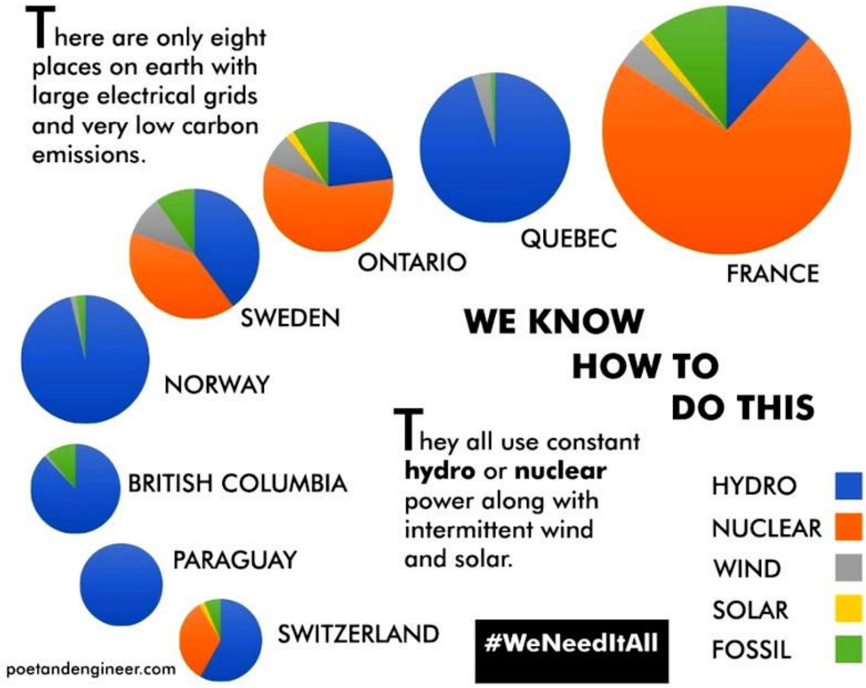

Figure 33 The world's already clean electrical systems

We've known for almost 60 years how to go about addressing the damage engendered by our civilization's dependence upon "dirty" fuels, most of which will likely be exhausted within another single human lifetime. Figure 33 points out how the countries that already possess low GHG emission electrical grids have achieved it.

1. If your country has been endowed with lots of mountains, high winter snowfalls, and summers warm enough to melt that snow (e.g., Norway), dam your rivers & install lots of big hydroelectric plants

2. If Mother Nature has not been so generous, build lots of nuclear power plants.

After reading X Prize Foundation – Wikipedia and watching Bezo's, Musk's & Branson's all-different spaceships all successfully complete their respective missions recently, I'll admit that some sort of "privatization" may indeed be the best way for humanity to get big things done. However, it can't be the same sort of privatization that's led to the disillusionment responsible for the rise of ethno-nationalism on the right, socialism on the left, the election of leaders like Adolph Hitler and Donald Trump, and the fact that although the USA is the world's largest producer of both oil and gas, its government can't protect its citizens from the consequences of both Mother Nature's "events" and the actions of a petrostate dictator like Vladimir Putin[160].

Assuming that "energy services" means electricity (that's reasonable because most of its applications are nearly 100% efficient) and that no worldwide, zero loss (magic) power grid has somehow come to be, generating Africa's share of the future's total energy/power supply would require about 12,000 [30*4.5/11.2*1012/109] full-sized (~one GW_e) "renewable" nuclear power plants generating an average output power of ~9 TW_e [4.5E+9*2 kW].

Electricity's value primarily is in its dependable energy, not its total yearly-averaged energy "capacity"[161]. An electrical grid should provide dependable power when and where it's needed, not just when the sky is clear and the wind is blowing. Most renewable electricity sources do not provide dependable power and therefore only have value as fossil fuel displacement sources for interruptible applications.

Wind and solar power's unreliability mean that individual power grid electricity markets should price (value) their energy at approximately zero cents per kwh. Such energy is basically a dump product with two uses; 1) whenever it's available it can displace energy currently being produced by sources whose operation generate pollution (fossil fuels) , and 2) storing such cheap energy for which the only sensible current applications are charging electrical vehicle & RV batteries because they must store electrical energy and equipped to do so. For those people, "dumped" solar energy is useful because it lowers their electric bills, provides some "free" transportation, and lets them park their RVs in campgrounds that don't allow visitors to run generators all night long. On the other hand, dumping tons of solar and wind energy into a "deregulated", all-of-the-above-based, electrical grid is harmful because it drives down wholesale (short term bid) – not retail – electricity prices to the point that reliable (firm) power sources cannot survive.

I'll start with an example that demonstrates why today's politically correct renewable energy sources could not meet that demand.

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[160] That's due to the "market forces" rendering it more profitable for American producers to both limit production and sell their oil and gas elsewhere. Unlike Russia, the United Arab Emirates, and Saudi Arabia, the US federal government does not claim rights to the oil and gas under private land and has no policy tool to quickly adjust production to insulate its economy from geopolitics, slow down climate change, or address the consequences of Putin's war. In the USA both production and marketing are determined by its "Project Independence's" privatized, greed-dominated, and amoral energy business models (e.g., GOOGLE "Texas RailCommission") America Is the World's Largest Oil Producer. So Why Is Losing Russia's Oil Such a Big Deal? - The Atlantic .

[161] Doing so is like basing your food choices solely upon taste ignoring protein, vitamins, and minerals. It'll work for a while, but ornery old Mother Nature's "technical details" will eventually catch up to you.

First, let's see how many of today's purportedly "cheap", roof top-type, solar panels would be required to produce 2100 AD-Africa's 9 TW_e's worth of useful energy. At Home Depot Dec. 2018 we could have purchased four, real, state of the art (19% efficient), 265 watt-rated, 1.61 m^3 (39" by 65") solar panels for $1412 (they'd cost you about $150 more today). If they were to be employed in Nigeria (close to the Earth's equator), which purportedly exhibits an average solar irradiance of 5.5 kWh/m^2/day (Ojuso 1990), each of those panels could theoretically generate a yearly-averaged power of 70.1 Watts [1.61*0.19*5500*3600/(24*3600)] which means that their average annual capacity factor (CF) would be 26.4% [70.1/265]. That CF is about four times greater than it would be if the same panels were installed in northern Europe and ~50% greater than that anticipated by South Africa's energy experts circa 2050 (Table 3).

Anyway, a CF of 26.4 % suggests that powering Africa's 4.5 billion future citizens with them would require 128 billion [9000E+9/70.1] such panels costing about $45 trillion 2018 dollars. Since solar power is ineluctably intermittent (unreliable), they would also have to buy enough batteries of some wort to keep things running during the 73.6% [100-26.4] of the time that their solar panels would not be producing much. How many batteries would that be? Assuming that Africa's future inhabitants decide that they could get by with just one day's-worth of energy storage (that's not "conservative" - widespread cloudy and windless periods often last much longer than one day) they would have to build/buy about 216 billion kWh's worth of storage capacity [2000 J/s*4.5E+9*3600 s/hr*24 hr/day/3.6 E6 J/kWh = 2.16E+11 kWh], which, if implemented with Tesla's equally real and state-of-the-art 13.5 kWh, ~$7000, lithium ion battery-based "Power Walls", would cost today's subsistence farmers' hopefully <u>much</u> more prosperous descendants another $100 trillion [$7000/13 kWh*200E+9 kWh/3.6E+6 J/kWh] 2018 US dollars to purchase the first time around (& don't forget that lithium ion batteries aren't apt to last more than ten years)[162].

People can starve or freeze to death within a few days or weeks which means that decisions based upon yearly-averaged renewable energy resource estimates (annual CF*nameplate capacity) aren't sufficiently conservative[163].

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[162] As far as economy of scale is concerned, in 2017 Tesla built the then world's largest utility backup battery (129 MWh) in South Australia for $66 million. Assuming those figures ($511/kWh), the purchase cost of this example's single days' worth of energy storage would be $243 trillion. Figure 34 depicts the fate of two of Australia's shipping container scale battery packs - a commonly encountered drawback of that approach to storage both there and elsewhere .

[163] Capacity Value (CV) = capacity factor of a source only during a region's peak demand periods- not the annual average. Its value for intermittent sources is inversely related to the fraction of the system's total capacity represented by that source. Ontario's wind power's CV=11% and PV-type solar is 5%.

For this sort of application Li ion batteries don't scale for several reasons one of which has to do with the most expensive component of the batteries in Mr. Musk's BEVs, cobalt.

Figure 34 Two of Australia's shipping-container-sized battery packs going up in smoke https://www.ans.org/news/article-3292/australia-has-invested-in-batteries-for-grid-security-its-not-going-as-planned/

When a Li ion battery charges/discharges, the cobalt within its cathode shifts back and forth between its tri and quadrivalent oxidation states.

Since…

- a lithium ion battery's voltage averages about 3.5 V
- one equivalent 's worth of charge is 96500 coulombs (one Faraday), and
- cobalt's equivalent weight for this reaction is 58.9 grams

…one kWh's worth of storage would require an absolute minimum of 628 grams [3.6E+6/96500*58.9/3.5] of cobalt. One day's worth of 9 TW power storage adds up to 216 billion kWh which translates to a cobalt requirement of 1.36E+11 kg. Last year's (2018) total world cobalt production was about 1.5E+8 kg or ~ 0.11% of that required by this scenario.

Elon Musk chose to use Panasonic's cobalt-cathode based lithium ion batteries for his TESLA cars because they represented an already available solution to the problem that he had set out to solve.

Panasonic picked that cathode because it represented an already worked out solution to the problem that it had set out to address, not because cobalt is the "best" or only transition metal that could serve that purpose.

Co-based BEV batteries represent a prematurely "locked in" technology just as today's LWRs do.

Lots more work has been done since then & Li-ion batteries using manganese, titanium, nickel, and iron-based cathodes have all been developed & could serve the purpose we're talking about here.

I suspect that his mystery metals are copper and steel along with whatever's in the car's switched reluctance motor's "advanced control system's transistors - probably mostly just silicon.

There's no compelling reason to believe that the future's EVs are going to require rare earth elements (REEs) in their motors or cobalt in their batteries.

A more real limitation has to do with lithium. A state of the art, 2Ah 18650 Li-ion battery contains about 0.6 grams of lithium (http://batteryuniversity.com/learn/archive/is_lithium_ion_the_ideal_battery). That works out to about 86 grams of lithium per kWh [0.6*3.6E+6/(3.5*2*3600) = 85.7]. Scaling that up to 216 billion kWh translates to 18.5 million tonnes of lithium - about 394 years' worth of current world-wide production/demand (~47,000 tonnes/year)[164].

Sovacool et al's Jan 3, 2020 *Science* paper lays out the near-impossibility of mining enough "technical metals" including lithium to reach a 100% renewable objective by 2050. Envision

[164] At the moment, an all-solid-state battery concept featuring a lithium metal anode appears to be a candidate for surpassing conventional lithium-ion battery capabilities (Lee et al 2020). It features a sulfide –based electrolyte (e.g., Li 9.54Si1.74P1.44S11.7Cl0. 3) enabled by a silver sulfide elemental –C composite anode with no excess Li that supposedly can prevent Li dendrite formation and therefore lead to genuinely long electrochemical recyclability (Lee et al., 2020) . However, it would still suffer from the same component (Li & Co) availability limitations of its extant cousins along with the fact that silver is an even more "precious" metal .

7100 GW of solar panels! Not surprising to me anyway, that paper's authors[165] "forgot" to point out the possibility of a nuclear alternative to their paper's scenario (Sovacool 2020).

Real-world windmills have year-round capacity factors similar to that assumed/calculated above for solar panels meaning that if they were to be used instead, a similar amount of energy storage capacity or other clean backup power would be necessary.

Natural gas – the primary enabler of today's heavily subsidized unreliable wind and solar power "capacity" growth– will probably be prohibitively expensive by 2100AD because all of the world's "cheap" natural gas will have already been discovered, fracked, and either leaked, flared off, or constructively consumed. Leaving it in the ground along with most of the world's remaining coal and oil would be an excellent idea because burning them would otherwise add to the already excessive amounts of anthropogenic greenhouse gases (GHGs) responsible for climate change – coal as CO_2 and methane both as-is[166] and after it's been oxidized to CO_2.

The above-derived numbers are optimistic because Africa is a better site for today's most popular renewable energy sources than is most of the already-developed world. For example, by 2014 European Union countries had invested approximately €1.1 trillion (about $1.4 trillion) in large scale renewable energy installations – mostly wind turbines and solar panels. That money built a nominal nameplate electrical generating capacity of about 216 Gigawatts, nominally ~22% of total current European energy demand (~1000 Gigawatts). Data supplied by Europe's Renewables Industry indicate that its total output throughout 2014 averaged 38 Gigawatts (~3.8% of Europe's current electricity demand) for a combined mean capacity factor of ~18%. When adjusted for that factor, the capital cost of Europe's wind/solar energy installations was €29 billion/GW_e - about 30 times that of its conventional gas-fired electricity generation facilities and 3 to 10 times greater than GEN III nuclear power plants.

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165 Dr. Sovacool is another western world energy "expert" that seems to be against doing anything practical. The university he works for (University of Sussex) was recently forced to retract a press release it had published about a blatantly antinuclear paper that he'd published in the journal *Climate Policy* when its readers pointed out many errors. Original https://futurism.com/scientists-nuclear-energy-waste-time Retraction : https://retractionwatch.com/2016/11/28/authors-retract-paper-linking-nuclearpower- slow-action-climate-change/

166 While carbon dioxide is typically painted as the bad boy of greenhouse gases, pound per pound, methane is initially ~400 times worse and several percent of that now being fracked leaks directly into the atmosphere (Alvarez 2012). Any gaseous substance's mass-wise Global Warming Potential (GWP) relative to CO2 depends on the timespan over which that potential is calculated. A short half-life gas which is quickly removed from the atmosphere may initially have a large effect, but over longer time periods, become less important. Thus methane's mole wise GWP over 100 years is about 28 but ~84 over the first 20 years (see APPENDIX XXI). Agriculture's current contribution to anthropogenic GHG emissions (~9%) is primarily due to methane (cow burps, rice fields, etc.) and nitrous oxide due to over fertilization, not the CO2 emitted by its machineries' engines.

Since the output of most of today's renewable energy plants depends upon the season, local weather conditions, how much dirt they've accumulated, and the time of day, their contribution to the grid is erratic, intermittent, and non-dispatchable. This means that they often can't contribute to supply when it's needed, thereby rendering them worse than useless (both ugly & covering land that could be used for something more constructive) much of the time. On the other hand, rules mandating use/priority of their "renewable" power cause major grid disruptions when their output suddenly rises because the distribution system's dispatchable thermal (fossil fuel and nuclear) "backup" power plants must be cut back to a zero-efficiency idling" state so that more politically correct source(s) can satisfy demand. Consequently, according to US EIA, despite their virtually zero fuel costs, renewable energy installations often cost up to 1.5 – 2.5 times as much to operate and maintain as do conventional gas fired power plants.

The following paragraph is excerpted from philosophy professor Don Howard's brilliantly written essay, "The Moral Imperative of Green Nuclear Energy Production." (Howard 2019)

> "*Critics of nuclear power have raised a number of ethical objections to nuclear power. But before we review them, let us recall that the decision to be made is not about nuclear power alone. Instead, the decision is a comparative one. The ethical issues concern a program of rapidly expanding nuclear power in comparison with other courses of action of which there are really only two:*
>
> *(1) Do nothing, which dooms the planet.*
>
> *(2) Continue on the path called for in the Paris Agreement by expanding renewables as rapidly as possible, reducing energy consumption, and developing new approaches to $_{CO2}$ capture and sequestration, all the while hoping for some miraculous technological breakthrough. This approach will mitigate the impacts of climate change but will still leave our children and grandchildren with a planet dramatically different from the world we know, a planet far less hospitable, where those who survive will lead seriously diminished lives.*
>
> *There are no other alternatives.*"

The leaders of several of the western world's countries consider their bailiwicks to be businesses which attitude serves the interests of their businessmen-producers rather than the citizen-consumers that they were elected to represent. Businesses are command economies which is the reason that their managers generally do not make good politicians. Populations and the nation states created to represent their common interests are voluntary collaborations, not businesses. Today's "climate crisis" provides a pretext for the creation of an overly bureaucratic command economy that's as apt to fail to address problems as did the USSR three decades ago and the USA during its seemingly interminable COVID-19 crisis[167].

Unfortunately, via persistent lobbying & generous political contributions, well-heeled (influential) producers pick society's decision & law makers to the general detriment of everyone else. If those politicians don't pay attention to doing things correctly their nations will become economically uncompetitive and like most of the past's other such economies (e.g., North Korea, and the Soviet Union) eventually become both poor and "dirty" [168](Ridley 2020).

Chapter 4. A sustainable nuclear renaissance's other "killer apps"

An appropriately scaled (big enough) sustainable nuclear renaissance would enable us to do several good things that wouldn't be possible otherwise including….

4.1 Atmospheric carbon sequestration

Let's begin this section with the ball-park calculation that convinced me of the "special" nature of fossil fuel-generated atmospheric CO_2

During the past few years, mankind has been dumping about 37 billion tonnes of CO_2 into the atmosphere annually which has raised its concentration therein about 2.4 ppm per year (ppm = part per million by volume/molecule count). If we/I assume that the fuel burned to produce it is about halfway between coal and methane chemistry-wise, it'd have a composition of $(CH_2)_n$ and

[167] See [The CDC's failed race against covid-19: A threat underestimated and a test overcomplicated - The Washington Post]

[168] China has had a mixed, not command, economy since circa 1980 featuring both socialistic and capitalistic elements. Consequently, it's much "easier" to do something new that's in that country's long term best interests but inconsistent with an already established industry's business model.

Representative Concentration Pathway (RCP)	Forcing compared to 1750 (Wm^{-2})	Climate policy associated with scenario	CO_2 Equivalent (ppm)	Projected global average temperature increase from 1986-2005 (°C)
2.6	2.6	Mitigation	475	1.0
4.5	4.5	Stabilization	630	1.8
6.0	6.0	Stabilization	800	2.2
8.5	8.5	None	1313	3.7

Figure 35 IPCC modeling conclusions

a heat of combustion of about 44 kJ/gram. Since burning one gram mole of CH_2 (MW (molecular weight =12+2*1) makes one gram mole of CO_2 (MWt = 44), 37 billion tonnes of CO_2-type GHG would have required   14/44*37 B tonnes of such fuel which when burned would have generated 14/44*37E9*1E+3 *44,000=5.18E+20 J worth of useful-to-humanity heat per year.

Error! Reference source not found. is an EXCEL plot of the **Error! Reference source not found.**"change forcing factors" values vs its atmospheric CO_2 concentrations fitted with a 2nd order polynomial trendline (the figure's equation).

The forcing factors predicted for 400 and 402.4 ppm (currently one year's concentration difference) work out to 1.6059 and 1.6385 watts/m^2 respectively. If we multiply the difference between them by the Earth's surface area (5.1E+14 m^2) and the number of seconds in one year (3.15E+7), we come up with an annual atmospheric heating effect of 5.24E+20 Joules.

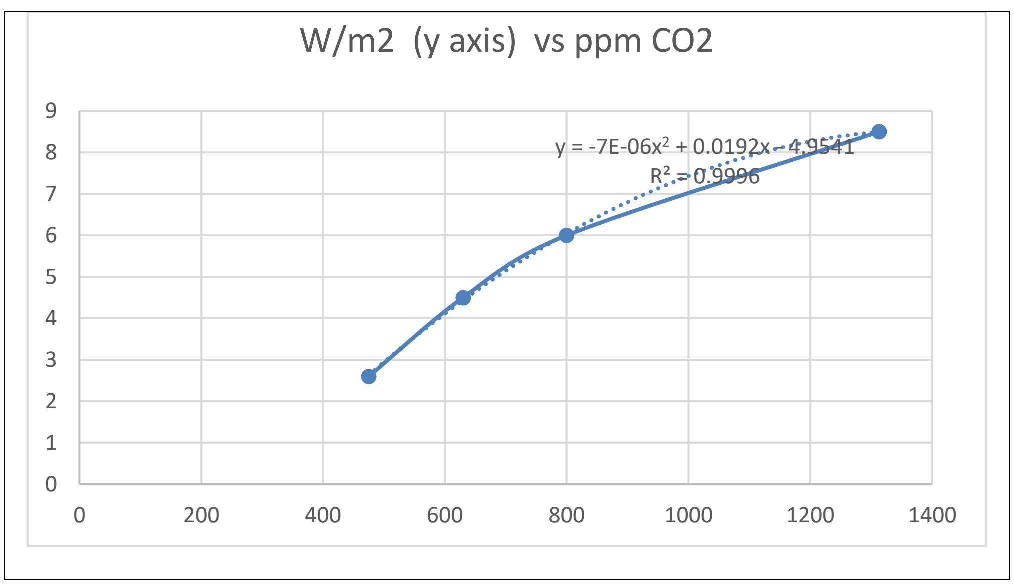

Figure 36 Plot of IPCC's conclusions

A comparison of that number with that fuels' combustion energy indicates that fuel burning's "bad" global-warming effects surpass its "good" effects (the reason that we burned it in the first place) within about one year. What's worse is that on the average, that same CO_2 will hang around in the atmosphere for at least 50 additional years and thereby continue to warm the globe long after producing it has done us any good

The energy generated building/ using nuclear power plants releases considerably less GHG/J – than that generated by building enough wind turbines or solar panels (Figure 37) to generate the same amount of useful energy. The future's more compact & efficient reactors would generate even less.

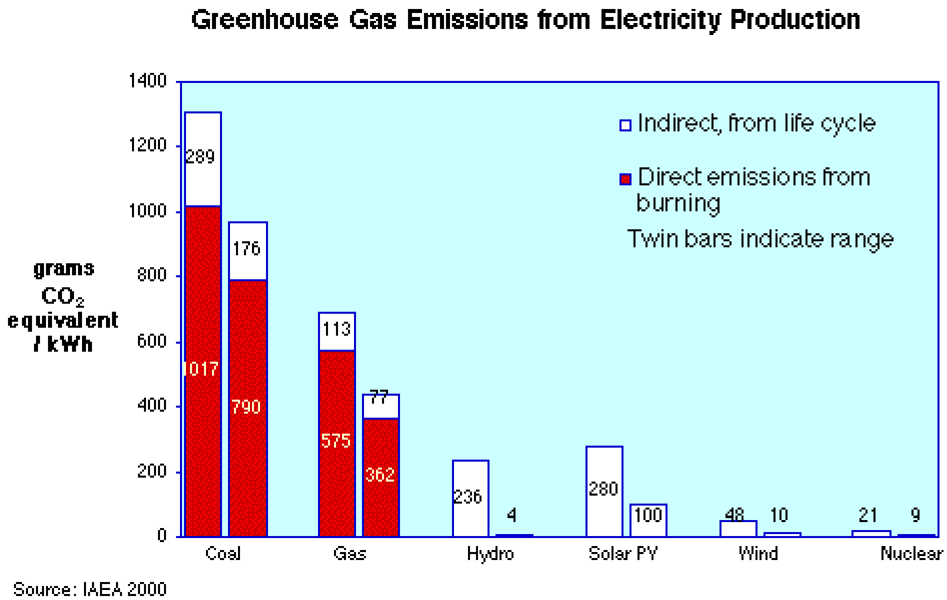

Figure 37 Greenhouse gas emissions of various energy sources (a more up to date but too "fuzzy" to reproduce figure along with its literature citations may be seen on p. 35 of https://www-pub.iaea.org/MTCD/Publications/PDF/CCNAP-2018_web.pdf)

Modern civilization's speediest large-scale reduction in anthropogenic greenhouse gas pollution occurred in France during the 1970s and '80s when the OPEC oil crisis convinced its decision makers to switch from fossil fuels to nuclear fission for producing electricity. That decision lowered France's GHG emissions ~2 percent per year and has kept them much lower than Germany's ever since despite the latter's heroic-scale Energiewende boondoggle (see Figure 38 - APPENDIX XXIII describes more of what happened).

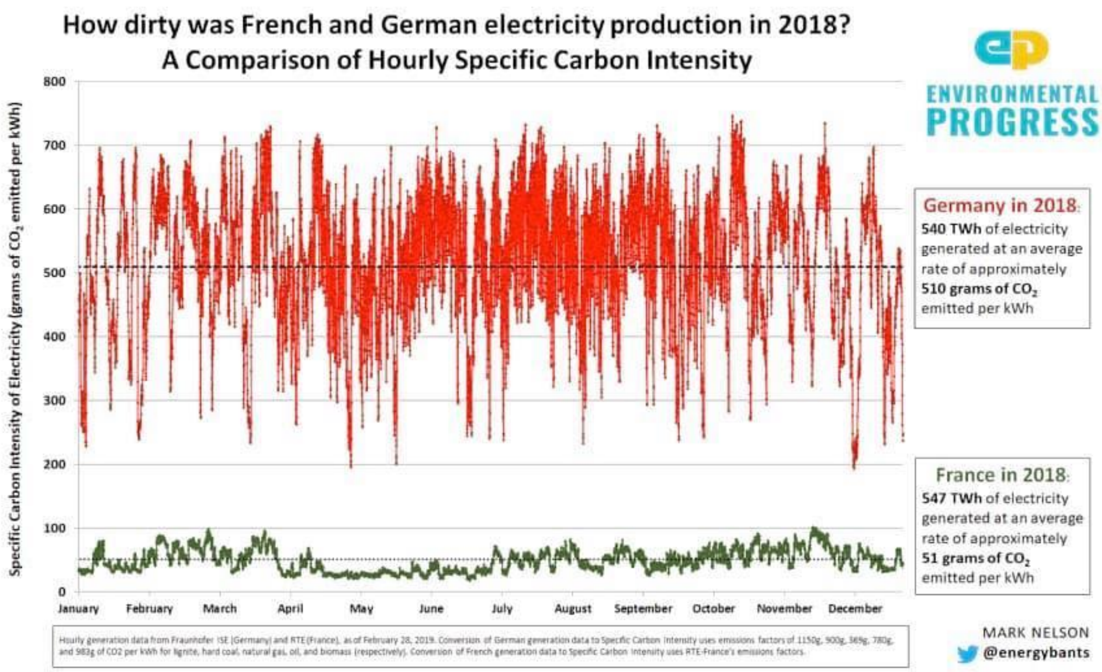

Figure 38 Relative "cleanliness" of French and German electricity

Nuclear power's GHG emissions are due to the fossil fuels consumed to first build and then "feed" its reactors in the way that it's done today.

According to James Hansen et al, (Hansen 2013) the task facing the entire world today is more difficult because *"emissions reduction of 6%/year plus 100 GtC storage in the biosphere and soils are needed to get $_{CO2}$ back to 350 ppm, the approximate requirement for restoring the planet's energy balance and stabilizing climate this*

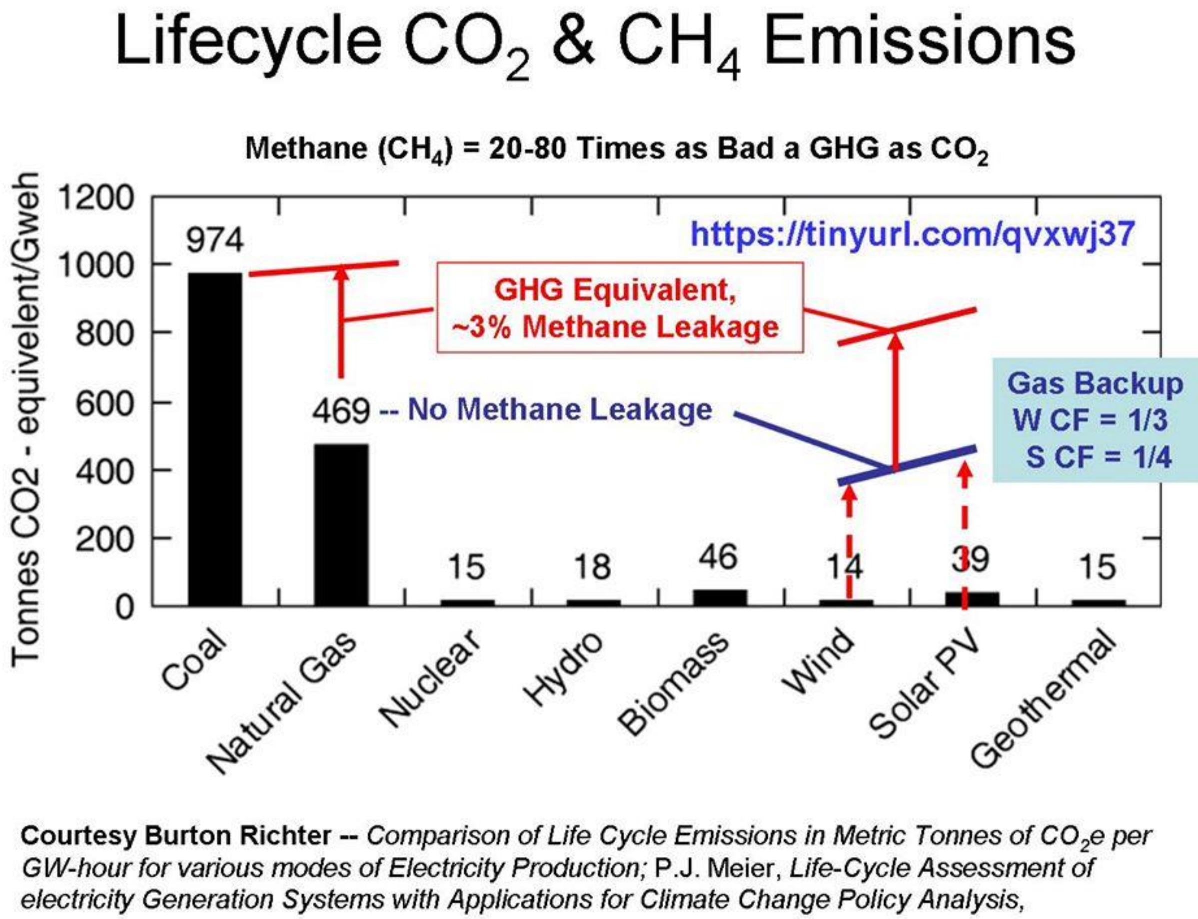

Figure 39 Energy source lifecycle GHG emissions including "back up" & leakage (natural gas) effects

century". His colleague & coauthor, Jeffrey Sachs, director of the Earth Institute at Columbia University says that, "On a global scale, it's hard to see how we could conceivably accomplish this without nuclear".

We've known for almost two centuries now that the ultimate sink for the atmosphere's carbon dioxide is basaltic crustal rock which when exposed to the atmosphere's oxygen, carbon dioxide, and moisture, eventually weathers to form the oxides, clays, feldspathoids, and carbonate minerals comprising much of the inorganic matter in the Earth's soils (Ebelman 1845). Those soils currently contain over three times as much carbon as does its atmosphere (Kramer 2017), yet their potential for deliberate atmospheric carbon-dioxide reduction (CDR) and thereby mitigating global warming, although much studied (e.g., Hartmann et al 2013) , is not yet being significantly exercised (Beerling 2018). When completely weathered by the mechanisms collectively responsible for it in soils, each gram of my example's basis basalt (10.06 wt% CaO and 7.65 wt% MgO) would release 7.35 milliequivalents [0.1006*2/(40+16)+0.0765*2/(24.32+16)] worth of base. If we assume that that base converts acidic soil-gas CO_2 which would otherwise transpire (to the atmosphere[169]) to bicarbonate anions (Hartmann 2013), the application/weathering of 8.95 t/ha of such basalt over 9.71E+7 ha of African farmland would remove/sequester 0.076 Pg (76 million tonnes) of carbon. That sounds like a lot of "sequestration" but represents only ~ 0.009% of the atmosphere's CO_2 (~ 3300 Gt CO_2).

Two more reports generated by the Leverhulme Institute's study of the effects of soil amendment with crushed basalt have just been published.

Here's the Abstract (open access) of the one describing experimental results (Kelland et al 2020).

"Here we report that amending a UK clay-loam agricultural soil with a high loading (10 kg/m^2) of relatively coarse-grained crushed basalt significantly increased the yield (21 ± 9.4%, SE) of the important C4 cereal Sorghum bicolor under controlled environmental conditions, without accumulation of potentially toxic trace elements in the seeds. Yield increases resulted from the basalt treatment after 120 days without P- and K-fertilizer addition. Shoot silicon concentrations also increased significantly (26 ± 5.4%, SE), with potential benefits for crop resistance to biotic and abiotic stress. Elemental budgets indicate substantial release of base cations important for inorganic carbon removal and their accumulation mainly in the soil exchangeable pools. Geochemical reactive transport modelling, constrained by elemental budgets, indicated CO_2 sequestration rates of 2-4 t CO_2 /ha, 1-5 years after a single application of basaltic rock dust, including via newly formed soil carbonate minerals whose long-term fate requires assessment through field trials. This represents an approximately fourfold increase in carbon capture compared to control plant-soil systems without basalt. Our results build support for ERW deployment as a CDR technique compatible with spreading basalt powder on acidic loamy soils common across millions of hectares of western European and North American agriculture.

The second paper (Beerling et al 2020) is another modeling exercise having to do with predicting potential global GHG sequestration rates (0.5 to 2 gigatonnes of carbon dioxide (CO_2) per year) based upon what's already been discovered about enhanced rock weathering.

It's difficult for an old technical nerd like me to come up with quantitative conclusions from reports written the way that these are: i.e., with times of "1-5 years", "coarse"- not defined - sample powder sizes, and "potentials" rather than definite values based upon measurements of

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[169] This phenomenon is called "respiration". It does not necessarily represent a net transfer of carbon from soils to the atmosphere because, at equilibrium, it is offset by vegetative carbon inputs. It currently releases about eight times as much CO_2 to the atmosphere as does mankind's fuel burning (Carey 2016). However, that cycle is currently not at equilibrium and is soon apt to be less so due to additional "land use changes" combined with the effects of global warming, especially within the Arctic, Central Africa, and the Amazon. Consequently, many climate scientists believe that a catastrophic "tipping point" is imminent.

before /after runoff-water bicarbonate amounts, carbonate mineral formation, and/or soil organic carbon (SOC) increases.

However, both are consistent with my contention that basaltic rock dust soil amendment represents a promising and the most "natural" way of addressing several of the problems discussed in this book.

If atmospheric carbon sequestration is to become one of future mankind's primary goals, another way to go about it would be to collect/convert my African example's corn stover [170] and peanut hulls/stems (their leaves would probably end up on the ground) to "biochar". Assuming that scenario's crops, this translates to converting about ~11.6 tonnes of biomass to ~3.1 tonnes of biochar and 5 tonnes of bio-oil per ha (Extension 2002 and Fortress 2011). Because biochar is ~70% elemental carbon, burying it would simultaneously increase Africa's soil's organic carbon (SOC) and sequester atmospheric carbon at the rate of ~0.25 Pg (250 million tonnes) per year. Another reason for "biocharing" some[171] of its agricultural residues would be that it should simultaneously produce more than enough carbon-neutral "oil" to fuel its farm machinery and thereby become a profitable sideline for their owners. Figures in recent reports having to do with Midwest USA farm fuel costs suggest that current conventional high-input corn farming requires about 35 US gallons of diesel fuel/ha/a (Agecon 2015, Gelfand et al 2010)[172]. Five tonnes of bio-oil purportedly have the energy content of ~37% that much No. 2 diesel oil (i.e., 2176 liters, 575

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[170] Stover is above-ground, neither grain-nor-root, crop matter - on a dry basis there is generally about as much stover as grain and approximately 80% of it can be readily collected.

[171] Efforts have been under way to discover more efficient ways of converting structural plant material (mostly cellulose) to motor fuels (primarily ethanol) for several decades. It still is not commercially viable but that could possibly change. One of the impending threats to agricultural sustainability is that if the conversion of plant structural material (cellulose and lignins, not grain) to ethanol does become commercially viable, farmers will be tempted to convert crop residues to an energy resource, thus depriving their soils of necessary organic inputs. For example, extensive studies have shown that most of the above-ground corn residue (2-5 tons/acre) should be returned to the soil to maintain its quality. Consequently, we must be cautious when considering quantitative removal of crop residues as a routine practice. As the legendary soil scientist Hans Jenny put it, "*I am arguing against indiscriminate conversion of biomass and organic wastes to fuels. The humus capital, which is substantial, deserves being maintained because good soils are a national asset*" (Jenny 1980).

[172] Gelfand et al compared four grain and one forage systems: corn - soybean - wheat rotations managed with (1) conventional tillage, (2) no till, (3) low chemical input, and (4) biologically based (organic) practices, and (5) continuous alfalfa under two scenarios: all harvestable biomass used for food versus all harvestable biomass used for biofuel production. Among the annual grain crops, average energy costs of farming for the different systems ranged from 4.8 GJ ha^{-1} y^{-1} for the organic system to 7.1 GJ ha^{-1} y^{-1} for the conventional; the no-till system was also low at 4.9 GJ ha^{-1} y^{-1} and the low-chemical input system intermediate (5.2 GJ ha^{-1} y^{-1}). Overall energy efficiencies ranged from output:input ratios of 10 to 16 for conventional and no-till food production and from 7 to 11 for conventional and no-till fuel production, respectively. Alfalfa for fuel production had an efficiency like that of no-till grain production for fuel.

US gallons, or 82 GJ's worth) and research suggests that should be possible to convert it to a diesel-type engine fuel (Cataluna 2013). Consequently, in principle anyway, such farms would generate about fourteen times as much motor fuel as they consume.

If everyone in the world circa 2100AD –not just its Africans - were to char their stover and fertilize fields with Snake River Plain basalt at the rate assumed above, it would collectively sequester ~3 Gt $_{CO2}$ per year. However, since the atmosphere already contains about 500 Gt of excess $_{CO2}$ [(~412 ppm-350 ppm)/412 ppm*3300 Gt = 496] and will surely become further polluted before we've kicked our addiction to fossil fuels, it would probably take over two centuries for the future's farmers alone to reduce it back to a "safe" (350 ppm) level via only those means.

Universal adoption of the sustainable "regenerative organic agriculture" principles developed/tested by the Rodale Institute (https://rodaleinstitute.org/wp-content/uploads/fst-30-year-report.pdf [fst-30-year-report.pdf (rodaleinstitute.org)] and redemonstrated for another two decades by Iowa State University researchers (https://www.cals.iastate.edu/inrc/marsden-long-term-rotation-study [Marsden Long-Term Rotation Study | Iowa Nutrient Research Center (iastate.edu)]) represents a practical way to re-sequester the atmosphere's excess carbon, i.e., the roughly 70 parts per million by volume (ppmv) of $_{CO2}$ it currently contains above a "safe" 350 ppmv level. The Rodale institute's primary goal is to restore the Earth's soil's biota - insects, worms, microorganisms, fungi, etc., and its soil organic carbon (SOC -aka "humus) back up to the "healthier" levels they were before we humans invented agriculture. Its principles include minimal tillage, rotation through a wider range of product crops (not just the US corn belt's habitual corn & soybean rotation) and planting a variety of cover crops all of which are "crimped" (killed & flattened) prior to product/cash crop planting & then left in place, not removed, while the latter is grown and harvested .

It is not just conventional "no till" farming. The crimped cover crop (often a mix of plants) initially serves as mulch thereby suppressing weed growth. When worms and bugs subsequently incorporate it into the soil, it then provides a natural fertilizer (esp. nitrogen), feeds beneficial soil organisms, improves water retention, and eventually restores SOC to natural levels. Rotation through a wider range of "product" crops discourages the establishment of crop-specific pests and root/foliar diseases.

For instance, experts tell us that the amount of SOC currently "sequestered" within the uppermost 0.3 meter of the world's soils is about 670 billion tonnes (Lal 2018). . If we assume that it is within a one-foot deep (~30 cm) layer of soil possessing a bulk density of 1.3 g/cc covering one half of the Earth's land surface (1.56E+14m^2), its concentration therein works out to be about 2.2 wt%. The amount of excess atmospheric carbon is currently about 122 billion tonnes. A comparison of those numbers suggests that all we would have to do to "fix" the atmosphere would be to adopt farming practices that increase that soil's SOC concentration back up to 2.6 wt%. That certainly should be possible for the future's more technologically advanced, better organized, better led, and hopefully more sapient, hominids to accomplish.

A recent study concluded that the rate at which the adoption of regenerative agricultural practices increases SOC is about 55 tC/km^2/year (Franzleubbers 2010). Scaling that up to the entire world's ~16 million km^2 of cropland, translates to sequestering 3.2 billion tonnes of atmospheric CO_2 per year.

Other reasons for doing this include at least equivalent crop yields, virtual elimination of both wind & water driven soil erosion, and significantly lower herbicide, nitrogenous fertilizer, and irrigation water requirements.

Unlike most of his fellow atmospheric experts, ex US Vice President Gore compensates for the greenhouse gases emitted by his jet-setting around the world to attend environmental conferences by practicing regenerative organic farming on his own family's farm.

Other reasons for adopting the Rodale Institute's approach to "organic" farming include at least equivalent crop yields, virtual elimination of both wind & water driven soil erosion, and significantly lower herbicide, nitrogenous fertilizer, and irrigation water requirements.

Another reason for adopting them is that doing so would address the root causes of the ongoing mass extinctions of the insects serving as the food of much of the Earth's other wildlife (especially its birds and fish - see Sánchez-Bayo 2019). In order of importance those causes are…

- habitat loss and conversion to intensive agriculture and urbanization
- pollution, mainly that by synthetic pesticides and fertilizers
- biological factors, including pathogens and introduced species
- climate change.

The last factor is particularly important in tropical regions, but also affects a minority of species in colder climes and mountainous regions of temperate zones.

Of course, since the potassium, phosphorous, and trace minerals in such soils would eventually become depleted, it would still be necessary to replace them with some combination of recycled "night soils" (manures -the best way), artificial fertilizers, and/or powdered rocks.

4.2 Oceanic acidification mitigation

A "nuclear clean new deal" could address another environmental consequence of fossil fuel burning.

The Earth's oceans contain 50 times as much carbon as the atmosphere and act as a biotic and abiotic thermostat, absorbing and releasing CO, and heat. They have also become an especially tragic "commons" with respect to the effects of the excessive atmospheric CO_2 causing global warming-driven oxygen loss and acidification (Orr 2005) - see APPENDIX XX. Acidification is currently killing a host of pelagic creatures with aragonite (calcium carbonate) skeletons/shells which are dependent upon oceanic chemistry (pH and temperature) remaining as it was while they were evolving. Such calcifying creatures constitute the Earth's dominant natural CO_2 sequestration mechanism, converting ~1 billion tons of CO_2 each year to oceanic sediments[173] and limestone (coral reefs). Land plants and soils currently don't accomplish that much sequestration because soils aren't being fertilized with powdered basalt and today's industrialized farming usually depletes SOC. Today, in many regions (e.g., China) soil microorganisms are still adding via respiration net GHG to the atmosphere via metabolism of the organic carbon within the small amounts of crop residues left on its croplands. Our civilization's conversion of the Earth's fossilized carbon to atmospheric CO_2 is driving oceanic extinctions apt to eventually eliminate a host of animal species ranging from coccoliths to whales, and thusly about 15% of human food protein.

A relatively inexpensive way to address those effects would be to implement the suggestion proffered by Professor Schuiling and his colleagues (Schuiling & Krijgsman, 2006); i.e., crush basalt, or maybe even better, dunite (it's more basic[174]), into coarse, sand-like, particles and scatter them along the oceans' coast lines and shallow reefs. When so situated, the particle grinding driven by natural wave action would greatly accelerate their weathering and thereby quickly relieve over-acidification while simultaneously rendering that water a better sink for atmospheric CO_2.

Another and probably more effective driver for implementing Dr. Schuiling et al's proposal is that a global sand shortage has come to be because we humans make brick and concrete out of it – especially in and around Southeast Asia's burgeoning metropolises. Consequently, vast amounts of sand is being "stolen" from beaches and river banks at the same time that rising sea levels and climate change induced river flooding are threatening more homes and businesses in the denuded areas. That's apt to render artificial basalt/dunite sand valuable enough to tempt entrepreneurs to sell megatonnes of it whenever the power required to mine/grind/distribute it becomes cheap enough.

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[173] About 80% of the geosphere's carbon is limestone and its derivatives formed from the calcium carbonate comprising the shells of deceased marine organisms. The remaining 20% is stored as still-organic kerogens/peat/oil/gas etc., formed via sedimentation and subsequent burial of terrestrial organisms under elevated heat and pressure (Berner 1999).

[174] Dunite is an ultramafic (very basic) plutonic rock with a chemical composition (majors only) falling somewhere between pure forsterite (Mg_2SiO_4) and pure fayalite (Fe_2SiO_4). High magnesium dunite is ~four times more basic than a typical flood basalt making it a better CO_2 absorber but poorer fertilizer.

Saving especially valuable waterfront-situated homes, businesses, resorts, & hotels is apt to be at least as strong a motivator to important people as is rendering everyone equally energy “rich”, agriculture sustainable, and/or protecting a commons (the Earth’s oceans and remaining wildlands).

Other ways that this book’s proposals would mitigate the Earth’s excessive atmospheric CO_2 issues include the cement/concrete-related suggestions discussed in section 3.3.

4.3 Nuclear powered transportation

4.3.1 Requirements

*“The automobile is especially addictive…it is a suit of armor with 200 horses inside, big enough to make love in. It is not surprising that it is popular. It turns its driver into a knight with the mobility of an aristocrat and, perhaps, some of his other vices. The pedestrians and people that use public transportation are by comparison, peasants looking up with almost inevitable envy at the knights riding by in their mechanical steeds. Once having tasted the delights of a society in which almost anyone can (*pretend to*) be a knight, it is hard to go back to being a peasant.”*
Kenneth Boulding

Petroleum currently provides the largest share - about 40% - of the world’s total primary energy. According to the US DOT, in 2020 almost all of the USA’s ~276 million registered million motor vehicles were fueled with petroleum, Transportation is the single-largest contributor to greenhouse gas emissions in the United States and accounts for about a fourth of global emissions. Many of the good things that citizens of today's richer countries have come to take for granted depend upon a world-wide transportation system that will inevitably suffer price shocks and shortages when petroleum finally does peak out and then decline.

Under current (2021) policies, the United States and the rest of the world won’t meet global emissions reduction targets that scientists say are necessary to curb the worst effects of climate change.

Changes in its price and availability will have tremendous impact because today’s alternatives don’t contribute much to the transportation sector. Petroleum production will inevitably decline due to the real-world laws underlying almost everything else that we need/use that isn’t renewable. It is often claimed that Hubbert’s “peak oil” concept – the fact that oil production via any means from any/all sources will reach a maximum level then decline, – is only about geology. Instead, it is a consequence of geology, reservoir physics, economics, government policies and politics. Their intrinsic limitations will eventually affect all human activities because neither economic incentives nor political will can overcome them.

Several natural depletion mechanisms affect petroleum production. Depletion-driven decline occurs during the primary recovery phase when decreasing reservoir pressure leads to reduced flow rates. This phenomenon is especially prevalent in fracked-type oil and gas wells. The secondary recovery phase involves water injection to maintain pressure but increasingly more water and less oil is recovered over time. Additional invested capital and technologies, e.g., CO_2 injection, can enhance oil recovery in a tertiary recovery phase but it comes at a still higher cost. It's like squeezing water out of a soaked sponge – easy to begin with but increasing effort is thereafter required for diminishing returns. Eventually, squeezing a sponge or oil basin harder isn't worth the cost/effort and will inevitably cease.

Another natural analogy would be the relationship of predator to prey populations: "easy" oil leads to increasing profits and therefore further investment in extraction capacity (lots of mice means that more kittens survive). The easiest (typically the largest) resource reservoirs are inexorably depleted – slowly with "conventional" oil wells, quickly with fracked ones. Extraction costs in terms of both energy and monetary inputs rise as production moves to lower quality deposits. Eventually, investments can't keep pace with rising costs, declining production from mature fields cannot be overcome and total production begins to fall. Additionally, regardless of capital availability or increasingly high prices, at some point, an oil well can no longer deliver net energy (most of the cats along with their kittens starve). In 1982, U.S. petroleum geologist M. King Hubbert said: "*There is a different and more fundamental cost independent of the monetary price: if oil is used as a source of energy, when the energy cost of recovering it exceeds its energy content, production will cease no matter what the monetary price may be*." Many of that industry's movers and shakers still can't bring themselves to believe that there ever will be a genuine shortage of what they're currently selling.

Here's another memorable Boulding quote (I would have preceded "mad" with " a politician").

"*Anyone who believes in indefinite growth in anything physical, on a physically finite planet, is either mad or an economist*."

Kenneth Boulding

LLNL's 2021 energy flowchart (Figure 40) indicates that the amount of fossil fuel consumed by the USA's non-nuclear thermal power plants (22.45 quads worth [9.54+12.7+0.21]), is about 85% of that consumed by its transportation system ~100% of which is petroleum-based. The efficiency with which its electrical power plants convert their fuels' heat energy to electricity is about 40% while its transportation system is only about 21% [5.91/28.10] efficient.

Consequently, ignoring other losses, replacing the USA's fossil fuel powered transportation system with one powered with electricity generated by 40% efficient thermal-to-electric nuclear power plants would require 7.76 [5.91*21/40/0.4] quads worth of heat. That's almost exactly that currently generated by its ~100 civilian LWR fleet (8.42 heat-type quads). At 3.2E-11 J/fission, doing this would require the fissioning of 96 tonnes of uranium per annum (a 5.5 ft./side metallic uranium cube) which reaction would generate ~96 tonnes of fission product radwaste.

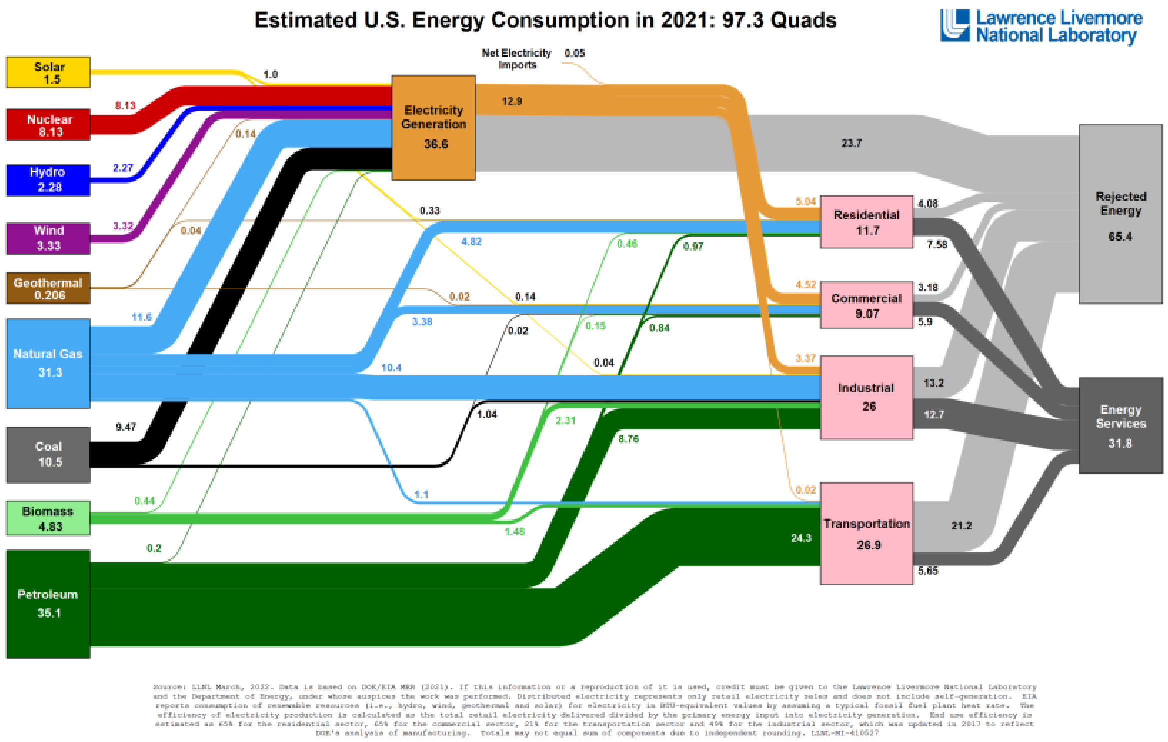

Figure 40 LLNL's 2021 US energy Sanky diagram

4.3.2 Direct electrical transportation

Electricity represents an almost ideal future transport "fuel" (Gilbert and Perl 2010) – lightweight electrified vehicles for local passenger and freight moving and high-speed trains for almost everything else[175]. Unlike other alternative transport energy scenarios, only electric mobility can move people and goods using any combination of raw energy sources – hydroelectric, wind turbines, and photovoltaic panels or gas turbines powered with coal, natural gas, oil, wood waste, switchgrass, solar energy, bio-oil or, preferably, nuclear fission. Energy-wise, most of the large vehicles should be grid-connected (GCVs) meaning that their electricity is generated remotely and delivered directly by wire or rail to its motor(s). GCVs currently do most of the world's electrified people/freight moving. Electric streetcars and trains were operating in many cities by the end of the nineteenth century and ~150 cities around the world already have or are developing electric heavy-rail (e.g., metro and commuter rail) systems running at either the surface, elevated, or underground. Some 550 cities in Europe and Asia have

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175 see APPENDIX XIX

streetcar and/or light-rail systems and about 350 have trolley buses. Electrification of intercity railroads began early in the twentieth century, though mostly occurred after 1950. Most rail routes in Japan and Europe are now electrified. Russia has the most extensive system; approximately half of its 85,000-kilometer total, including the whole of the 9,258-kilometer Trans-Siberian Railway is electrified. China's rail system is being rapidly electrified and now boasts the world's second-most extensively electrified transport system: 49 lines totaling about 24,000 kilometers. In these countries and elsewhere, those are mostly main routes and thus carry a disproportionately large share of their county's passengers and freight. The revolution caused by introducing high-speed electrified passenger rail has transformed the way that people move between major cities in China, Japan, and Western Europe. Their primary advantage relative to privately owned/driven battery-electric vehicles (BEVs) is lower cost and greater efficiency.

APPENDIX XXX goes through several scenarios having to do with reliably powering Texas's ~30 million people based upon that region's (ERCOT's) wind and solar power potential (Texas has ~zero hydropower potential). Because any scenario invoking lots of today's renewables also requires lots of "backup" (e.g., fossil fuel fired power plants and/or some sort of huge energy storage system), many of its examples assume millions of imaginary "smart" Grid Integrated Vehicles (GIVs) that could reversibly discharge back to the grid and thereby affect "cheap" storage capacity.

Other types of GCVs have been and continue to be used for moving goods. These vehicles include diesel trucks with trolley assist such as those employed at the Quebec Cartier iron ore mine from 1970 until it was worked out in 1977. Those trucks were hybrid vehicles with electric motors powered from overhead wires that provided additional traction when heavy loads were being carried up steep slopes. A diesel generator provided their electricity. The result was an 87 percent decrease in total diesel fuel consumption and 23 percent higher productivity.

Several direct comparisons of raw/primary energy consumption by GCVs with similarly capable vehicles with diesel-engines confirmed that GCV vehicular energy use is invariably lower. For example, in 2008 San Francisco electric trolleybuses used an average of 0.72 megajoule of energy per passenger-kilometer; in contrast, the average for diesel buses in thatcity was 2.67 megajoules per passenger-kilometer.

If the electricity powering trolleybuses were to be produced by a diesel generator operating at 35 percent efficiency, with 10 percent distribution loss, the buses would still use less overall energy than conventional direct diesel-powered buses. When electricity is produced renewably (e.g., via this thought experiment's sustainable nuclear fuel cycle) the only thing that would count is such vehicles' energy demand.

The big problem with today's BEV's is that a long-range vehicle must cart around a huge, heavy, expensive, battery which takes up lots of space and increases energy consumption. For example, an 85 kWh, "TESLA 3" car battery weighs 478 kg, currently costs about $12,000 and stores as much primary energy as does about 2 gallons of diesel fuel. AGCVs would either need no batteries at all or only relatively small/cheap ones for limited “off-wire” travel[176]. A GCV is subject only to energy distribution losses in moving electricity from its source to the motor. For a BEV, losses incurred during the charging and discharging of its battery would likely be several times that distribution loss[177].

3.3.3.3 Privately owned automobiles (POVs)

Nevertheless, as the Boulding quotation heading up this section suggests, there definitely would be a huge demand for small lightweight POVs suitable for commuting, grocery shopping, joy riding, etc.

Figure 41 The USA's people moving costs” - puts the energy costs of first-world people-moving into proper prospective. To me the surprising thing is that its public transportation systems (esp. buses the way that we apparently use them) are often less fuel efficient than automobiles. The keys to increasing automobile efficiency is regenerative braking[178], not buying oversized gas guzzlers, & becoming willing to wait until your wife also wants to go to town so that you don't have to drive there separately. A little car with 3 (not 1.6) people in it would be more energy efficient than commuter rail as well as much more flexible because it could go almost anywhere, not to just a few widely scattered stations. There's no good reason for us Americans to be driving around, usually alone, in ~3500 lb. cars or ~5500 lb. pickup trucks unless we weigh over 1000 lb. ourselves.

The Energy Intensity of Different Forms of Travel

Vehicle Type	Load Factor (persons/vehicle)	Energy Use (Btu/vehicle mile)	Energy Intensity (Btu/passenger mile)
Cars	1.6	4,702	3,034
Light trucks	1.8	6,156	3,345
Taxi & van (demand response)	1.4	20,047	14,106
Bus–Transit	9.1	36,760	4,025
Airline	113.2	263,971	2,332
Rail–Intercity (Amtrak)	20.5	30,972	1,187
Rail–Transit	25.8	20,022	776
Rail–Commuter	31.6	51,888	1,643

[176] Another reason for “small” … number of big (e.g., 75 kWh) BEV batteries that co…

[177] Another scheme being band… batteries. Its much-hyped advantage would be alm… s, supercapacitors feature higher peak currents, lo… non-corrosive electrolyte, and low material to… mportant in most contexts, much higher energy densities (kWh/kg) and lower purchase cost. After several decades of development, a “big” (166 Farad, 54 V) state of the art supercapacitor costs ~$1500 (https://www.tecategroup.com). Its specifications translate to 0.067 kWhr’s worth of energy storage ($E=0.5*F*V^2$) – enough to move one of Mr. Musk’s TESLA cars about 1100 feet (not miles) down the road if it’s already up to cruising speed - not nearly as far otherwise .

[178] Regenerative braking recharges a hybrid’s drive battery which is what makes them much more efficient than a conventional car during stop and go type-urban driving.

Figure 41 The USA's people moving costs

A 1000 lb car could carry around two normal-sized people plus enough groceries to feed them for a week. The problem is that few people here in the USA would buy one. The best little reasonably-popular car I've seen here in the USA was Chevrolet's Japanese-built (Suzuki), GEO Metro hatchback. It got ~60 mpg on the highway, weighed about 1700#, & could carry four people & enough groceries to feed them for a month.

They were popular for a while but when gas got "cheap" again after 2008-2009's "Great Recession", its survivors[179] quickly switched back up to even bigger (1.5 to 2 tonne) "crossovers" instead.

We ourselves are the "enemy", not the cars we've bought. It's just another unfortunate manifestation of our all-too-human nature.

Anyway, to generate a comparison between todays and the future's POVs, let's translate some of the numbers in a recent analysis (Romare and Dahllöf 2017) of lithium-ion battery-powered automobiles to figures facilitating comparisons of BEVs and ICE powered transportation.

According to them, the energy required to make these batteries ranges from 350 to 650 MJ/kw. That's equivalent to from 7.6 to 14.1 kg or from 23 to 43 gallons of 46 MJ/kg, 0.8 SpG petroleum/gasoline.

If we then assume that Mr. Musk's 75 kWh BEV batteries last for 500,000 miles (ha, ha), we can equate each kWh's worth of its battery to 6667 [5E+5/75] miles worth of transport.

Assuming that an ICE-powered car driving that far would average 30 mpg, that lifetime (6667 miles/kWh) corresponds to ~222 gal gas/oil

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179 Hundreds of thousands of the USA's erstwhile middle class lost their homes, retirement savings, and jobs/incomes that never came back because its businessmen and politicians embraced different paradigms. That's what's caused much of today's political unrest and given rise to the nomadic, gypsy-like, lifestyle documented in Jessica's Bruder's, best-selling book & movie, "*Nomadland: Surviving America in the Twenty-First Century*".

So, assuming free electricity, in principle we'd be over five times better-off with the BEV (222 /43= 5.16) in terms of both energy use & CO_2 emissions.

On the other hand, if the energy charging a BEV's batteries comes from a coal-powered grid with an overall coal energy to battery energy charge efficiency of 30%, the BEV's energy/CO_2 advantage relative to the ICE is no longer overwhelming (222/43/0.3) = 1.55).

Another way to address range anxieties would be to equip streets, highways, and parking lots with inductive charging pads that could charge smaller/cheaper/lighter short-trip-capable BEV batteries "on the fly". That technology, developed by a former NASA engineer at Pennsylvania-based Momentum Dynamics, would solve the biggest disconnect in EVs: How to bring convenient charging to the urban masses—including apartment dwellers and drivers of taxis, buses, and delivery trucks—without littering the landscape with bulky, unsightly chargers. It's now being implemented in Norway's capitol city, Oslo, which has ruled that all of its taxis generate zero tailpipe emissions by 2024—effectively banning even gasoline-electric hybrids. Due to its punitive taxes on fossil-fueled cars and incentives for electric models, 50 percent of Norway's new cars are already EVs, and all new cars must be zero-emissions by 2025. That's led to a partnership between Jaguar, Momentum Dynamics, Nordic taxi operator Cabonline, and the inductive charging company Fortam Recharge to create the world's first wireless-charging taxi fleet. To that end, Jaguar is equipping 25 of its I-Pace SUVs with Momentum Dynamic's inductive charging pads. The pads, which are about 60 cm square, are rated at 50 to 75 kilowatts. As the cars work their way through taxi queues, they will stop over a series of inductive coils embedded in the pavement. Using resonant magnetic coupling operating at 85 hertz, a charging pad will route enough energy to a taxi's batteries add about 80 kilometers of range for every 15 minutes hovering over the inductive coils—with no physical plugs or human hookup required.

Other demonstrations are now going on with inductive systems designed to charge moving vehicles. A serious drawback of this approach is that real world inductive chargers are currently only 40-50% efficient.

Another, and in my opinion solution, solution would be to adopt Thomas Edison's BEV paradigm; i.e., standardize battery configurations so that smaller/cheaper batteries could be rapidly switched out at "filling stations"[180]. Range anxiety is the main reason why people aren't convinced that EVs make sense and the reason that I'm preaching that our government mandate design of EVs with batteries that could be easily/quickly switched out at "filling stations". As is now the case with gasoline, competitive market forces & technical advances would determine

[180] Car owners would "own" the car, not its battery.

exactly what's in your car's standard-configured "black box fuel tank" but we wouldn't have to worry our pretty little heads about getting stranded.

We would still own the car & pay for the battery that it came with - from then on we'd just be paying for energy & whatever service we'd get when we go for an "outside" fill up on long trips.

This world doesn't need yet another big, luxurious, "perfect" car built to impress millionaires and wannabe drag race car drivers - it needs lots of good-enough, cheap, reliable transportation.

Several years ago, BetterPlace.com implemented a system within both Israel and Denmark, with eyes on California's much bigger potential market. It would be simple for car owners: BetterPlace owned the batteries and they, the EV and BetterPlace were mutually connected via cellular service. The driver selected a destination and BetterPlace examined the battery's state and returned a route, perhaps directly to the desired destination, or to a intermediate stop where a fresh battery would be swapped in to continue the trip as Edison had proposed. Batteries at the swap stops were connected to the utility system and charged//discharged per utility needs, under contract. Similar charge/discharge service could be performed at the EV owner's home. In any case, batteries were always in productive use and remotely monitored for both charge, and performance. Any time that an EV owner wished to travel or change route, BetterPlace would remotely update their and the customer's systems. Getting batteries out of customers' hair was a great idea. They began an operation near San Francisco's airport, but then faded away. (this paragraph's info came from Alex Cannara.)

EV owners are increasingly frustrated with home charging, and it should worry every electric car maker because electricity rate inflation is making home charging a miserable experience for some drivers at the absolute worst time.

A new J.D. Power study of EV owners using Level 2 home-charging stations found that overall satisfaction in their home charging experiences declined 12 points since last year. A major factor in that decline was the inflationary rise in electricity prices.

This could pose a real problem for the EV market because home charging is held up as a solution to daily range-anxiety issues. Without a robust public charging infrastructure, daily home charging is currently key to effective EV ownership, according to automotive executives, dealers, and

There are of course several programs designed to ease the cost of EV home charging mostly having to do with scheduling charging at the most affordable times of day via "smart" metering. However, the J.D. Power study found that there is little awareness or implementation of such tricks.

Geography played a role in overall home charging satisfaction levels; e.g., in New England, where electricity prices surge at peak hours, home charging satisfaction saw the largest decline.

Different brands also had different levels of satisfaction, with Tesla home charging stations topping the list.

However, such "tricks" won't solve the problems engendered by policies that encourage businesspersons and their supporters to pretend that intrinsically unreliable and expensive electricity generation can replace intrinsically more reliable and cheaper power sources.

The trick of course is powering everything having to do with transportation - cars, battery factories, and the energy sources charging them - with a reliable and big-enough source of clean, green, and sustainable power - not with wishful thinking, "resilience", or "all of the above". Since a typical US BEV consumes about 0.346 kWh/mile, US drivers collectively drive about 3.2 trillion miles per year, and their country can't generate nearly enough hydropower, it would take ~126 one GW_e reactors to keep us as mobile as we are now.

Like it or not, all of today's full sized electric vehicles are for the world's more affluent people. Internal combustion engine powered vehicles are relatively cheap because they are made of iron, glass, and plastic. Tesla is no longer talking about a cheap all-electric vehicle because Mr. Musk currently doesn't see a way for it to happen based upon projections like those of the International Energy Agency about what replacing today's cars implies in terms of mining during the next 20 years (The Role of Critical Minerals in Clean Energy Transitions – Analysis - IEA[181] . Its page 9 suggests that we'd have to increase lithium production by 42 times, cobalt production by 21 and nickel production by 19. It currently takes about 10 years to bring a new mine into operation, environmental laws would have to be rewritten, and the governments of Bolivia, the Congo, Russia, and several other countries would have to be replaced to meet such production targets.

Sony initially developed the lithium battery in the 1980s. It took 35 years to get to where we are now with that sort of battery and there is no proven alternative to replace it. Lithium ion-based battery prices are rising, Mr. Biden's $7000 BEV tax credit is not enough, and the U.S. is both not electrical energy rich enough to power such a fleet nor apt to become so unless his government's other energy-related policies radically change.

Global solutions must be based on globally abundant materials because nothing else works at scale. That's the point behind MIT Professor Donald Sadoway's battery research. His team has looked into a plurality of cheap metal (e.g., sodium, calcium, aluminum, magnesium…) battery

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[181] Currently (Mar 9, 2023), the zero upgrade, 60 kWh battery, rear-wheel drive trim version of the Tesla Model 3, , not including any taxes, destination, or other fees. starts at an MSRP of $42,990

chemistries the latest of which utilizes a metallic aluminum negative electrode, an elemental sulfur plus graphite positive electrode, a safely low melting molten salt electrolyte (about 90°C) - mixture of sodium, potassium, and aluminum chloride salts, and a spacer that looks like a thin layer of fiber glass matting - see A new concept for low-cost batteries | Aluminum-Sulfur Battery | Donald Sadoway | Avanti - YouTube & Fast-charging aluminium–chalcogen batteries resistant to dendritic shorting | Nature. To me this seems to be the breakthrough that could render an almost totally electrified transportation system including even farm tractors practical. All of its components are dirt cheap and neither particularly flammable nor apt to create much smoke if something surrounding the battery catches fire. Its voltage per cell is about 1.05 volts which along with the fact that both of its electrode materials have low equivalent weights suggests a theoretical electrode energy storage capacity of about 96500*1.05/(27/3+32/2)/3.6E6 or 0.001126 kWh/gram[182]. Professor Sadoway estimated that his entire Al/S batteries will eventually cost about $8.99/KWh and have capacities of about 300 milliamp-hours/gram . At a voltage of 1.05 volts, that's 1.05 volts*0.3 amp*3600 s/ 3.6E+6 J/kWh or just a bit over 0.0003 kWh per gram. For a premium Tesla BEV-sized battery (90 kWh) that totals up to 300 kg (90/0.0003 grams) of battery costing 90*8.99 or about $810. If you drive it 15,000 miles per year & its Al/S battery lasts for 5 years[183] & TESLAs really can go 300 miles/full charge, that's a battery (not electricity) driving cost of 1.08 cents/mile ($810/(15000*5) - happy days are here again!!

As far as "conventional" BEV battery durability is concerned, Mr. Musk is now promising us that his cars' super lithium-ion batteries will soon be lasting a million miles! Even better, Dilbert, apparently an especially clever US nuclear engineer, has discovered a way to generate their energy sustainably - see Figure 90 (the core of his reactor could be the mortal remains of either Alvin Weinberg or Admiral Rickover).

If MIT Professor Charles Forsberg[184] were writing Mr. Biden's policies, there wouldn't be subsidies or tax breaks for fully electric cars because they would likely impose excessive external societal costs. The reason for this is that Californian studies indicate that 100% EV would be a nightmare for its electrical grid because it would add to peak demand at all the wrong times. From a grid perspective, a "smart" hybrid EV is radically different than a 100% EV

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182 96500=one Faraday = number of coulombs/of electricity per equivalent of charge. The oxidation of one gram mole of aluminum (27 grams) generates three Faraday's worth of electrons & reduction of one gram mole (32 g) of sulfur to sulfide sucks up 2 Faradays

183 Since the battery would be undergoing only 50 full charge discharge cycles/annum (15000/300 =50) it's quite likely to be able to last at least five years.

184 These paragraphs reflect Charles Forsberg's opinions most of which I agree with.

(BEV) because its charger could kick off the grid if there's a power problem and most people (not "the 1%") would charge only during off-hours to save money. For example, most of Brazil's cars can run on almost any mix of ethanol and gasoline. Everyone owning one of those cars has a card showing what gasoline price corresponds to what ethanol price for their specific vehicle and therefore fill its tank with ethanol or gasoline based upon whatever is cheapest per mile. With a plug-in hybrid you still get what most people buy cars for--assured transportation anytime you want and not having to share air with crowds of maskless strangers. According to Dr. Forsberg we'll eventually decide to replace crude oil with "nuclear biofuels" because there are no other options.

If reliability to individuals is ultimately deemed to be a primary goal, hybrids win by a hefty margin due to their reliability and resilience.

Ford's ultra-popular 150 hybrid pickup truck currently comes with options providing its owner with from 2 to 7.2 kW of 120/240 volt 60 Hz electricity. It is often used to provide electricity where there's no grid (e.g., isolated construction sites and campsites) and power its owner's home during grid blackouts. It's far more practical than its all-electric F 150. The latters' downsides are that they are not yet "smart", too expensive (roughly $60,000), and their drive train batteries are too small (1.5 kWh) to back up homes or an electrical grid by themselves.

His bet is that grid-compatible hybrids will ultimately become the USA's primary vehicle—partly due to the costs of providing both enough all-electric car batteries and sufficient grid capacity to charge them during peak demand times. The batteries of millions of "smart" plugged-in hybrids could recharge the grid for short periods and much longer from their fuel tanks.

If Dr. Forsberg were to become the USA's all-powerful energy guru, there would be subsidies for "smart" plug in vehicles paid for by taxing both internal combustion and all-electric vehicles.

Of course, any hybrid vehicle-based energy scenario would still require a good deal of fuel, the manufacture of which will be the subject of the next section of this book.

In any case, we tend to over-invest in our POVs regardless of what sort they might be. Most of the future's relatively "cheap" (much simpler), non-hybrid, BEVs should utilize lightweight government-standardized 10-35 kWh batteries which could either be quickly charged at home, on the fly with inductive chargers, or quickly switched-out at the sorts of "filling stations" envisioned by Thomas Edison over a century ago.

4.3.3 "Nuclear hydrogen"'s synthetic transportation fuels

Contrary to popular belief, electric cars aren't as environmentally friendly as they appear to be because although not powered by gasoline, electricity production is still mostly done by burning fossil fuels. This means if we were to switch over to electric vehicles entirely, we would be switching from one fossil pollution source to becoming more reliant upon another. Some experts say that if electric cars become the main mode of people transport, carbon emissions will only shrink about 10-percent. That might come as a surprise to many politicians like those of California which plans to ban the sale of internal combustion engine (ICE) cars by 2040. The production of electric cars along with their manufacturing and shipping are also massive sources of pollution. Electric cars produce so much carbon in the production and manufacturing stages that one needs to be driven for 100,000 miles before it can truly generate a smaller carbon footprint than do well designed ICEs.

This makes me wonder if electrification is truly the solution to the pollution caused by combustion engines. However, because today's motor fuel production system isn't sustainable the future's combustion powered cars must eventually be fueled with one or more synthetic fuels (aka"e-fuels").

However, that's easier said than done. There are many steps in making a practical synthetic fuel which sans subsidies, currently renders makes them much more expensive than is traditional gasoline or diesel fuel. This means that the costs of an e-fuel-powered car may greatly exceed the long-term cost of an electric vehicle. But since the raw ingredients of e-fuels (air, water, and carbon) are easy to come by and some e-fuels could fuel today's ICE's combustion engines, they may be a better alternative than options requiring the manufacturing of millions of new vehicles, along with the infrastructure required to fuel and power them.

Though the manufacture of synthetic fossil fuel-based transport fuels (synfuels) such as coal or gas to-oil liquids is apt to increase over the next several decades, it is unlikely to compensate for the inevitable decline of petroleum production and would exacerbate such fossil fuels' environmental impacts.

Table 6 Comparison of batteries to jet fuel

Specific energy	**Energy Source**	**E_x/E jet fuel/kg**	**Useful energy ratio/kg**
~42 MJ/kg	jet fuel	1.00	1.00
500wh/kg	Li-metal battery	0.045	0.103
340 why/kg	Li-S battery	0.0309	0.0701
250 why/kg	Li-ion battery r	0.021	0.0487
55 why/kg	Ni-Cd battery	0.0046	0.011
25 why/kg	Pb-acid battery	0.0021	0.0049

*assumes 33% fanjet and 75% electric motor/propeller efficiencies

Table 3 compares specific energies (Wh/kg) of today's rechargeable batteries to that of today's predominant hydrocarbon-based aviation fuel. It's obvious that batteries are unlikely to power any air transport system requiring long ranges or high speeds.

The fact that a properly implemented nuclear renaissance would render electrolytic hydrogen much cheaper than it is now raises a host of other transport fuel and energy storage possibilities. For instance, hydrogenation of the ~11.6 t/ha of product crop stover mentioned in Chapter 3.1 would produce about 3x as much synthetic fuel oil (~4.9E+8 tonnes/a) as would making it from biocharing the same stuff's bio-oil byproduct (Agrawal 2007). At equilibrium, such synfuel would be carbon-neutral because its carbon moiety originated from the atmosphere's carbon.

Cheap-enough hydrogen would also render the raising of cellulosic-type biofuel crops easier to rationalize. The reason for this is that the hydrocarbonaceous $(CH_2)_n$ –type fuels that could be made from carbohydrates $(CH_2O)_n$ are better fuels than is any alcohol that might be "brewed" from them. In principle, that scenario has a great deal of potential because it should be possible to raise a great deal more cellulose with minimal short-term impact upon food production[185]. The key to doing so is "double cropping" - utilizing the primary cellulose producer as a cover crop (e.g., rye grass) during that part of the year when the food crop (e.g., corn or soybeans) isn't growing, i.e., plant the cover crop immediately after the food crop is harvested and cut it just before the food crop is planted. A recent USDA study (concluded that the USA's corn & soybean acreage could produce about 4.2 tonnes of rye grass cellulose per hectare in that fashion (Feyereisen et al 2013). If that entire ~97 million acres of so-devoted US farmland were to be utilized, it could produce about 164 million tonnes of cellulose[186] which, in principle, could be hydrogenated to about 77 million tonnes of hydrocarbonaceous fuel which in turn corresponds to about 24% of current annual US gasoline consumption or twice its aviation fuel demand.

A selling point for that scenario would be that it could reduce erosion because soils would be covered by plants for almost the entire year, not just during the primary food/cash crops' growing season which would retain water and reduce erosion.

However, we humans have been strip mining our agricultural lands from the git-go & most of the world's implementation of Dr. Borlaug's "Green Revolution" greatly accelerated its rate. Double cropping all of it for the purpose of making fossil fuel substitutes is likely to double the rate at which such soils' plant nutrients end up in industrial waste heaps,

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[185] Human-type food that is. Most of the US corn belt's food crops (mostly corn (maize) and soybeans), feed animals along with synfood manufacturer and biofuel/grain-exporters' bank accounts, not its citizens' bellies. Those two crops alone could provide each of its ~330 million people with ~15 kcal of a well-balanced vegan diet per day (five times what they would require) if that were the way that their/our food system worked. However, it doesn't work that way because in practice it's almost impossible for a typical US citizen/consumer to buy either of those cheap commodities for under an order of magnitude more than what its farmers received for producing them. The reason for this is privatization-driven "market control" – there's far more money to be made in feeding us with the flesh of grain-fed animals and "value added" concoctions made from fractionated staple food commodities (e.g., high fructose corn syrup and soy protein isolate) - not those "whole foods" themselves - and selling the remainder to foreign buyers and "confined animal feeding operations" (CAFOs).

[186] Since dried-out annual ryegrass contains about 26% "crude fiber" Chemical Composition of the First Cut of Forage Ryegrass (Lolium) Species | SpringerLink, mostly lignans , which could also be hydrogenated, this/my carbohydrate-only based estimate is somewhat low.

I'm all for cover crops but most of them along with the cash/food crop's stover should be left in the fields where they can serve to restore soil humus (soil organic carbon) back to the "healthier" levels they possessed before we started to farm them. Restoring topsoil SOC concentrations would also be the most efficient way for humanity to go about removing the atmosphere's excess carbon.

APPENDIX XXXIX is a note from Dr. Charles Forsberg (6Aug2021) , sent to other members of Dr. Pavlak's chat group having to do with an ongoing conference devoted to the hows and whys of "nuclear biofuels".

Dimethyl ether represents an especially promising synfuel because it's an especially clean (no particulate emission), especially efficient (Cetane number almost twice that of #2 diesel oil), and easily handled diesel fuel - a readily liquefied gas like butane that can be made by hydrogenating carbon derived from anything from captured atmospheric carbon dioxide to corn stover. Its chief downside is that liquefied DME has about one-half the specific energy (J/cc) of petroleum-based diesel fuels and thereby requires a larger fuel tank if used by the same engine. However, the greater engine efficiencies possible with it would partially compensate for that[187].

What would the hydrogen required to do such things cost?

According to WIKIPEDIA as set out in DOE's 2015 hydrogen production report (https://en.wikipedia.org/wiki/Hydrogen_economy), at an electricity cost of $0.06/kWh, hydrogen would cost $3/kg.

Since there's no good reason to expect that power generated by a sustainable nuclear renaissance's reactors would cost more than does that generated by today's converters (~3.4 cents/kWh), let's assume that figure. Since that same WIKIPEDIA entry also says that it currently takes approximately 50 kilowatt-hours worth of electricity to generate one kilogram of hydrogen and $0.06*50 = $3, most (100%?) of the cost of such hydrogen must be that attributed to the electricity going into making it. If so, then the cost of nuclear hydrogen should be ~$3*0.034/0.06 or $1.70/kg.

Let's put that number into perspective by comparing it to something that most of us do have a pretty good feeling for – the cost of gasoline.

Assuming 0.7489 g/cc, 76.4 MJ/kg gasoline, what would that hydrogen cost translate to in terms of gasoline cost? Well, since there's 3.785 liters/US gallon, a kg of gasoline must weigh 2.835

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[187] In 2009, a Danish University's Shell Eco-marathon DME-fueled "Urban Concept Car" entry set a "gas" mileage record of 1385 miles/US gallon (DME 2019).

kg. Dividing the cost of let’s say $3/gallon gas, by the joules of heat gotten by burning it generates a cost-per joule of 2.24E-8 $/J. Dividing nuclear hydrogen’s cost per kg ($1.70) by its combustion heat of (143 MJ/kg) we come up with 1.19E-8 $/J. That translates to a H_2 cost equivalent to $1.59/gallon gasoline [$3*1.19E-8/2.24E-8].

That’s pretty darn affordable.

(For exercises having to do with wind power-generated hydrogen scenarios, see homework problems 76-81.)

Let’s look at some more transportation fuel possibilities that cheap nuclear hydrogen would render doable.

If Africa’s 4.5 billion future inhabitants were to consume as much Portland-type cement per capita as we do now, Fisher Tropsch hydrogenation of the CO_2 so-generated would produce about 8.2E+8 Mg (Mg = metric tonne) of transportation fuel/a, which figure divided by 4.5 billion is ~28% of current per capita worldwide petroleum consumption rate. Unfortunately, even if that cement were to be made with nuclear-powered kilns, such fuel would still not be carbon neutral because its carbon would be derived from limestone’s already- sequestered carbon (mostly calcium carbonate).

Another possibility would be to fuel engines and/or fuel cells with “nuclear ammonia” (Siemer 2011, Kanga and Holbrook 2015). For example, the shipping industry is beginning to evaluate ammonia as a potential carbon-free alternative to the heavy fuel oil (“bunker fuel”) used in maritime transport. Table 7 compares key

Fuel/energy source	MgJ/kg	MJ/liter	Relative volume	Storage pressure bar
Fuel oil	40.5	35	1.0	1 bar
LNG (-162°C)	50	22	1.59	~350
LPG (-25°C)	42	26	1.35	50
methanol	19.9	15	2.33	~1
ethanol	26	21	1.75	~1
Ammonia	18.6	12.7	2.73	70
Liquid H_2 (-253°C)	120	8.5	4.12	?
Marine battery	0.29	0.33	106	
Tesla 3 battery	0.8	2.5	14	
See https://www.ammoniaenergy.org/articles/man-ammonia-engine-update/				

Table 7. Alternative transportation energy sources

characteristics of both real and potential marine fuels.

Putting proposals like that into proper perspective requires another ballpark calculation.

According to the EIA, of the 7.3 billion barrels of petroleum consumed by the USA during 2017, 47% was motor gasoline, 20% was distillate fuel (heating oil and diesel), and 8% was aviation fuel – in toto about 75% of petroleum is used to fuel some sort of engine. That year, the entire world consumed about 83 million barrels of it per day or 30.3 billion barrels total. Oil's raw combustion heat energy is about 6.1 GJ/barrel (159 liters or 42 US gallons) which translates to about 42 GJ/tonne: liquid ammonia's combustion heat is 383 kJ/gram mole (17 grams) which translates to 22.5 GJ/tonne and making it via electrolytically-generated H_2 typically requires about 14.2 MWh's worth of electrical energy.

75% of 30.3 billion barrels of oil consumed by 35% heat-efficient engines adds up to 4.85E+19 (0.75*30.3 E+9*6.1E9) Joule's worth of energy services (useful work). Providing that much useful energy via "direct electricity" would require the full-time output of 1538 [4.85E+19/1E+9/3.15E+7] one GW_e reactors.

If we instead assume that those energy services are provided by engines burning "nuclear ammonia", 6.19 billion [0.75*30.3E+9*6.1E+9/22.5E+10] tonnes of it would be needed per year. At 14.2 MWh/tonne, making that much would require the full-time output of 9970 [6.19E+9/14.2*3.E+9/1E+9/3.15E+7] one GW_e nuclear reactors.

If we then assume that the electrified vehicles' mechanical energy is generated by 90% efficient electrical motors, the relative numbers of reactors required to implement these scenarios would be about 5.8:1 (9970/1538/0.9).

Finally, Appendix XL is a simplistic spreadsheet scoping out two proposals that I've hearing about. The first is that we here in the USA decide to make enough "nuclear biofuel" utilizing carbon gotten from the most productive super weed that agricultural scientists have yet discovered to replace the petroleum-derived fuels powering our and most of the rest of the world's transportation system. It's second section (lines 30 on down) determines what turning that same biomass into ethanol might accomplish.

The lesson that ball parking exercises like these should teach us is that our descendants should electrify as much of their world as possible. It simply boils down to the fact that if the electricity generated by a 40% thermal-to-electric energy efficient nuclear reactor could produce compressed hydrogen with 80% efficiency (both percentages are "aspirational') and that hydrogen converted back to electricity with a 60% efficient real-world fuel cell, the system's overall energy efficiency would be only 19% (0.4*0.8*0.6).

Antonia and Saur 2012 modeled a hypothetical wind-to-H_2 plant situated in the desert hills of Southern California. Its conclusions were as follows: The hydrogen produced from a hypothetical, optimally sited (CF ~43%), wind farm site near the Mohave Desert and delivered/dispensed at Los Angeles refueling stations would cost $9.4/kg in 2010 dollars, $5.5/kg from the production plant costs and $3.9/kg from the storage and delivery costs for its base case scenario employing compression-less refueling stations. The total delivery cost for delivery pathways employing 350 bar and 700 bar conventional hydrogen refueling stations increased by \$0.7/kg and \$1.0/kg, respectively. A significant portion of their scenario's production cost was due to the variability of the wind farm's energy output (see Figure 42).

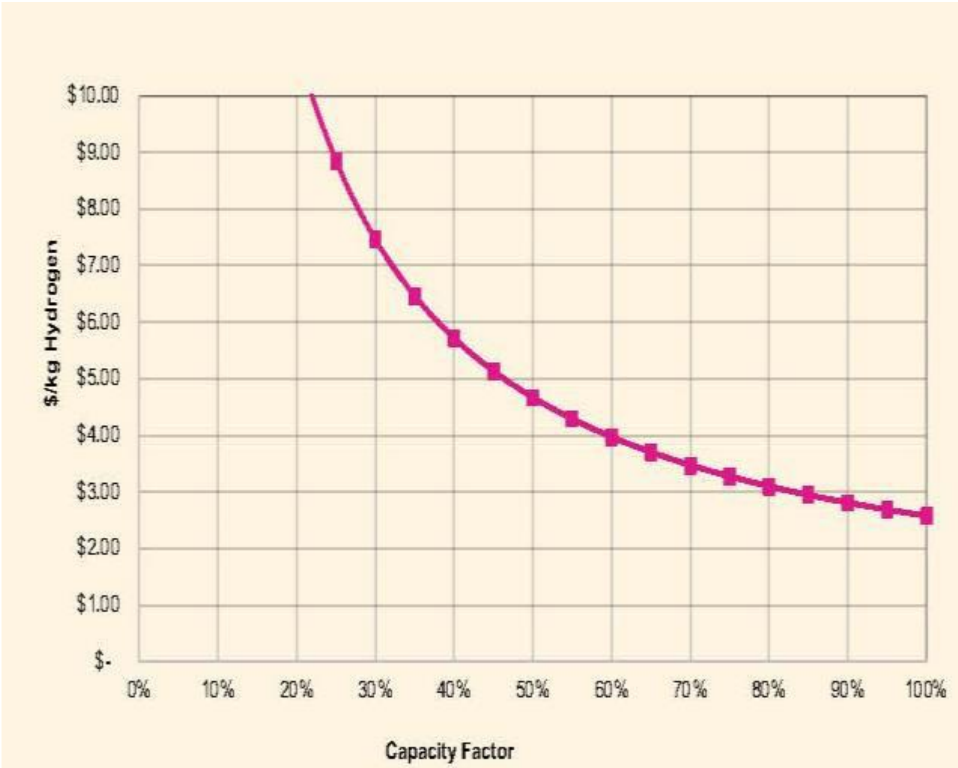


Figure 42 Cost of electrolytic hydrogen as a function of power source capacity factor (Courtesy of LucidCatalyst)

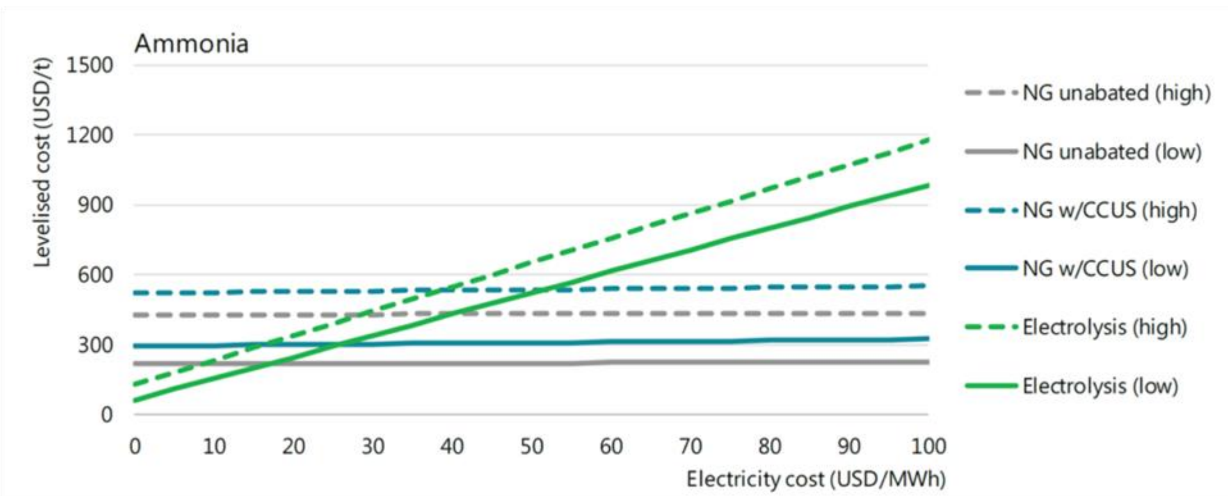
The most efficient hydrogen production method is high-temperature steam electrolysis[188] . Because of the high capital costs (the electrolytic cell is only part of the story), electrolyzers need to operate at high-capacity factors which means that they are a poor match to unreliable power supplies. Real hydrogen plants have large economics of scale which means that hydrogen electrolyzers coupled with low-capacity factor energy sources would kill their economics.. There is no free lunch.

It seems to be difficult for many of the USA's energy experts to understand that unreliable renewables-to-hydrogen scenarios represent an extremely expensive way to retire fossil fuels. Energy generated by "advanced" fission–based nuclear reactors should be able to produce H_2

[188] high temperature electrolysis is more efficient than traditional room-temperature electrolysis because some of the energy is supplied as heat, which is cheaper than electricity, and the electrolysis reaction is about 35% more efficient at ~750 C than it is room temperature. It's especially well suited for close coupling to MSR reactors because they run at sufficiently high temperatures to supply that heat directly o

more cheaply but is still unlikely to match the cost of that from natural gas at current US gas prices. However, that’s just a temporary hiccup. Today’s (March 2020) Corona Virus scare is throttling global economic activity along with fossil fuel prices which means that the world’s more expensive fracking wells will be valved off and new wells delayed until prices come back up which they inevitably will and with a vengeance because it is getting progressively more difficult to find new cheap-to-mine gas/oil reservoirs.

Figure 43’s plots indicate that if a "nuclear renaissance's" power were to cost 5 cents/kWh, the cost of making innocuous GHG-wise ammonia via electrolysis/Haber Bosch would be about \$150/tonne. It would be a lot higher than that using equally cheap wind/solar power instead because several times as many factories would be required to make it at the same annual averaged rate.



Notes: The *levelised cost* includes the cost of CAPEX on core process equipment, fixed OPEX, fuel and feedstock costs, and the cost of capturing, transporting and storing CO_2. Best practice energy performance is assumed for natural gas-based routes. Electrolyser CAPEX range = USD 455–894/kW$_e$. Electrolyser efficiency range = 64–74% on an LHV basis. More information on the assumptions is available at www.iea.org/hydrogen2019.
Source: IEA 2019. All rights reserved.

Figure 43 IEA ammonia cost estimates

Here's another ballpark calculation suggesting that a properly implemented nuclear renaissance would let us keep running our cars, trucks, ships etc. in pretty much the same way we do now.

Since ammonia has a heat of combustion of about 22.5 MJ/kg, that's about 150 million J's worth of fuel heat per US dollar.

Assuming that \$2/gallon gasoline has a SpG of 0.8 & combustion heat of 46MJ/kg, a dollar's worth of it generates about 70 million J worth of useful heat.

These figures suggest that it shouldn't cost as much to fuel the future's cars, truck, ships, etc. with nuclear ammonia than with today's relatively cheap (compared to 14-15 years ago) gasoline.

The western world's energy experts devote far too much of their collective energies trying to integrate intrinsically intermittent energy sources into both real and imaginary systems all of which would work much better and more affordably with reliable power.

4.3.3.1 Air transport

Peak oil will impact air travel/transport especially hard because it cannot be fully electrified. Tables 6 & 7 show why battery powered airplanes will never match the performance (speed or range) of today's airliners. That suggests that when the next century begins, there's apt to be less air transport as there is now[189].

4.3.3.2 Farm synfuels

As mentioned earlier, in a first world farms (e.g., Nebraska) it currently takes about 35 gallons of diesel fuel to raise a hectare's worth of corn (maize). Scaling the "acreage" figure (1.36E+8 ha) that I came up with to feed Africa's 4.5 billion future inhabitants up to that entire world's 11.2 billion people and assuming the same fuel consumption rate, our descendants will need the equivalent of 6.8E+9 [1.36E+8*11.2/4.5*35] US gallons of diesel fuel equivalent per annum. Assuming 0.82 SpG and 42E+6 MJ/kg fuel, that's 1.54E+18 J of heat-type energy consumption by the futures' farm machinery per annum.

Next, assuming that the efficiency with which farming's heat engines convert heat to useful work remains ~ 25%, that's 3.58E+17 J useful (mechanical) energy demand per year. Finally, assuming the same 17% overall round-trip efficiency figure of my "nuclear ammonia"/heat engine estimate a couple pages back, it'd take 67 full sized nuclear reactors to power that future's farmers [3.58E+17/0.17/1E+9/3.15E+7]. Fraction-wise that's just 0.23% of that required to power everything that that happy scenario's inhabitants would need.

Finally, a full-sized ($1GW_e$) conventional nuclear reactor dedicated to powering state of the art, 75% efficient, electrolyzers could generate about 200,000 tonnes of hydrogen per year which if

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189 The world's largest electric commercial airplane, a much modified, nominally nine-passenger Cessna Caravan, boasts a range of 30 minutes/100 miles. Unfortunately, its two tonnes of lithium-ion batteries and their cooling equipment leave much less room for its passengers. Carrying the energy equivalent of the aviation fuel used by a that-sized airliner flying to Asia would require $60 million worth of Tesla-type batteries weighing five times more than that plane itself It's likely that the real potential for electric people moving is providing short range VTOL (vertical take off and landing) taxi service for the super-rich "elites" wishing to avoid ground level transport traffic hassels/delays. .https://www.greencarreports.com/news/1128377_world-s-largest-commercial-electric-airplane-flow-for-30-minutes-can-go-100-miles .

reacted with cement plant carbon dioxide could make about seven times that much of something suitable for powering both airplanes and farm tractors.

4.3.3.3 Shipping synfuels

According to "Low Carbon pathways 2050" (a "$4 million multi-university and cross industry research project (Lloyds 2016)), the world's shipping industry currently emits about 1 gigaton of CO_2 per year (~2.3% of global emissions). International trade associations are leading the effort to decarbonize that economic sector in alignment with the goals set by the Paris Climate Agreement. Their immediate challenge is simple to state but hard to address: "*ambitious CO_2 reduction objectives will only be achievable with alternative marine fuels which do not yet exist*."

To meet the targets defined by the Paris Agreement, that study determined that the shipping industry would need to achieve "*net zero emissions by approximately 2035 (1.5°C) and 2070 (2°C).*"

Its key findings conclude that the industry needs to do two things: first, act swiftly and, second, identify a viable carbon-free liquid fuel.

- Shipping will need to start decarbonisation soon because as stringency increases over time, increasingly costly mitigation will be required. The later we leave decarbonisation, the more rapid and potentially disruptive it will be for everyone.

- A substitute for fossil fuel will still be required because energy efficiency improvements alone will not be sufficient in the medium to long term.

- Energy storage in batteries and politically correct renewable energy sources will have some role to play but will likely still leave a requirement for a liquid fuel source.

While low carbon fuels (bio or synthetic fuels like ammonia) may be necessary in the timescales modeled in its report to enable international shipping's low carbon transition, under current technology costs they were not then deemed economically viable (UMAS 2017).

Another recent Canadian Insurance Services Regulatory Organizations (CISRO) study concluded that, " *Liquid hydrogen and methanol, despite also being alternative energy vectors, have lower round trip energy efficiencies [than ammonia] as estimated in previous studies. Further, the infrastructure required for liquid hydrogen transport is almost nonexistent and methanol is an emission producing fuel at the point of use; make these alternatives less attractive at this stage. Ammonia therefore provides an attractive option in terms of RTE, as well as being an emission-less energy carrier*" (Giddey 2017).

At least four major maritime ammonia projects have been announced during the last few months, each of which aims to demonstrate an ammonia-fueled vessel operating at sea (Brown 2020).

In Norway, Color Fantasy, the world's largest roll on, roll off (RORO) cruise liner, is to pilot ammonia fuel. Across the broader Nordic region, the Global Maritime Forum has launched NoGAPS, a major consortium that aims to deploy "the world's first ammonia-powered deep-sea vessel" by 2025. Norway's clean synfuel-making project will be built in **Sauda on its southwestern coast** and owned by Hy2gen, Trafigura and Copenhagen Infrastructure Partners. Hy2gen is already developing a similar hydro-ammonia in Quebec Norway's Sauda plant – dubbed the Iverson eFuels project – will feature 240 MW of electrolyser capacity and produce 600 tonnes per day (>200,000 tonnes per year) green ammonia via hydroelectricity. Its owners intend to scale-up this capacity in the future. The project is scheduled to begin construction in 2024 starting the year after, and then full operations starting in 2027.

In Japan, a new industry consortium has launched that goes beyond on-board ship technology to include "owning and operating the ships, supplying the ammonia fuel[190] and developing ammonia supply facilities." The Ministry of Land, Infrastructure, Transport and Tourism (MLIT), which published its roadmap last month, aims to demonstrate ammonia fuel on "an actual ship by 2028" — specifically, a 80,000 dwt ammonia-fueled bulk carrier. The first demonstration vessel was announced in January 2020: the Viking Energy, which is to be powered by an ammonia-fed fuel cell from 2024 on.

In a June 17, 2021, statement the Korea Atomic Energy Research Institute (KAERI) and Samsung Heavy Industries announced a plan to develop molten salt reactors for marine propulsion and floating nuclear power plants, using molten fluoride salts as the primary coolant.

The race is on to demonstrate such ships. The winners will be the first to deploy both low-carbon vessels and their bunkering (fueling) infrastructure. The prize will be a dominant position in the value chains enabling the decarbonization of global shipping. That contest is just starting but the Nordic countries and Japan are leading the pack.

Most of these studies assumed that ammonia would be used in the currently expensive "ammonia fuel cells", overlooking its potential in combustion-based engines.

The first such use that I'm aware of occurred at the same Norwegian hydropower plant that produced the heavy water (D_2O) which was to become the moderator of Germany's first nuclear

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[190] Such interest is what's been "fueling" a great deal of interest in the southern hemisphere in producing both green hydrogen and green ammonia with wind power. The largest such project I've heard of is to be sited in the **Magallanes** region along the West coast of southern Chili. Its developers propose to produce 4.4 million tonnes of ammonia per year with a 10 GW onshore wind farm coupled with 8GW of electrolyzers. A similar-size project is to be sited along the west coast of Namibia – both of those sites are extremely windy and otherwise undeveloped.

reactor circa 1944[191]. Before WWII most of its electricity had been used to make fertilizer ammonia with electrolytically-generated hydrogen. A bit of that ammonia went to fuel the truck depicted in Figure 44. Germany's war time scientists never did get their reactor built but the Norwegians continued to power that truck and fertilize their fields with "green"ammonia[192]. If France's leaders 30–40 years ago had decided to build enough additional reactors to produce its own synfuels as well as clean electricity, its "yellow vest" populist uprisings would likely not be happening.

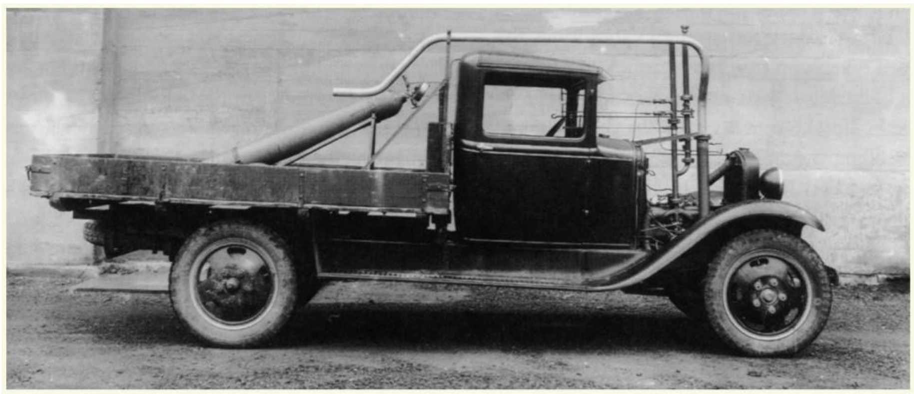

Figure 44 Norsk Hydro's ammonia-fueled truck circa 1933

Other than supply[193] there are several technical challenges that ammonia-fueled internal combustion engines must overcome. The Caterpillar Corporation put it succinctly in a 2008 patent application describing a *"power system having an ammonia-fueled engine"*: "*When ammonia is combusted, the combustion produces a flame with a relatively low propagation speed. Its low combustion rate causes it to be inconsistent under low engine load and/or high engine speed operating conditions. Most existing combustion engines that use ammonia as fuel*

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[191] Since electrolytic hydrogen gas is somewhat richer in its light isotope (H) than is the liquid water from which it was made, repeated electrolysis can produce the pure heavy water (D_2O) required to moderate natural uranium-fueled (e.g., CANDU) reactors. That's why Hitler's Germany demanded that making heavy water become Norsk Hydro'primary wartime mission.

[192] An update to our circa 2009 "nuclear ammonia" slide shows just sent to me by Bob Hargraves (27 Oct2020) includes a link to a press release about the ammonia-fueled sports car that Toyota built a few years ago. It's pretty snazzy-looking: see https://marangonipress.com/2013/02/28/toyota-gt86-r-marangoni-eco-explorer-sport-and-technology-in-the-new-2013-show-car-fitted-with-marangoni-m-power-evored-tyres/

[193] The world currently consumes about 76 million, 42 US gallon, barrels of petroleum per day. Replacing the ~80% of it used as a heating or motor fuel, would require about 50 times as much ammonia (about 8.8 billion tonnes/a) as the world makes/consumes now.

require a combustion promoter (i.e., a second fuel such as gasoline, hydrogen, diesel, etc.) for ignition, operation at low engine loads and/or high engine speed."

In other words, one option is to use a liquid combustion promoter. However, as Caterpillar's patent subsequently noted, this approach "*generally requires dual fuel storage systems, dual delivery systems, and dual injection systems, thus adding additional weight, complexity, and cost to the engine system*."

The fact that marine engines run much more slowly than do the relatively tiny engines powering cars, truck, and tractors should render ammonia's relatively slow flame propagation rate less important.

The second option is to use hydrogen as the combustion promoter. The most promising variant of this approach is to insert a thermal "reformer" between the fuel tank and engine. The reformer would "crack" enough of the ammonia to fast- burning elemental hydrogen (plus nitrogen) to ensure reliable combustion. Crackers are quite simple mechanically, consisting of a heated chamber lined with a catalyst. However, the patent mentions another challenge: *"The requirement for the combustion promoter fuel fluctuates with varying engine loads and engine speed, which can cause control issues.*" This means that cracking a fixed proportion of the ammonia (or a proportion that simply varies with fuel flowrate) is unlikely to optimize engine behavior.

A third option would be to use ammonia as Honda currently does gasoline with its hybrid cars: An optimally operated, tiny,[194] fuel burning IC engine charges the battery that powers the car's motor - it doesn't drive the car directly. This makes especially good sense in regions that get too cold for "pure" BEVs to function properly (e.g., most of Canada).

There are many ammonia engines in development by several companies including Caterpillar, a major supplier of maritime, tractor, truck, and industrial engines. Some of these projects will soon be demonstrating the environmental benefits of ammonia in dual-fuel systems. If the shipping industry is genuinely committed to acting quickly to identify practical carbon-free liquid fuels, it must evaluate ammonia as a short-term bridge fuel for IC engines, as well as a long-term hydrogen carrier for fuel cells.

Ammonia is already an economically viable substitute for natural gas fuel in dual fuel engines (Technavio 2016). When so used, a significant reduction in CO_2, PM (particulate matter) and

[194] It's small because car engines must provide only 7 to 15 KW (10-20 horsepower) most of the time. A reasonable size, e.g., 5 kWh, lithium ion or lithium hydride battery can provide far more power than that for short bursts. This also means that a relatively small (perhaps 15-20 kW) direct ammonia fuel cell coupled with a roughly 3-5 kWh battery could power our descendant's automobiles with roughly twice today's overall efficiency (Zhao 2019)

rather surprisingly even NOx, emission levels is observed. Ammonia is a high-octane fuel (high resistance to pre-ignition), which means that higher compression, more efficient, engines can be used. Consequently, properly modified ammonia-fueled engines exhibit enhanced power output compared to their gasoline or diesel-fueled counterparts.

Technavio noted that shipping represents roughly 65% of the market for dual fuel engines, which are "*gaining popularity in the marine industry as a growing number of vessels are using these engines over conventional diesel or gas engines … enabling the crew to adhere to various marine pollution (MARPOL) regulations regarding propulsion engine emissions.*"

Farm tractors represent another important potential market for such engines because they typically run "full load", and, due to liquified ammonia's popularity as a fertilizer,[195] much of the necessary fuel distribution infrastructure (tanker trucks, train cars, and pipelines) already exists.

The problem that the world's environmentally conscious shipping experts have is the same one faced by similarly motivated people in our land-based electrical power systems.

It's not that there aren't lots of great ideas and promising alternatives. The problem is that fossil fuels are still relatively cheap and immediate economic considerations drive decision making. We also haven't yet decided to stop giving major polluters a free ride with respect to carbon dumping by imposing a reasonable carbon tax and don't yet have rules requiring us to take up cleaner new technologies. We need caps on emissions and "polluters pay" schemes so that clean technologies can outcompete fossil fuels.

Doggett agrees that far more policy and government action is needed to help reduce shipping emissions, and part of Sailcargo's remit is pushing for this. At the same time, she says, the private sector can demonstrate what is possible.

Let's finish up this discussion of fueling the future's transport infrastructure with a genuine energy expert's opinion.

"*I was asked today about the role of hydrogen in transportation. This is my reply.*

Regenerative breaking makes electric battery vehicles a winning concept for metropolitan and suburban transportation applications. Cities and States can commit to metropolitan electrification infrastructure with minimal risk that another technology will obsolesce EVs during investment timeframes.

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[195] Gaseous ammonia injected directly into moist soils is immediately hydrolyzed to ammonium ion which is strongly retained by the soil's cation exchange capacity.

However, EVs are not a universal solution as there are firm physical limits to electrochemical battery technology: long distances, heavy vehicles, and cold climates are problems. For these applications, synthetic carbon (biofuels), hydrogen or ammonia, in combination with internal combustion engines, hybrid power trains or fuel cells are options. Hydrogen is an essential component of all these chemical fuels, though the simple concept of compressed hydrogen gas or liquid hydrogen is not necessarily optimal system. How this plays out near term and long term and the boundary between pure EVs and chemical fuels is not clear. We will need multiple pilot programs."

Alex Pavlak, PhD, PE

Chairman, Future of Energy Initiative

4.4 Weinberg & Goeller's " Age of Substitutability"

The term "technological fix" characterized engineering innovation as a generic tool for addressing problems usually considered to be social, political, and/or cultural was coined by technologist/administrator Alvin Weinberg circa 1960[196].

A longtime Director of Oak Ridge National Laboratory, government consultant, and essayist, Dr. Weinberg had also popularized the term "big science" to describe national goals and the competitive research funding environment obtaining in the USA post WW II. He argued that big science reoriented towards technological fixes could provide a new "*Apollo project*" to address the future's social problems. His ideas have channeled both confidence and controversy ever since.

Weinberg envisaged vast nuclear-power stations at the hubs of networks generating copious electrical power to desalinate seawater, energize irrigation systems, manufacture fertilizer and heavy chemicals, and provide the motive force for an industrial society. The idea shifted the technological fix notion from a short-term repair to an international development tool. He also updated and generalized an ORNL research project spawned by the Eisenhower administration's "Atoms for Peace" initiative of the late 1950s to investigate nuclear desalination plants for supplying water to arid regions in the United States. Weinberg's vision consequently pulled together his experience as national lab director, essayist, and government advisor. As he later recalled, "*I regarded nuclear energy as a magical panacea . . . [with] seemingly unlimited possibilities . . . for solving social problems, poverty, ethnic rivalries exacerbated by quarrels over water, even war itself.*" An initiative, developed principally by Lewis Strauss and Weinberg in collaboration with Israeli and Egyptian engineers to do just that was not pursued by the Johnson administration. Weinberg subsequently declined Strauss's offer to join a Richard Nixon presidential campaign group, because he "*assiduously tried to separate his personal political beliefs from public statements*." Instead, he sent a briefing paper to each of the major presidential candidates describing agro-industrial complexes as the "Apollo of the '70s." He argued that federal funding was crucial for such technology projects because they are "*too expensive, too long-range and too important for the long-term future of the country to be supported by the free market.*"

Weinberg was right about that too.

Table 5: The USA's *material* needs circa 2009

[196] He also coined the term "trans scientific" to characterize nominally technical issues (e.g., radioactive waste disposal) the solution of which depends upon factors that "technical" people aren't empowered to deal with. Those issues are now commonly called "wicked problems" of which there are more now because politicians and their constituents have become more polarized and less concerned with national survival.

Material	Mtonnes/a (% Imported)
aluminum	3.25 (45%)
ammonia	22 (45%)
plastics	28 (?)
steel	93 (25%)
cement	100 (20%)
natural gas	403 (19%)
coal	858 (2%)
oil	984 (71%)
∑fuels/total materials	90.12%

Table 5 lists major US raw materials consumption other than water and sand/gravel circa 2009. Note the dominance of fossil fuels. Goeller and Weinberg's iconic paper, "The Age of Substitutability" approached the problems posed by the future's inevitable depletion of "cheap" raw resources with empirical data rather than the then and still prevailing economic models. In it they go through the entire periodic table examining all the elements along with some of their more important compounds[197], to determine humanity's likely demand for them circa 1970, estimating for each total resource availability assuming a broad definition of potential sources – the atmosphere, the oceans, and the uppermost one-mile-thick layer of the earth's crust – not just the relatively "rich" ores that we've been accessing. The ratio of total resource to demand was determined for each element in terms of years until exhaustion – a measure of relative abundance or scarcity. In cases throughout that list where there was a clear indication of a finite lifetime, they identified that element's most important uses and possible substitutes. For example, some combination of abundant titanium, aluminum, and iron could probably serve the purposes currently served by much rarer metallic elements. Aluminum could be obtained from abundant

[197] For instance, unless a great deal of some other sort of energy is available, the fully oxidized carbon within carbonate rocks can't be used for the same things as can the reduced forms of carbon within fossil fuels. [198] The world's per capita Portland-type cement consumption is ~4 billion tonnes/~7.6 billion people or about 520 kg/person/year. Cement is about the only thing that we "Americans" consume less of (about 310 kg/capita) than does the world's "average" inhabitant. That's largely because we "consume" things and no longer do much infrastructure building or repair. When we do build things, it's usually done with wood, metals, or something derived from petroleum such as plastics or asphalt.

clays rather than rare bauxite and titanium substituted for many of our stainless steels. Based upon their analysis of geological and technological data, they then pronounced the principle of “infinite substitutability”; i.e., except for phosphorus, mercury, and most importantly, the chemically reduced forms of carbon and hydrogen (coal, oil and gas) serving both then and now as fuel, a rich modern civilization could continue indefinitely utilizing only the Earth’s nearly inexhaustible natural resources. The key to such a future would be the availability of energy cheap enough to wrest valuable materials from low grade ores rather than from the much less abundant rich ones.

Another reasonable substitution that Goeller and Weinberg didn’t mention would be to switch from Portland to geopolymeric-type cements [198](Hardjito 2005). Cement is one of humanity’s greatest inventions and currently the world’s fourth- most human made/consumed substance after water, sand/aggregate, and fossil fuels. An average of approximately three tons of concrete is produced for every person on earth each year. Making the Portland-type cement binder utilized for most of it accounts for ~5% of current anthropogenic CO_2 emissions, ~one-half of which is due to the fossil fuels (mostly coal) currently heating most cement kilns.

Figure 45 ***Green Mineral***'s[199] concept is a super green idea that’s being investigated in Europe. Heidelberg Cement and RWTH Aachen University are exploring the reaction of CO_2 with olivine and basalt to form value-added Portland concrete-based building materials (e.g., railroad ties). The project is being supported by the Potsdam Institute for Advanced Sustainability Studies (IASS) and the Dutch start-up “Green Minerals” Concrete - Green Minerals (green-minerals.nl). In principle it would fix at least as much carbon dioxide as is required to make its products Portland cement binder.

[198] The world's per capita Portland-type cement consumption is ~4 billion tonnes/~7.6 billion people or about 520 kg/person/year. Cement is about the only thing that we “Americans” consume less of (about 310 kg/capita) than does the world's “average" inhabitant. That's largely because we “consume” things and no longer do much infrastructure building or repair. When we do build things, it’s usually done with wood, metals, or something derived from petroleum such as plastics or asphalt.

[199] “Green Minerals” is now PAEBBL, see www.paebbl.com.

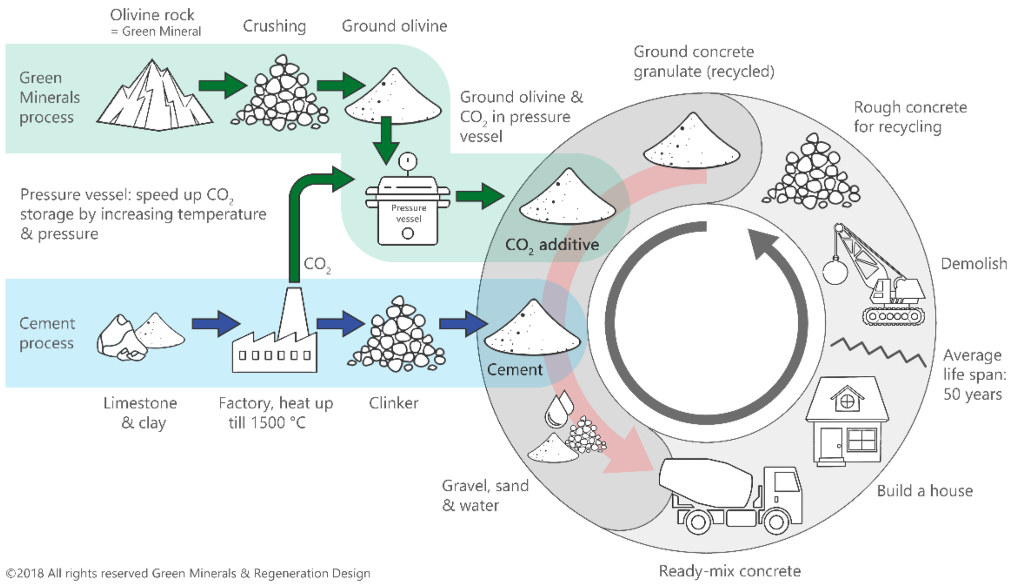

Figure 45 Green Mineral's concept

An Australian outfit named Calix is working on an electrically powered cement plant which heats the limestone from the outside of the kiln rather than its inside. This halves the amount of CO_2 generated and enables "cheap" CO_2 capture because it doesn't have to be separated from the motley mix of nitrogen and gases generated by burning carbonaceous fuels. This means that if that CO_2 is sequestered in some fashion and the electricity to make it were green, the resulting cement would also be green. A German firm, Heidelberg Cement, has been running a pilot plant in Belgium as part of a European Union research project . A larger demonstration plant is due to open 2023 in Hanover, to guide the scale up of that technology.

Since about 3 GJ of heat energy is required to make one ton of Portland cement (Hewlett 2012), the ~3.7E+9 tonnes of it currently produced/consumed each year would require ~1.12E+19 J of electricity – equivalent to the output of about 355 full-sized nuclear reactors (~1.2% of the total (~30,000) needed to satisfy 100% of our descendants' energy needs).

The substitution of geopolymeric cements – mixtures of low calcium fly ash and/or calcined clay "activated" by solutions containing ~15 wt% Na_2O in the form of sodium silicate and 45 wt% NaOH – for Portland-type cements would greatly reduce anthropogenic carbon emissions. Even if the sodium hydroxide utilized to make their activators were to be produced by reacting lime (CaO) with sodium carbonate (trona), only about 15% as much limestone would have to be calcined to produce an equivalent amount of finished concrete.

Another plus for geopolymeric concretes is that they are more durable than are those made with either Portland cement or "Roman" (lime-pozzolana) cementitious binders. The reason for this is that the sand/aggregate binding-mineral assemblage formed during their curing is neither hydrated nor readily recarbonated by atmospheric CO_2 and/or bicarbonate-containing water.

A third alternative to conventional Portland cement would be granulated "dry process phosphate slag". It is a byproduct of a process (Swann 1922) that employs an electrically blown/heated "blast furnace" to convert a mixture of powdered phosphate rock ore, iron ore, and coke into gaseous elemental phosphorous (its primary product) , liquid ferrophosphorus (a valuable by product), and a molten glass-like calcium silicate "waste" slag [200]. That slag is essentially identical to iron blast furnace slag which means that if it were to be properly treated - rapidly cooled, powdered, and mixed with an activator (e.g., lime or sodium silicate and water) – it could serve the same purposes as does ordinary Portland cement (Criado 2017). It couldn't totally supplant the latter because the world's current demand for phosphate rock (~250 million tonnes) is well under its demand for Portland cement (~4 billion tonnes)[201].

Finally, regardless of which sort of cementitious sand/aggregate binder is employed, the future's concrete infrastructure would last much longer if basalt fiber reinforcing bar/wire were to replace today's steel rebar (Basalt rebar 2016). Modern lightweight steel rebar-reinforced concrete structures are less durable over the long haul than were those made by the Romans because the carbonation of any calcium silicate-based concrete eventually lowers the pH of its pore fluids to a point that allows embedded steel rebar to rust, expand, and thereby crack the concrete surrounding it. Basalt fiber rebar cannot rust and is intrinsically cheaper than steel rebar because most of the earth's crust consists of basalt and melting/spinning it requires less energy than does iron smelting. It is also ~7 times stronger mass-wise than steel, which means that less of it would be required.

The energy generated by ~75 one GWe reactors could produce ~1.5 tonne/year of environmentally correct, basalt fiber reinforced, geopolymeric concrete for eleven billion people each year.

Of course, those substitutions would be impossible unless some sort of abundant, reliable, cheap, and clean power/energy source replaces today's finite, dirty, carbon-based industrial fuels. Of the possibilities consistent with Mother Nature's rules and facts, Goeller and Weinberg concluded that breeder-type nuclear reactors offered the most promise. Unlike most of the world's political leaders both then and now, they recognized that over the long haul, decisions

[200] The fact that it requires much more electricity is one of the main reasons that that old fashioned "dry" phosphate process has been supplanted by a sulfuric acid leaching-based process. Electricity used to be much cheaper in the USA's Pacific Northwest because its rapidly increasing population's power demand now exceeds its venerable hydroelectric-dominated energy grid's ability to supply electricity. That's also one of the reasons why domestic aluminum production (not its consumption) is now considerably lower than it was 60 years ago https://www1.eere.energy.gov/manufacturing/resources/aluminum/pdfs/al_theoretical.pdf

[201] In today's world a downside of such cement is that phosphate rocks contain relatively high concentrations of uranium (typ. 50-200 ppm) along with its still slightly radioactive daughters.

based upon technical information (facts) will serve humanity better than would those based upon convenient political and econometric assumptions (“alternative facts”).

4.5 Population control – a sustainable nuclear renaissance’s ultimate killer app -

Eventually we’re going to have to address the over-population problem that had inspired Dr. Borlaug's Nobel Prize winning effort to feed the world’s poor people. In 1968, Paul and Ann Ehrlich wrote The Population Bomb, to shine a spotlight on the famine, social collapse, and environmental destruction that they believed would come to pass if population growth and other environmental threats continued to expand exponentially. It garnered massive public attention but was also attacked by religious leaders, free-market economists who assumed that infinite growth is always good, optimists who believed technology can overcome adverse consequences of expanding populations, and some for failing to adequately acknowledge the role of consumption, wealth inequality, and racism in that debate.

Religion is the most obvious source of pro-natal ideology. Put bluntly, ” true believers” people have more babies. This is especially true for orthodox or fundamentalist religions, which tend to have a pro-natal ideology. While the religiously unaffiliated worldwide have an average of 1.6 children per woman, Christians average 2.6 children and Muslims 2.9 children. Some smaller religious groups outstrip even these, such as US Mormons at 3.4 children per woman.

That politically incorrect point was made over 10 years ago by UK professor Eric Kaufmann in his book “*Shall the Religious Inherit the Earth?”* .

The basic pro-natal idea of Abrahamic faiths can be traced to God’s command to Noah after the flood: “be fruitful and multiply.” The empowerment of women is key to addressing the ecological crisis and the population boom. Women with education, contraception, and meaningful careers tend to have fewer children. Traditional patriarchal religious beliefs tend to keep women subordinated and confined to domestic life. That’s why liberating religion from patriarchy may be one way to slow population growth.

Among the most important factors here is the liberation of sexuality from reproduction. The human sex drive is powerful. But religions that are opposed to contraception actively refuse to restrain reproduction in other ways as well.

The best way to win that war would be to make the lives of already-living people better by eliminating the precarity-generating policies and regulations that have caused so many of them to vote for more ultra-populistic wannabe “El Duces” like Donald Trump.

Choosing to decide to address the energy-related technical issues apt to lead to another world war would surely result in lessened fertility (CATO 2013). Figure 46 depicts the effect that increasing a population's prosperity[202] has upon its reproductive choices (replacement fertility per woman~2.1). This strongly suggests that if the future's world were to become both much richer and fairer than today's, unsustainable population growth would quickly end.

[202]Norway's performance at the 2018 Winter Olympics exemplifies how the "UN's Inequality adjusted human development index" reflects a county's citizens' "quality of life". Halfway through that gathering, Norway, with 1.6% of the USA's population, had won almost twice (37/21) as many medals. Why? It's not because its people are "richer" than are the USA's: GOOGLING reveals that Norway's after-tax GDP/capita income level is almost identical to the USA's - $45,348 vs $45,648. The real reason is that because Norway's people govern themselves in a way that benefits them rather than special interests and entrenched politicians – their tax dollars support them, not serve "elites". Its policies have generated a much more equitable distribution of wealth/GDP top-to-bottom than the USA has (it's got very few poor and almost no homeless people); its medical service providers can't force anyone into bankruptcy due to injury or illness; its public schools are much better than the USA's; its federal government doesn't profit by increasing its college students' debt burdens; and its employers must grant its citizens far more paid leave than the USA's are entitled to (25 days/year Norway vs zero USA). It's also unlikely that Norway's government routinely forces its "essential" employees to work without pay (slavery?) while its topmost politicians bicker with each other. Consequently, Norway's citizens feel much more secure freeing them up to do more of whatever they wish, including expensive & risky things like skiing that only "special" Americans can afford. This argument explains the relative per capita athletic performance of other northern European nations and Canada's Olympic teams to the USA's. The USA's electorate also doesn't seem to care that their political leadership's credo seems to be: "*For whosoever hath, to him shall be given, and he shall have more abundance: but whosoever hath not, from him shall be taken away even that he hath*" (Matthew, 13:12).

It is also no coincidence that Norway and other Scandinavian countries have since surpassed the rest of the world in terms of achieving high living standards for their own people and embracing the principles ensuring them for their descendants. The chairman of the UN's Bruntland Commission, Gro Harlem Brundtland , had served three terms as Prime Minister of Norway. That/his commission's goal was to unite the world's countries in pursuit of the sustainable development goals described in its iconic report, "Our Common Future" (Bruntland 1991 – homework problem: read it!).

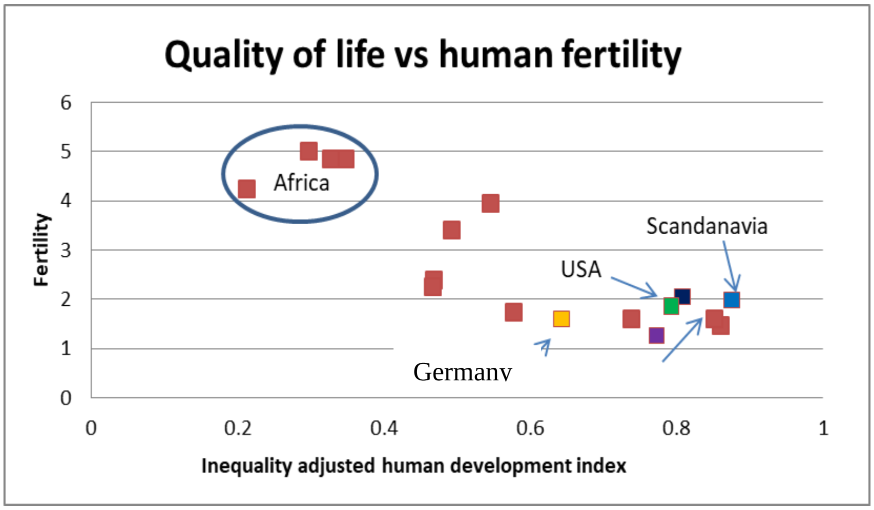

Figure 46 Prosperity vs human reproductive choices (WIKIPEDIA data)

If it were to be fully electrified in the manner I've proposed, its air and water would be cleaner, its homes and cities more livable, and far more interesting, better paying, and more secure employment opportunities would be available to its reproductive-age people because they would be busy building, maintaining, and enjoying their brave new world[203].

Finally, another rarely mentioned (too politically incorrect) reason for China's monumental success during the same decades that the USA's "middle class's" prospects were being downsized is that its leadership adopted/enforced a one child per family mandate at the same time they decided to encourage/enable its people to become more creative and entrepreneurial (Conly 2015). The purpose of that policy was to free up time and capital which could be and was devoted to "making China great again"[204]. It also rendered its children born during that era especially "special" to their parents and society-at-large which in turn rendered their lives more

[203] A couple years ago UK Prime Minister Boris Johnson announced that investment in nuclear power will be included in the government's climate change plans. Those plans are expected to support up to 250,000 jobs, including 10,000 nuclear power jobs, and back the development of advanced small nuclear reactors. https://www.bnnbloomberg.ca/u-k-green-plan-backs-nuclear-hydrogen-to-support-250-000-jobs-1.1523793 18Nov2020

[204] China has become one of a small number of countries with significant national interests in every part of the world and able to command the attention of every other country and international organization. And perhaps most important, China is the only country widely seen as a possible threat to U.S. predominance. Although China's relative power has grown significantly in recent decades, the main tasks of Chinese foreign policy have been defensive and have not changed much since the Cold War era: i.e., blunt destabilizing influences from abroad, avoid territorial losses, reduce its neighbors' suspicions, and sustain economic growth. Over the past decades China is now so deeply integrated into the world economic system that its internal and regional priorities have become part of a larger quest: to define a global role that serves Chinese interests but also wins acceptance from other powers. Chief among those powers, of course, is the United States (Nathan and Scobell 2012).

enjoyable and successful. All children should become special and there shouldn't be so many of them that all of them can't live well. .

Table 8 compares the USA's economy to those of several other nations. In terms of nominal Gross Domestic Product (GDP), the United States' economy remains the world's largest. The biggest contributor to its GDP is its "service sector" including finance, real estate, insurance, professional (e.g., education, legal & health services), and business/financial services. Many of its "heavy industries - steel, cement, aluminum, ship construction, etc. - have either completely disappeared, been radically downsized, or moved offshore. Others including petroleum refining and plastics manufacture haven't growth much for several decades.

The USA's "open" and largely privatized economic system's policies are designed to facilitate the business strategies/models of its own and foreign investors. It remains the world's dominant geopolitical power (i.e., maintains its biggest/most expensive military system) and, because the US dollar has been the world's primary reserve currency since the end of WW II, has accumulated/maintained a huge external and internal national debt burden. In many of the new "high tech" industries, the U.S. remains at the forefront of development but no longer leads in implementation. Its "working" people face rising threats in the form of economic inequality, rising healthcare, housing, and social safety net costs, and deteriorating infrastructure all of which contribute to the angst and political unrest responsible for their inability to agree to do anything likely to address this book's technical issues[205].

The same outsourcing/deindustrialization-favoring policies responsible for the USA's current dearth of good working-class jobs, has encouraged its "luckier" young people to enter those professions providing the well-paid, white collar, ancillary "services" (legal, scientific, regulation, inspection, consulting, and financial advisory) responsible for the fact that the retail cost of electricity in the USA is several times its wholesale or production costs and that it has become almost impossibly expensive to build a new nuclear reactor of any sort.

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[205] Through interviews filmed over four years, Noam Chomsky's REQUIEM FOR THE AMERICAN DREAM https://youtu.be/hZnuc-Fv_Tc?t=11 provides insight into what may well be the lasting legacies of my generation - the death of the USA's middle class and swan song of its once well-functioning democracy. It is a definitive discourse on the deliberate concentration of its wealth and power into the hands of a select few listing a half-century of policies designed to favor the super wealthy at the expense of the rest of us. It's a potent reminder that power ultimately should rest in the hands of the governed and how important it is for us to exercise it.

Table 8 The Wealth of Nations

	USA	China	France	Germany	Sweden
Nominal GDP $trillion	21.4	14.3	2.72	3.86	0.531
PPP* $trillion	21.4	23.5	3.22	53.8	0.574
PPP/person $k	64.4	16.4	42.3	46.4	51.6.2
2019 percentage growth rate	2.3	6.1	3.2	0.6	1.3
*PPP = purchasing power parity (cost- of-living adjusted GDP) in US/international dollars					

richer. The USA's placing on the UN's "inequality adjusted GDP" list https://en.wikipedia.org/wiki/List_of_countries_by_inequality-adjusted_HDI is not particularly high and its ranking (number 28) on its 'inequality adjusted human development index" https://en.wikipedia.org/wiki/List_of_countries_by_inequality-adjusted_HDI is already below that of all of the northern European countries, Canada, Japan, and So Korea and rapidly dropping.]

In current international-type dollars, China has the world's second largest nominal GDP and its largest in terms of its citizen's purchasing power (see table). With an annual growth rate consistently several times that of the USA, it will soon become the world's largest economy in nominal GDP as well. In particular, China's 2.3% GDP increase throughout 2020 surpassed analysts' forecasts and made it the only major economy to log positive growth during that part of COVID 19 pandemic. The USA's GDP shrank by 2.3% and the EU's by 6.6% during that period.

As China progressively opened its economy during the last four decades, its people's economic development and living standards greatly improved which eventually lifted about 800 million of them out of abject poverty. Because its government gradually phased out collectivized agriculture and industry, allowed greater flexibility for market prices, and increased the autonomy of businesses (i.e., changed policies/incentives in a planned, "science based", not politically determined, fashion), both foreign and domestic trade and investment really took off. An industrial policy that encourages domestic manufacturing had succeeded in making China the world's number one exporter of finished goods by 2009.

Critics emphasize China's issues including its rapidly aging population and the environmental degradation caused by its balls-to-the wall industrialization rate.

An aging population isn't necessarily "bad" because it probably means that a country's people are living longer and have chosen to live their lives in ways that benefited them, not religious leaders determined to grow their denominations or politicians & businesspersons desiring plenty of cheap labor and/or cannon fodder for their next war. That's the main reason that birthrates in most of the first world's better-run democracies (e.g., Norway, Germany, Sweden, Finland, Japan, South Korea, Switzerland,…) are currently well under a modern civilization's replacement level (~2.1 per woman).

China recently dropped its "one child" policy after it had helped to "make China great again" but that's not convinced its now freer and more secure people to resume the habits that continues to keep many of the world's still-poor people (e.g., many of Africa's and South America's) poor. China's people know that it already has more than enough people and is able to automate the sorts of low paying/low status gigs & jobs (Uber drivers, store clerks, etc.) that the USA's industrial policies provide its "working-class" (aka "essential") citizens.

On the other hand, China's now "older" people are busy all over the world doing the sorts of things required to address the same issues that convinced me to write this book.

Making everyone in the developing world "rich" enough to want to do thigs like that too is my/Goeller's/Weinberg's/Hubbert's etc. nuclear scenario's ultimate killer app.

The world's population growth rate would drop precipitously (CATO 2013) as would the degree of misery/desperation/frustration currently driving young people in many countries (mostly males) to join terrorist gangs and hate groups. In other words, the world's currently desperately poor people would experience the same benefits of nuclear-powered prosperity that Japan's, France's, Sweden's, South Korea's, and now China's have enjoyed.

A government's job is not just to give its currently most important citizens whatever they want, but to pave the way for a prosperous, stable, and safe future for everyone that it's topmost bosses are supposed to serve. Any kind of government-mandated fertility control is unattractive, but unless its goals are achieved otherwise (e.g., by improving the lives and futures of already-living people), it is apt to become necessary everywhere if a WWIII doesn't render it moot.

Chapter 5. Today’s power reactor concepts

5.1 Gas Cooled Reactors

Figure 49’s “gas graphite” reactors basically just consist of a huge steel-tank-encased pile of graphite moderator perforated with holes through which a coolant gas (to begin with, it was air, then carbon dioxide, and now usually helium) is blown and containing widely-dispersed (about 20 cm apart) chunks of uranium (usually uranium oxide) . Originally those “piles” contained natural uranium fuel encased within metal can or tube-type cladding. It was dispersed so that most of the freshly created and therefore fast neutrons generated by fission didn’t encounter another fissile atom (^{235}U) until they had been slowed down enough to have a good chance of reacting

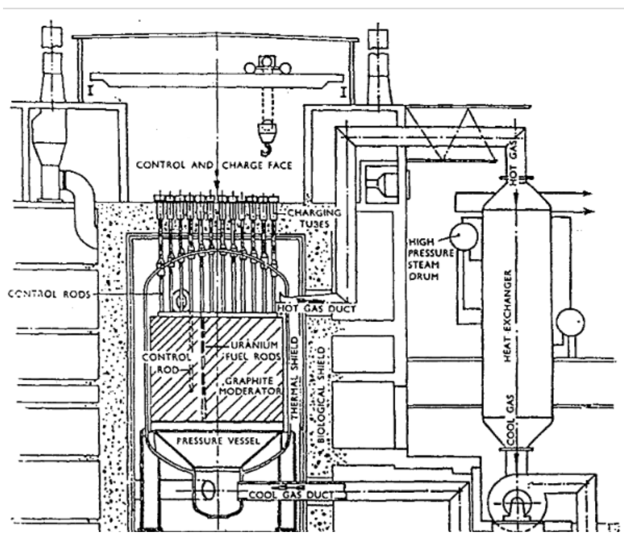

Figure 47 Great Britain's "Magnox" reactor

Figure 48 HTGR

with it. That reaction probability or “cross section” is roughly proportional to the amount of time that a moving neutron spends close to whatever it’s encountering and is therefore higher if it’s been “moderated”. Gas-cooled, graphite moderated reactors were initially built/used by France & Great Britain (Figure 48) because they could be fueled with natural, not enriched, uranium which neither nation could then produce for itself. The main drawback of any moderated, natural uranium-fueled, reactor is that their fuel must be replaced quite often because only about 1 in 140 of the uranium atoms within their fuel is fissile meaning that the latter gets burned-up quickly. Because refueling any solid fueled light water moderated reactor is both expensive and labor intensive, as soon as enriched uranium became available, it was usually added to these reactors' fuel too. However, access to enriched uranium also meant that reactor owners no longer had to bother with all the fuss associated with dealing with several-hundred tonne graphite piles and could therefore either buy or design/build their own versions of the USA's LWRs.

However, because gas-graphite reactors run at far higher temperatures than can water moderated reactors and their coolant (usually helium) is inert, they are both "safer" and intrinsically more efficient (convert a higher percentage of their heat energy into electricity) both thermally and uranium consumption-wise than do LWRs[206]. This has sparked a myriad of "high temperature gas cooled reactor concepts (variously acronymed AGR, HTR, HTGR, PBMR & VHTR) some of which have been built. However, in practice they have not proven to be competitive with LWRs in the power marketplace for two reasons: 1) if heat energy is cheap enough, maximizing the efficiency of its use from ~33 to about 45% isn't terribly important, and 2) a properly designed/operated LWR is already sufficiently "safe" – certainly safer than a coal-fired power plant.

One of the current front runners in the USA's SMR sweepstakes is X Energy's X 100 80 MWe pebble bed type, helium cooled, HTGR that can be scaled into a four-pack 320-MWe power plant. X-energy and TerraPower were selected by the DOE in October 2020 as the first recipients of cost-shared ARDP funding to develop, license, build, and demonstrate an operational advanced reactor by the end of the decade Its details are a bit fuzzy, but we do know that each reactor's roughly 200,000, ~ 6 cm diameter fuel pebbles are to contain ~18,000 TRISO kernels containing ~19.75% enriched uranium and that about one fifth of that uranium will be converted to fission products (i.e., its fuel's burnup is to be about 160 GWt/d/tonne). According to X-energy, it is road-shippable and intended to drive scalability, accelerate construction timelines, and create more predictable and manageable construction costs."

On Mar 1, 2023Dow and X-energy announced that they had signed a joint development agreement (JDA) to demonstrate the first grid-scale advanced nuclear reactor at plant at one of Dow's U.S. Gulf Coast sites, where it would provide both power and heat for industrial processes within one decade. Working with the DOE, Dow and X-energy expect to finalize site selection—subject to the DOE's review and approval—in 2023. Te JDA includes up to $50 million in engineering work, up to half of which is eligible for ARDP funding, with t he other half funded by Dow. The JDA work scope also includes the preparation and submission of a

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[206] However, in practice the degree of such improvement has proven to be rather modest. The heat-to-electricity conversion efficiency of the USA's nominally 779°C Ft St Vrain HTGR was 39.1% while that of its Peach Bottom Atomic Power Station's light water cooled/moderated reactors was 34.4%.

Since that award, X-energy has completed the engineering and basic design of the nuclear reactor as well as advanced development of a fuel fabrication facility in Oak Ridge, Tenn., and is preparing to submit an application for licensure to the NRC. In April 2021, X-energy, Energy Northwest, and the Grant County Public Utility District agreed to support a demonstration of the Xe-100 in Washington state. Meanwhile Dow has apparently decided to buy four of X energy's 200 MW thermal (80 MWe output) modular pebble bed gas-cooled reactors for one of its Texas chemical plants. Over a decade ago, the U.S. had a program to develop a high-temperature reactor to provide high-temperature heat to the chemical industry. That program died because very cheap natural gas showed up. Although not described as such, X energy is the DOE's Next Generation Nuclear Plant (NGNP) program reborn with DOW likely owning some fraction of it.

DOW is the world's second largest chemical company (about 60% the size of Germany's BASF) with about $57 bln annual sales. Dow has several very large industrial sites each with multiple chemical plants requiring massive heat and electricity demands. In comparison, the largest U.S. A's largest utility (Exelon) has annual sales of about 36 billion dollars.

In December, the NRC accepted an application from X-energy's fuel subsidiary, TRISO-X LLC, for a proposed TRISO-X Fuel Fabrication Facility (TF3) in Oak Ridge, Tenn., and developed a 30-month review schedule targeting completion in June 2025.

On the other hand, China's first two-unit 250 MWt "small modular" HTGR power plant is already online. Both of its reactors feed a single turbine to produce 210 MWe. If that plant works out reasonably well, I expect the Chinese to order at least a dozen more because…

1. At that individual reactor heat output, there's almost zero risk of off-site consequences caused by some sort of accidental "melt down".
2. Ordering a series of them will establish real costs. A larger fraction of the total cost of an HTGR can be built in factories than with water cooled reactors which means that there's large potential to drive down costs.
3 Since their heat outputs match Chinese coal-fired plants, it enables the backfitting of 500 coal plants with nuclear heat sources. 500 coal plants times 6 modular reactors each works out to about 3000 modular reactors—which matches any definition of mass production.

I'd be a lot more enthusiastic about HTGRs if the USA's power reactor R&D experts were willing to embrace the US navy's willingness to fuel reactors with HEU (highly enriched uranium). If that ^{235}U oxide (or carbide) were to be diluted with/surrounded by thorium rather than ^{238}U, TRISO pellets made with it would "burn" longer & also render the reprocessing/recovery/recycling of its fissile-both its startup and subsequently inbred ^{233}U - both far more worthwhile and easier/cheaper to accomplish.

To demonstrate what that could do for us, here's the ABSTRACT of a paper written over four decades ago by the folks that had designed, built, operated, and tested Germany's HTGRs

(Teuchert et al 1979) before its ”Green” politicians won the war that they’d declared against nuclear power.

> *For the pebble bed high temperature reactor, a Th/U based closed fuel cycle is introduced which achieves a conversion ratio of 0.82 averaged over 30 years with a fissile inventory of only 1270 kg/GWe. It minimizes uranium ore requirements for some 2 generations. Secondly, a Th/U-prebreeder is introduced which produces U-233 for starting the installation of HTR-net breeder fuel cycle inventories. Its U-233 production per U_3O_8 is 2.3 times that of a LWR’s Pu production . Thirdly, an alternative of the closed thorium cycle is introduced which meets the demands of non-proliferation. No weapons grade uranium appears anywhere in the cycle. The plutonium in its reprocessed fuel is strongly denatured by the even isotopes Pu-240 and Pu-242 and there’s very little of it. All three cycles are economic. The technological feasibility of the fuel elements is largely ensured by the THTR element test experience. The detailed features of the cycles are outlined as far as relevant for their assessment (14 refs., 11 figs., 16 tabs).*

5.2 Light Water Reactors (LWRs)

Light (natural) water cooled/moderated reactors generate most the world’s nuclear power (Figure 49) – it’s become a locked-in technology (Cowan 1990).

Any nuclear reactor’s job is to house and control nuclear fission—the process where actinide atoms split forming new neutrons, two fission product atoms and releasing a great deal of energy. 100% of today’s civilian power reactors utilize uranium as fuel. That uranium is…

- first separated from everything else in the ore which typically represents well over 99% of it (“depleted” ore constitutes another radwaste because it contains virtually all of uranium’s still mildly radioactive decay daughters)…
- then converted to a gas to enable its enrichment during which most of its non-fissile ^{238}U (~80%) is discarded…
- then converted to uranium dioxide which is heat/pressure -sintered to make ~2 cm long, ~1 cm diameter cylindrical ceramic pellets which…
- are finally stacked up within hermetically sealed zirconium alloy tubes which are then pressurized with helium gas and sealed to make the roughly 100,000 individual fuel rods required by a full-sized LWR’s core.

Typically, ~250 such rods are bundled together to form ~14-foot-long fuel assemblies. Reactor cores typically contain several hundred such assemblies, which number depends upon its power rating.

Inside the reactor vessel, the fuel rods are immersed in the “light water” (H_2O) serving as both its coolant and moderator. Moderators slow down the “fast” neutrons generated by nuclear fission thereby enabling the chain reaction to be sustained with fairly low enrichment uranium fuel (LEU) - typically 3-5 % fissile ^{235}U with the rest being fertile ^{238}U)

Control rods containing a neutron-absorbing "poison" (e.g., cadmium or boron) are inserted into the reactor core to reduce the reaction rate or withdrawn to increase it[207].

The heat generated by fissile fission is conducted through the walls of the fuel rod tubes and transferred to that water which may or may not be allowed to boil depending upon which sort of reactor it is.

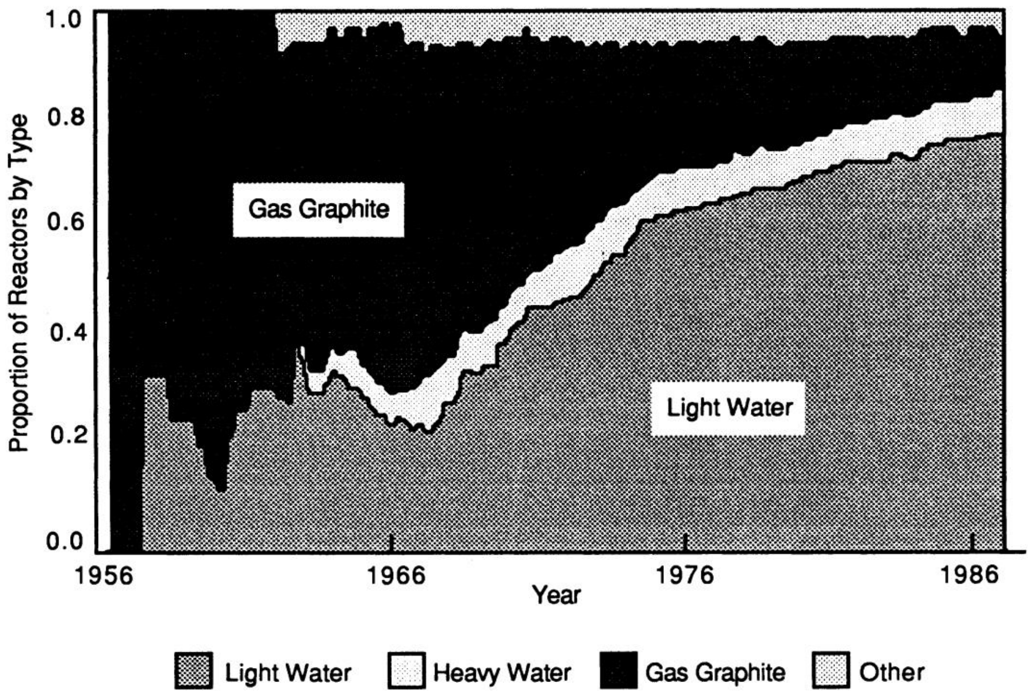

Figure 49 Commercial power reactor types, IAEA 1987 (gas graphite reactors were initially used by France & Great Britain because they could be fueled (for a relative shot time) with natural (not enriched) uranium)

There are two basic types of LWRs: Pressurized Water Reactors (PWRs) in which the normal (i.e., H_2O aka "light") water surrounding/cooling their fuel rods isn't allowed to boil (Figure 50), and Boiling Water Reactors (BWRs) in which it is.

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[207] Control rods & burnable poisons waste neutrons but required in discontinuously fueled (e.g., every 18-24 months) reactors. Such reactors must start out each of their "burn cycles" with excess reactivity (more fissile than required to reach criticality) which excess must be quelled (wasted) until it's been burned out.

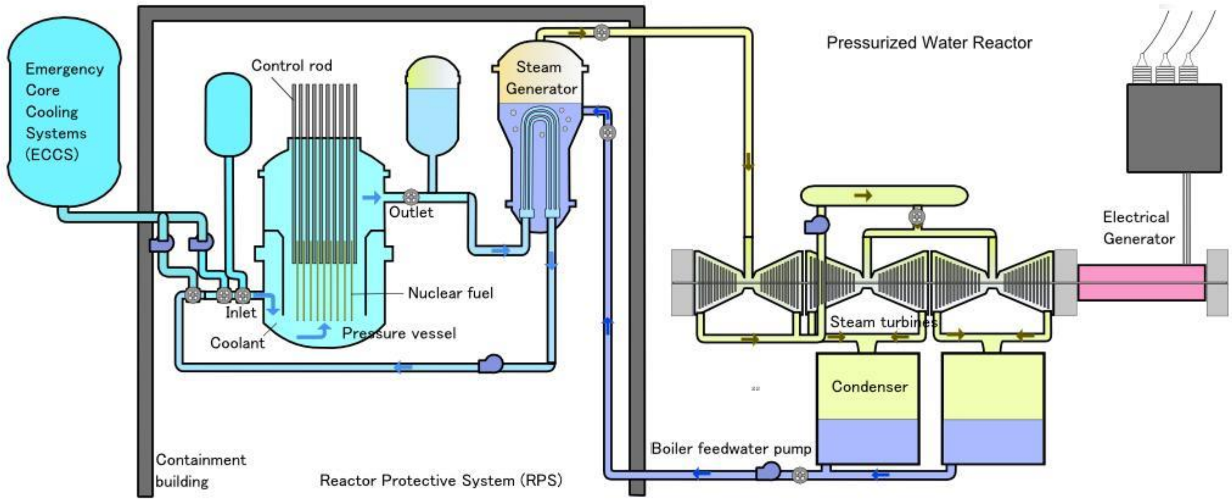

Figure 50: State of the art Gen III$^+$ PWR schematic[208]

They are otherwise similar in that: 1) their fuel rods consist of zirconium alloy tubes containing enriched (typically 3 to 5% ^{235}U) uranium oxide pellets; 2), they operate at very high pressures (>1000 psi) but low temperatures (~285-300°C); and 3), they "waste" many of the neutrons generated by fission"[209]. The latter characteristic refers to the fact that in light water moderated reactors, too many neutrons are captured by materials (water, zirconium, fission products, control rods, and "burnable poisons") other than the fertile ^{238}U comprising the bulk of their uranium, meaning that they can't "breed" nearly as much new fissile (in this case, ^{239}Pu) as they consume. Consequently, regardless of how small, modular, and "advanced" they might become, fueling any version of today's LWRs (e.g., NuScale's 60MWe SMR) would consume at least ~160

[208] Gen III and Gen III+ nuclear reactors are essentially Gen II reactors with evolutionary design improvements. These improvements are in fuel technology, thermal efficiency (slight), modularized construction, safety, and standardized design. Perhaps the most significant improvement over second-generation designs is the incorporation of passive safety features that do not require active controls or operator intervention but instead rely on gravity or natural convection to mitigate the impact of abnormal events. A downside is some of their "safety" improvements render them more difficult/expensive to build than they should be – GEN II reactors are already safe enough.

[209] 100% ^{235}U fission to begin with - a mix of ^{235}U & in-bred ^{239}Pu fission thereafter.

tonnes[210] of natural U/GWe/year, most of which, primarily ^{238}U, would be discarded during its fuel's U-enrichment preparation step[211].

5.3 Heavy water moderated reactors

While Great Britain and France were building their GCRs, the Canadians decided to build natural uranium fueled heavy water moderated reactors[212]. Their CANDU (CANadianDeuteriumUranium) reactors consist of a huge but low-pressure steel "calandria" tank

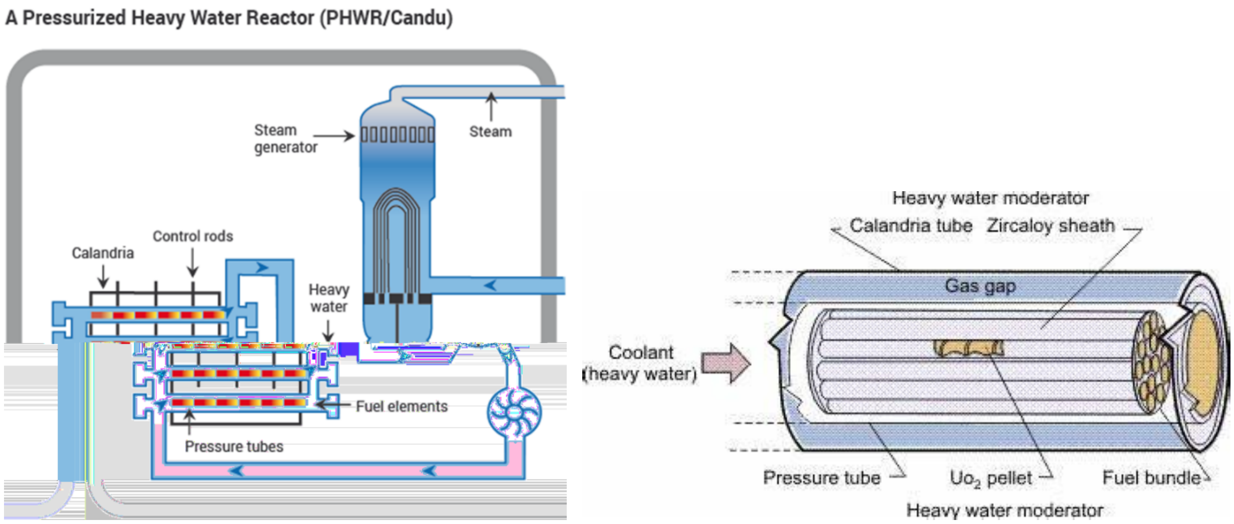

Figure 51 CANDU reactor[213]

containing its heavy water (D_2O) water moderator (not coolant). Its ~18-inch-long zirconium tube-clad-uranium oxide fuel rod bundles/assemblies are inserted into an array of stainless-steel

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[210] 160 tonnes/GWe-year is a low (optimistic) estimate of the amount of natural uranium (NU)required to fuel today's power reactors. According to Worldnuclear.org's website, the amount of uranium required to generate the world's 2676 TWh worth of power during 2019 was 68,240 tonnes which translates to 223 tonnes NU/GWe-year. This is largely due to the fact that it's cheaper to mine additional natural uranium than it is to better separate its isotopes. Economics is the single most reliable predictor of business-related decision making.

[211] Although most of the natural uranium (NU) discovered/mined/processed to run LWRs never ends up in their fuel, 100% of it must be converted to uranium hexafluoride – the gaseous form required by the world's isotopic separation (fuel enrichment) facilities.

[212] This was likely because Canada had lots of cheap hydropower to implement heavy water isotopic separation with. That's one of the reasons why Germany invaded Norway in WWII – Hitler's nascent nuclear R&D program needed the heavy water being generated at Norsk Hydro's electrical power/ammonia production plant.

“pressure tubes“ running laterally across the calandria tank[214] (see the right side of **Error! Reference source not found.**). Its pressure tubes are double-walled, ~4 inch wide zircalloy tubes with a “heavy”[215], non-corrosive gas (usually CO_2) between its walls to thermally insulate their contents from the surrounding calandria’s low (almost room) temperature heavy water moderator from the much smaller volume of high temperature/pressure heavy water run through them serving as the reactor’s coolant and heat exchange medium. The main advantage of its heavy-water moderator is lessened absorption of the neutrons sustaining its chain reaction which permits operation with natural (unenriched) uranium fuel and better fuel efficiency (more energy/gram of natural uranium). However, all else being equal a CANDU reactor’s core must be larger than a LWR’s because deuterium’s greater mass means that more moderating collisions are needed which translates to larger distances (more moderator) between its fuel rods. That’s the main reason for its multiple pressure tube-in-calandria design – a pressurized vessel containing the reactor’s moderator would be impractically heavy/expensive.

Natural uranium’s low ^{235}U (fissile) content also means that less of its uranium will be consumed before the fission rate drops too low which fact translates to a total actinide (“heavy metal” or HM) burnup of one-fourth to one-sixth that of a state-of-the-art, ~5% enriched, U-fueled, PWR (i.e., typ. 7.5 GW_t-day/tonne HM). However, a modern CANDU reactor’s automated fuel shuffling (moving) and/or refueling occurs within just one of its calandria tubes at a time meaning that it can be run continuously, not completely shut down for batch refueling. That means that it’s easy/simple/cheap to “breed” medical isotopes such as ^{125}Tc in CANDU – something that’s almost impossible to accomplish with the USA’s batch-fueled LWRs.

A CANDU’s moderator is at much lower temperatures than is that of other moderated reactors which means that most of its neutrons end up at lower energies and therefore are more likely to cause fission. That & the fact that deuterium absorbs fewer neutrons than does “regular” hydrogen means that CANDU not only can "burn" natural uranium but also more fuel efficient. Overall, CANDU reactors use 30–40% less mined uranium than light-water reactors per unit of electricity produced. That and the fact that its uranium does not have to be enriched means that its fuel is much less expensive to both make and “store” when it’s become “spent”. Again, CANDU’s purpose was to generate useful power without the enriched uranium which only the

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[214] Each of a CANDU reactor’s fuel tube bundles is about 0.5 meter long, weighs about 24 kilograms, has a diameter of about 0.1 meter and contains ~20 kilograms of uranium within thin-walled Zircalloy tubes. The Pickering fuel bundle is 92 wt% UO^2; its 8 wt% Zircaloy makes up its sheaths, endcaps, structural endplates, and tube spacers. Its structural material represents only 0.7% of its fuel bundle’s thermal neutron cross section. (see R37033.pdf (ipen.br)).

[215] A gas’s cooling ability is inversely related to its molecular weight because smaller molecules move more rapidly at any given temperature.

USA and USSR could produce at the beginning of the nuclear age. Finally, unlike the USSR, Great Britain, and France (and later, both Israel and India), Canada is "nice" and did not therefore employ its power reactors as "production" reactors of weapons-grade plutonium (>90% ^{239}Pu) and tritium.

5.4 Small Modular Reactors

There has been an immense amount of hype and considerable nonsense about Small Modular Reactors. When you are trying to solve the problems that have inspire this book, small is not beautiful , because there are strong economies of scale in nuclear power generation. Any "nuclear" solution that does not recognize this fact will be hopelessly wasteful. However, it is also true that we must take advantage of the order of magnitude improvement in both productivity and quality associated with assembly line manufacture compared to conventional on-site construction. What the world needs are Big Modular Reactors, the biggest reactors that can be factory built and transported to wherever they're needed.

A desire for any sort of "small modular reactor" (SMRs, including very small, "mini", and "micro" reactors) has been identified by several user and vendor nations. Many of the potential users are developing countries possessing small or no existing electrical grid and/or lots of remote regions facing a growth of domestic energy demand which could be satisfied with cheap-enough, small, simple, power plants. The vendors have responded with relatively small (under 300 MWe) light water reactor (LWR)[216], heavy water reactor (HWR aka CANDU), gas-cooled reactor (GCs) and liquid metal reactor (LMRs) based-concepts   (see SMR-Book_2018.pdf (iaea.org)). Furthermore, since half of the world's primary energy consumption goes to generating hot water, steam, or some other form of process heat, but only a small fraction of today's full-sized & generally isolated nuclear power plants can be so-used[217], "super safe" small reactors capable of providing both electricity and heat to nearby areas could play especially important future roles. High temperature gas-cooled reactors (HTGRs) are especially promising for the smallest of such applications because they could be relatively simple to both make and operate and could provide relatively high thermal efficiencies. The safety-related characteristics of both their graphite coated TRISO-type particle fuels and that type of reactors have been amply demonstrated by the USA's General Atomic, Peach Bottom and Fort St. Vrain facilities.

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[216] The US navy's most powerful reactor is the Westinghouse AW4, two of which power each of its Nimitz class aircraft carriers. It's an especially compact 550 MWt (roughly 180 MWe) "small modular PWR" that's fueled with enough "bomb grade" (~90% ^{235}U) uranium to run continuously for ~25 years.

[217] Most of the world's power reactors are sited too far from potential raw heat energy users to so-serve them.

The most promising such concept matching the "developing nation" criteria I've seen utilizes the CANDLE (Constant Axial Neutron flux, nucleoid densities, and power shape, moving region burning scheme originally proposed for liquid metal cooled fast reactors(a version of which is currently(?) being studied/developed by Bill Gate's TERRAPOWER nuclear startup. In a Candle reactor the burning region moves with a constant velocity along the core's axis from bottom to top or from top to bottom. At any given moment, that core can be roughly divided into three regions: (1) fresh fuel region (k_{inf} <1), (2) burning region (k if≥1) and (3) spent fuel region (k_{inf} <1). In a block or prism type HTGR in which the particles never move, enough burnable poison (for e.g., gadolinium) is used to adjust the k_{inf} of the fresh fuel initially subcritical. During CANDLE burn-up, neutrons leaked from the burning region into the fresh fuel region are absorbed by the burnable poison and the "hot: region therefore slowly moves into the fresh fuel region as its poison is depleted. Within the core's burning region, the depletion of fissile material generating the energy is accompanied by conversion of fertile material to new fissile material which generates some extra useful energy. The spent fuel region behind the moving burn region contains fission products and fissile depleted fuel. For a unique combination of core geometry and fresh fuel composition, there's an equilibrium critical condition where the moving (axial) velocity of the burning region is constant. Analytical codes for obtaining either equilibrium conditions or for simulating reactor start-up have been developed by Japanese researchers (Lleim et al.2020). However, as far as I know, no such reactor has ever been built largely because its fuel's cladding would likely have to be made of unobtanium.

Table 9 Small modular CANDLE HTGR concepts

	Core Size			fissile loading		Burnup	startup fissile	t fissile/GWt		
	height/vol	burn velocity	CR	g/MWD	W/cc	GWD/t	kg	@45%		
Th	2.9m/20.5m^3	0.080 cm/day	0.271	1.05	4.96	76.3	95.8	169.6		
U	4.1 m/29m^3	.0.113 cm/day	0.492	1.53	3.55	52.3	139.6	116.2		
both: 25 MWt . 3 meter diameter prismatic HTGRs that burn for 10 years with 700°C outlet/ 250 C He, 8% initial enrichment										
	TRISO kernel in graphite prismatic configuration, 8% initial enrichment									

Most of Table 9's figures were excerpted from another table within a nicely written paper by Liem et al 2008. It characterizes both thorium and uranium-based 25 MW_t gas cooled prismatic (not pebble bed)-type CANDLE SMR concepts.

Its conclusions are typical of all such comparisons of moderated uranium and thorium-based reactor concepts in that the latter would be significantly more fuel efficient and neither would be genuinely sustainable nor require under ~8 tonnes of startup fissile per GW_e[218].

[218] For example, 10 years' worth of 25 MW fission heat would require the fissioning of about 96.5 kg of a 234 grams/mole actinide [10*25E+6*3.15E+77/3.2E-11/6.023E+23*0.234]. Both SMR concepts require at least that much fissile in their initial fuel load.

Several first world nations have embraced a nuclear power model based upon factory fabrication of relatively small modular components that can be road-shipped for rapid on-site assembly thereby promoting prompt startup of the reactor's owner/investor's revenue stream.

At this point in time Canada is leading that charge. Its nuclear safety commission (CNSC) has completed the first phase of a vendor design review of ARC Nuclear Canada's, ARC-100, small modular reactor. It is the third such concept to complete the first phase of the CNSC's regulatory pre-licensing review other two being Terrestrial Energy's Integral Molten Salt Reactor and Ultra Safe Nuclear Corporation's MMR-5 and MMR-10 high-temperature gas cooled reactors.

ARC is developing the ARC-100, a 100 MWe integrated sodium-cooled fast reactor with the same sort of metallic uranium alloy core proposed for GE Hitachi Nuclear Energy's (GEH) three times more powerful PRISM LMFBR. Both designs are based on the Experimental Breeder Reactor-II (EBR-II) integral sodium-cooled fast reactor prototype operated at the USA's Argonne National Laboratory from 1961 until 1994. As was amply demonstrated by the EBR II's operators almost forty years ago, the ARC-100's pool-type design should be "walk away" passively safe meaning that it won't meltdown even if some sort of disaster causes complete power loss to the plant's site (that's what caused Fukushima's meltdowns). In addition, like GEH's PRISM in principle it could be fueled with the nuclear "waste" produced by today's power reactors, and its 20-year refueling cycle would increase "proliferation resistance".

I used to think that Canada should become the USA's biggest & newest state. I now feel that the USA should become Canada's biggest province.

5.5 The drawbacks of today's nuclear fuel cycle

The International Atomic Energy Agency's (IAEA experts see the most optimistic global electricity , not total energy, market share for nuclear circa 2050 as ~5 percent, down from 10 percent today with greater relative declines in US and European ("Western") markets. That constitutes institutional failure.

Figure 52 depicts what's been happening; i.e., with the exception of China no big country is generating more nuclear power than it did twenty-five years ago and its fractional contribution is dropping.

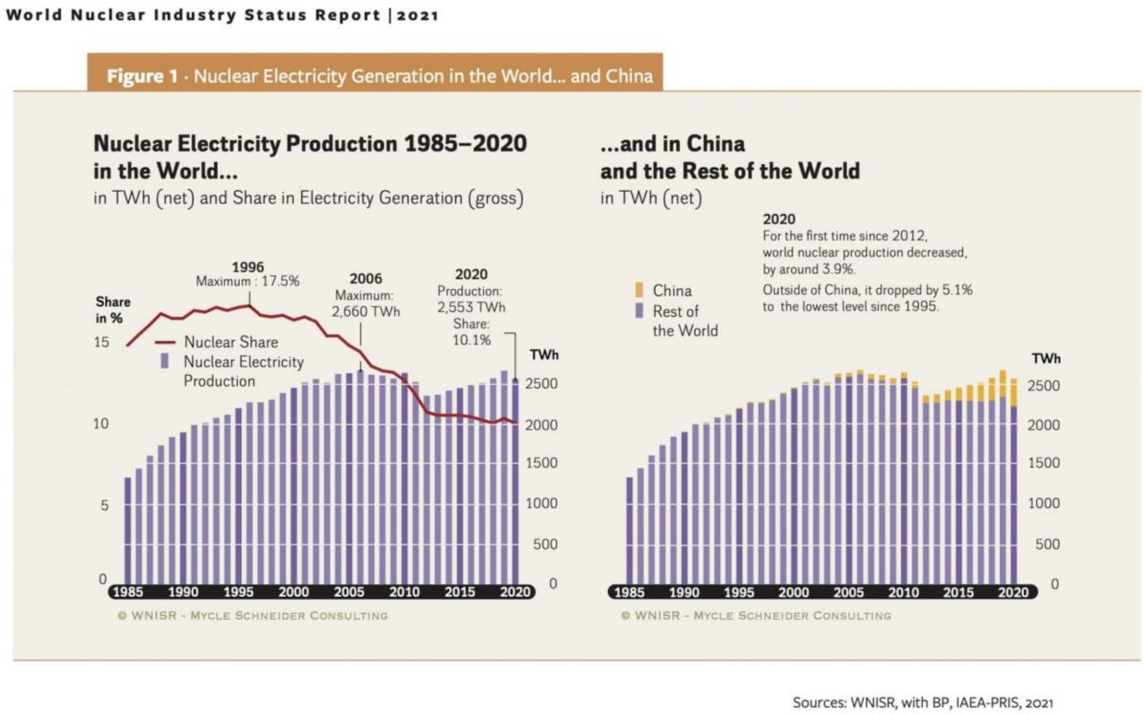

Figure 52 Fractional and total world-wide nuclear power.

Igor Pioro et al recently identified three undeniable factors that have contributed to this stagnation (Poiro 2019):

- The Chernobyl and Fukushima reactor accidents. The problem wasn't so much the damage they caused, but the costs generated by the responses to them which were enough to bankrupt even the most deep-pocketed owners and operators. Both public & bureaucratic panic increased licensing times, design costs, and the cost of providing extra backup power and cooling systems for both existing and proposed power plants.
- The massive rise of unconventional oil and gas production. Thanks to widespread adoption of its "fracking" technology, the United States is now able to resume exporting some relatively low-cost petroleum and natural gas. That technology has undermined worldwide nuclear industry sales by rendering its power plants noncompetitive in energy-only[219] based power markets where cheap natural gas has temporarily become available.

[219] The USA's deregulated electricity markets/grids (e.g., ERCOT) sell power generated by a plethora of suppliers ("all of the above") who to be competitive, must submit bids based upon what it would incrementally cost them to produce another unit of electricity during the period in question - typically the next 15-60 minutes (i.e., "the variable cost of production", not total production cost). That business model devalues reliability which effectively rules out long term planning.

Widespread switching to gas from coal has reduced CO_2 emissions, lowered generating costs, reduced pollution, and increased efficiencies. Fracking has also caused a good deal of damage to brittle-built structures due to earth subsidence and anthropogenic earthquakes [Earthquakes Are Jolting the Netherlands. Gas Drilling Is to Blame. - The New York Times (nytimes.com)]

- Loss of confidence in project completion costs have led to the bankruptcy and/or reorganization of three of the Western World's biggest nuclear reactor vendors—the USA's Westinghouse, France's Areva, and Canada's AECL. Today's capitalistic investment markets demand short-term guaranteed returns and low risks, which its nuclear projects can't provide unless they get the same type and number of subsidies (e.g., enforced power purchase agreements and guaranteed prices) that have sparked explosive growth of the world's wind and solar power industries.

A fourth issue almost never mentioned by the nuclear industry's champions is the raison d'etre of this book, i.e., that neither its existing large nor most of its proposed SMRs could address the future's energy-related conundrums - that is to say, provide our descendants with at least 20 TW's worth of clean (no "greenhouse gas" (GHG) emissions) power indefinitely.

In other words, the most important drawback of today's nuclear fuel cycle is that it is neither sustainable nor renewable (i.e., fuel limited).

For example, a prominent champion of anything nuclear recently opined that "*we must be nice to Canadians, given just one (of its) mine(s) has enough U to run us at 100% nuclear for >1000 years, even without breeding*"

He was referring to a particular mine, …"*McArthur River, which sits atop the world's largest high-grade uranium deposit, estimated to contain more than 400 million pounds of uranium oxide!"*).

This is an example of the sorts of gee whiz, technical sounding, pronouncements that always prods me into doing a bit of ball parking to put it into perspective.

GOOGLing tells me that the world currently generates about 2700 TWh/year's worth of nuclear power which represents about 5% of its/our total raw energy demand (~580 exajoules/a)

EXCEL translates that to 296 GW_e's worth of steady-state nuclear power.

More GOOGLIng reveals that each GW_e-year of LWR power (or that of any other of today's burner-type reactors, real or imaginary, full-sized or "small", advanced" or primitive, requires the mining/refining/enriching of about 200 tonnes of natural U (NU)

Since there's 2200 pounds/tonne, EXCEL also says that 400 million pounds of NU would feed just today's reactors for 3.06 years

Finally, it tells me that a more-of-the-same-implemented nuclear renaissance big enough to totally power today's world – not 2100 AD's hopefully bigger/richer/fairer and therefore more energy-needful world, would consume 100% of Canada's super mine's anticipated uranium resource within ~55 days.

A second drawback is that a breeder-based fuel cycle would greatly reduce the amount of long-lived actinide wastes, particularly plutonium and minor actinides destined to end up in some sort of repository - especially if it's fueled with thorium rather than uranium. Since a breeder-based closed fuel cycle would "burn" (reduce to fission products, most of which would soon become non-radioactive) almost all of the actinides fed into them as fuel, it would reduce its reactors' natural actinide fuel consumption and raw radwaste volumes by a factor of about 100. The initial radioactivity of such waste would be about the same as that produced by a light-water reactor, but would "cool off" much more quickly because it would contain far less residual transuranic isotopes.

A recent report (Poiro 2019) does a fine job of summarizing the characteristics of today's power reactors along with some of the improvements that the future's reactors must possess. That review points out that…

The next generation of nuclear power plants should be based on new designs—not just old ideas that have been rehashed yet again—to achieve the eight requirements. And these new designs must be better than "safe enough" or "safer than coal"; they should feature walk-away safety that precludes large accidents, core meltdown, and possible radiation releases, as well as the potential for weapons proliferation. The designs must produce electricity as cheaply as natural gas and with efficiencies like those of CCGTs—better/higher than 45 percent. Any new design must have broad public and regulatory acceptance and be capable of rapid licensing.

And it should go without saying that the next generation of nuclear reactors must provide for real, worldwide carbon-dioxide reduction without needing "carbon credits" or "offsets" to compete.""

However, that report doesn't point out that the most important features of any such future nuclear fuel cycle is that it is both 50-100 times bigger than today's and genuinely "sustainable".

A non-renewable resource (aka finite resource) is one that cannot be readily replaced by natural means quickly enough to keep up with consumption. Fossil power/energy is non-renewable because Mother Nature's fossil fuel-making reactions are many orders of magnitude slower than is the rate at which we humans currently consume them.

For example, every year the Earth's plant life "fixes" about 7.8E+13 kg of atmospheric carbon ~99.9% of which is oxidized back to CO_2 and returned to the atmosphere soon after those plants die (Ableson 1975). On land the majority of the ~0.1% that isn't so-oxidized mixes with the underlying soils' clay fraction and eventually forms high-organic content "black" shales where it then gradually is converted to a combination of humic acids, kerogens, graphite, coal, natural gas, and petroleum.

Scientists estimate that 50-80% of the Earth's oxygen production comes from the ocean primarily from oceanic plankton — drifting plants, algae, and some photosynthetic bacteria. One species, Prochlorococcus, the Earth's smallest photosynthetic organism, apparently produces up to 20% of the oxygen in its entire biosphere –more than all of it's the tropical rainforests combined.

When everything is in equilibrium, roughly the same amount of CO_2 is generated by the decomposition of oceanic photosynthesizers as was absorbed by them when they are alive. That CO_2 then finds its way back into the atmosphere establishing a steady state carbon cycle. However, when the bottom of the ocean becomes anoxic for some reason, some of which are anthropogenic (e.g., over-fertilization of river water entering it), a substantial fraction of the surface water's planktonic and larger organic matter becomes buried in anoxic muds and eventually converted to the same fossil fuels currently under continental soils.

This is particularly problematic when the decomposition of algal blooms consumes oxygen faster than it can be replenished creating large hypoxic "dead zones, because the oxygen levels are too low to support most marine life."

~99.5% of the roughly 2 % of such captured organic that eventually ends up as petroleum remains tightly bound within lithified sand/mud/clay shales.

Consequently, Nature's overall petroleum-type fuel carbon production rate is about 1.56E+9 (7.8E+13*0.001*0.02) kg/year of which ~7.8E+6 kg is as easily/cheaply recoverable as was Saudi Arabia or Texas's petroleum several decades ago. Mankind currently consumes (mostly by burning to CO_2 plus water vapor) about 93 million barrels of petroleum per day which translates to about 3.7E+12 kg of carbon (='s 13.6E+12 kg CO_2) per year which mostly ends up in the atmosphere: in other words, we're burning petroleum ~475,000 times faster than Mother Nature is creating it.

"*It is hard to know which is the more remarkable - that it took 600 million years for the Earth to make its oil, or that it took 300 years for us to use it up.*"

M. King Hubbert

A genuinely sustainable nuclear renaissance could not be implemented with NuScales[220] or any other "advanced" burner/converter-type reactor[221] because the uranium industry's own official

[220] NuScale is a scaled-down Pressurized Water Reactor small enough to allow natural circulation to handle its shut-down decay heat - no AC power would be required to circulate enough cooling water to keep anything from melting

estimate of all affordable (in that context) “proven”, “inferred”, and undiscovered uranium resources” adds up to only ~18 million tonnes (Redbook 2014). Generating 2 kW’s worth electrical energy for 11.2 billion people with today’s converter/burner-type reactors, “advanced” or otherwise, would consume 100% of the world’s “affordable” uranium within about four years [1.8E+7 t/ (22,000*223 t/GW$_e$/yr = 3.65 years].

The realization of Weinberg and Goeller’s utopian (but possible) future can happen only if the world’s decision makers finally decide to first develop and then implement an appropriately scaled (big enough) genuinely sustainable, nuclear renaissance and then see to it that untrammeled human nature does not turn that/their project into yet another of the interminable cost-plus nuclear boondoggles described in this book.

People championing “advanced” burner/converter reactor-implemented nuclear renaissances do so based upon immediate economic considerations (are trying to “sell” something) & wishful thinking rather than engineering or scientific data, i.e., we are assured that sufficiently cheap uranium will inevitably be discovered somewhere when the definition of “affordable” rises beyond today’s upper limit, <$260/ kg. For example, if a ten-fold price increase would indeed unearth 300 times as much uranium (Deffeyes & McGregor 1980)[222], a conventional light water

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down. Since NUSCALEs are apparently almost up-and-ready to go and a half dozen of them *might* be able to replace a medium-sized coal fired power plant’s boilers, they could and are being, (see https://k2radio.com/nuclear-reactors-may-replace-aging-wyo-coal-fired-generators/) characterized as a convenient, cleaner-than-gas, “bridge to the future”. I say “might” because they would be generating ~285°C, not >500°C steam. Steam turbines are driven by the ”wind” generated by permitting high pressure steam to expand with them. They constitute a part of a closed “Rankine” cycle in which so-expanded steam is condensed and then turned back into high pressure steam again via more heat input. The turbines of a fossil-fueled steam plant are typically designed to work with 500-600°C steam. In almost all such facilities several turbines configured for high, medium, and low-pressure steam are arranged sequentially to optimally convert their respective input steam’s pressure to rotational energy. The Carnot efficiency of a “perfect” heat engine running between 550°C and 35°C is about twice that of one operating between 280°C and the same steam-condenser low temperature. This suggests that straight-across substitution of mini-LWRs for a coal plant’s water boilers isn’t apt to work very well unless its turbines are also replaced. On the other hand, a molten salt (MSR) or high temperature gas cooled reactor (HTGR) could produce the same sort of steam that the power plant was originally designed for.

[221] In this context, “burner” means a moderated (slowed neutron) reactor primarily powered by the fissile isotopes - usually ^{235}U - within “fresh”, not recycled, uranium-based fuel assemblies. Most such reactors also “convert” some (but not enough) of the fertile isotope(s) (e.g., ^{238}U) accompanying that fissile to additional fissile (e.g., ^{239}Pu) some of which also burns before the fuel becomes no longer able to support fission (“spent”). Since only about 0.2 % of the Earth’s natural thorium and uranium fuel resources is fissile, “burners/“converters”, regardless of how “advanced” they are do not represent a sustainable solution to humanity’s energy-related issues (see Figure 55).

[222] Kenneth Deffeyes was another geologist who worked with M. King Hubbert at the Shell Oil Company’s research laboratory and then became a Princeton University professor. He authored the book, *Beyond Oil: The View from Hubbert's Peak*. His and McGregor’s rule-of-thumb was that a doubling of the effort/expense devoted to uranium recovery would increase the amount so-recovered by an order of magnitude (factor of ten).

reactor -based, 22 TW_e, nuclear renaissance could be fueled for several centuries before the cost of its fuel source (i.e., natural uranium – NU) exceeded that of coal-fired power plants ***if*** the price of coal were to remain the same as it is now. Unfortunately, I see no proof that Mother Nature's uranium distribution follows that relationship, which, in turn, renders such

Table 10 Average uranium concentrations (parts per million) in ores, rocks, and waters (Ulmer-Scholle 2018)

Material	Concentration (ppm U)
High-grade orebody (>2% U)	>20,000
Low-grade orebody (0.1% U)	1,000
Average granite	4
Average volcanic rock	20 – 200
Average sedimentary rock	2
Average black shale	50 – 250
Average earth's crust	2.8
Seawater	0.003
Groundwater	>0.001

assurances unconvincing (see Höök &Tang 2013). For example, the uranium industry's latest (2018) Redbook's fuel resource figures do not support that contention, i.e., plots of its $\log_{10}$(resource size) vs $\log_{10}$(cost) data possess slopes of from 1.10 to 1.25 depending upon whether the resources are "identified", "reasonably assured", or "inferred" - Deffeyes & McGregor's rule of thumb implies a slope of 2.477 ($\log_{10} 300/\log_{10} 10$).

If Professor Deffeyes' conclusions are indeed right (Deffeyes 2005, p 147) then it would be *theoretically* possible to "power the future" (i.e., continuously generate ~22 TWe) with LWRs fueled with the uranium within the Earth's relatively U-rich & plentiful sandstones & '"black shales" (e.g. ~10^{15} tonnes) for > 10,000 years. However, doing so would require the mining/processing of far more such rock (~72 vs ~0.36 billion tonnes) per year than would utilizing their uranium to fuel breeder-type reactors. To put the former figure into perspective, 72 billion tonnes/yr is thirteen times Mankind's current coal production rate suggesting that that particular "nuclear alternative's"' environmental impact would be thirteen times worse than is coal's now. (Homework questions 23-25 deal with this issue.)

On the other hand, a breeder-based nuclear power system would be renewable because it would be easy/cheap to fuel it with the natural actinides within such shales, sandstones, and coal bed ashes for much longer than Homo not-not-so Sapiens is apt to exist – for at least another million years.

The contention that we simply haven't yet bothered to look hard enough for uranium (and/or thorium) is also questionable because unlike most of the mineral resources we seek, natural actinides are invariably accompanied with enough sufficiently radioactive decay products to be easily detected/discovered with a cheap, portable, meter.

The Earth's total surface area is about 510 million square km, ~29% of which is land. Assuming a rock density of 2.8 g/cc the mass of land-sited crustal rock to a depth of 1 km is about 4.14E+17 tonnes. Since such rock contains an average of 2.8 ppm uranium, the total mass of "accessible" uranium in it comes to about 1.16E+12 metric tonnes or ~64,000 times that currently deemed "affordable" by the experts running today's burner/converter reactor-based nuclear fuel cycle. We're already digging deeper than one kilometer for oil, gas, gold, and diamonds.

The real problem is that most of the world's uranium is in low grade (~10-200 ppm) deposits (shales, phosphate rock, etc.), too expensive to mine/process to feed an inefficient commercial nuclear fuel cycle.

Another commonly made/heard assertion, that the "reprocessing" of today's ~240,000 metric ton (total actinide) accumulation of spent LWR fuel could address their fuel limitation issues is also wrong[223]. It takes the plutonium within about six spent LWR fuel assemblies to make one "MOX" fuel assembly and that process can only be done once because those reactors degrade "reactor grade plutonium" to "crap grade plutonium" that cannot be further burned in the same type of reactor (too little fissile & too much ^{240}Pu). This means that the maximum such fuel supply enhancement would be about 17% (1/6). MOX fuel is also relatively expensive to make and dangerous/bothersome to both use (too radioactive) and dispose of which is why most independent reviewers (Garwin 1999) and the owners of all US electrical utilities have concluded that such reprocessing isn't worth doing.

Let's go through another example: A 2007 analysis of the pros and cons of reprocessing concluded that a US built reprocessing plant would cost about $50 billion and its operating cost would be $1000–3000 per kg of spent fuel processed (Bollgren 2007).

Ignoring build costs and assuming a $2000/kg spent fuel processing cost, making 1 kg of fuel for a reactor-grade plutonium-based, MOX fuel would cost about $12,000 (6*2000). Assuming 4.5% enrichment and 0.0015 tails (^{235}U) discard (21%), making one kg of NU-based fuel would require ~8 kg of NU [0.045/(0.0071-0.0015)]. The current cost of NU is about $62/kg which makes the U in a kg of such fuel worth about $498. Doubling that figure to account for its

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[223] Appendix I goes into the hows and whys of reprocessing.

enrichment cost, one kilogram of that fuel's initial "heavy metal" (actinides) comes to $996 or ~8% that of a MO_x-based fuel.

The bottom line is that the reprocessing of spent light water reactor fuel makes economic sense only if the so recovered actinide(s) fuel breeder-type reactors[224]. That's why the UK recently decided to shut down its Sellafield site's $2.3 B Thermal Oxide Reprocessing Plant (Thorp) just 24 years after it had first started up. During that time, its workers had processed 9331 tonnes of used nuclear fuel generated by 30 customers in nine different countries all of whom have apparently decided that doing so was no longer worth paying for[225]. That much spent fuel likely contained enough recoverable fissile to start up 7 to 20 $_{GWe}$'s worth of genuinely sustainable breeder reactors but of course was not so employed. Therefore, that worthwhile opportunity was lost along with several thousand more of the Western World's better-paying industrial jobs.

DOE's recent history of multibillion dollar nuclear project costs and zero-accomplished products or services translates to infinite unit costs. Its insistence upon spending/wasting $billions on its Savannah River Site MOX LWR fuel facility when the USA's topmost decision makers refuse to commit to a sustainable nuclear fuel cycle, carbon tax, or anything that else that they consider either "too expensive" or "too controversial", is another of the reasons that it's become so difficult to convince "outsiders" that an appropriately scaled nuclear renaissance's power would be affordable.

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[224] However, even at $12,000/kg such fuel costs only about one half as much per kWh as does today's typical US coal.

[225] President Carter's much second-guessed decision to shut down the USA's commercial fuel reprocessing plants (the "Carter Rule") was probably as much due to the practical/economic considerations made in these paragraphs as it was to show the rest of the world how "serious" the USA was about reducing proliferation risk. At that time his government was trying to break the USA's addiction to foreign oil and the cost of producing electricity with nuclear and coal were essentially a wash. He isn't a dummy and knew enough about how the USA's military-industrial complex behaves to discount much – maybe too much - of what he was being told. He was & still is a genuine patriot willing to do things inconsistent with the USA's business models. For instance, The Federal Reserve has finally started to raise interest rates a year late and a few hundred basis points short. Current Fed Chairman Jerome (Jay) Powell's initial actions during the early days of the COVID 19 pandemic suggested that he was the right man for that job despite his lack of economic experience when Mr. Obama originally gave it to him. Unfortunately, while he was quick to address that crisis' ancillary issues, he was inordinately slow in moving to address its aftermath's almost inevitable "real" cost-of-living inflation. He and his current boss should have consulted former Treasury Secretary Lawrence Summers, who accurately predicted that… "*The Fed is charting a course to stagflation and recession. The past 60 years of economic history record few if any instances of inflation declining substantially without significant slowdown. Policymakers can either learn from that history or repeat it*." . Paul Voelker, the "radical" Fed Chairperson that Carter had appointed in 1979 much to his own political disadvantage, wasn't so bashful about doing what had to be done (raise the USA's prime interest rate) which of course then worked to the advantage of Carter's "pro-business" successor.

Oh well.

Because any genuinely sustainable nuclear fuel cycle would require the resumption of reprocessing in one form or another, I've written APPENDICES I & II to describe its history and what its future might look like.

Finally, fueling burner/converter-type reactors with uranium extracted from seawater – another oft-parroted contention - couldn't "save the world" either. The country most involved with testing/developing that what-if is Japan (see Tamada 2009 for his slide set and lecture). Dr. Tamada's slides begin with the contention usually prefacing such reports, i.e., that "*there's 1000x as much U in the oceans as on land*". That's incorrect because there's about 350 times as much U in "readily accessible" rock (the first kilometer of the ~3 ppm U crustal rock covering the earth's land surfaces) as within seawater (~1.33 billion km^3 of ~3 ppb U water). Dr. Tamada's presentation then goes on to describe his/Japan's pilot plant scale demonstrations and ends with the conclusion that a 68.7 by 15.2 km (1030 km^2) array of the most promising uranium adsorbent he'd tested (amidioxime-coated, irradiated polyethylene fiber "ropes" - it's still the "standard" material) would be able to collect enough uranium to fuel six of Japan's almost state-of-the-art LWRs (i.e., ~1200 tonnes U/a) at a "reasonable" cost.

His conclusion assumed that the adsorbent would trap ~4 g U/kg adsorbent per collection cycle, roughly three times more than was generally recovered during his demonstrations (Regalbuto 2014). A subsequent US study concluded that an "improved" version of that adsorbent would capture ~3.3 g U/kg adsorbent (Kim et al, 2014). In any case, because such adsorbent arrays must be bottom-anchored, experience significant wave action, and situated where natural currents quickly replenish the water surrounding them, almost 4 million km^2 of shallow (mostly coastal region) ocean bottom would have to be so-covered to fuel 22 TWe's worth of burner/converter-type reactors. Finally, anyone considering such schemes should expect the world's professional fishermen and "Rainbow Warriors" to raise heck – the former because their nets and lines would surely become entangled by so-situated gigantic synthetic "kelp beds", the latter because those arrays might also entangle/strangle seals, whales, and turtles.

Other than for those little technical details, mining the oceans to fuel business-as-usual reactors is a great idea[226].

On the other hand, coupling Dr. Tamada's uranium filters to a breeder reactor powered desalination plant's brine outlet could collect about 20 times as much uranium as its reactor

[226] This reminds me of the joke about the probably apocryphal newspaper reporter who asked Mrs. Lincoln, "*Other than that, how did you like the play*? ("Our American Cousin", Ford's Theater, Washington DC, April 14, 1865)

would consume[227]. This means that if the energy devoted to the future's water desalination systems represented >5% (1/20) of mankind's total needs, seawater sourced uranium could indeed fuel/power everything.

While it currently costs far more than it should to build state-of-the-art LWRs anywhere outside of Russia, China, and South Korea[228], even there they are intrinsically expensive (~3-4 $\$B/_{GWe}$) because they must safely withstand tremendously high pressures. Nuclear power could be much cheaper (and probably a bit safer) if its reactors were cooled with something possessing a much lower vapor pressure at their working temperatures.(Chapter 6 goes into greater detail about nuclear power's cost issues).

In today's electricity markets, an equally annoying drawback is that many civilian-type LWRs (especially PWRs) can't "load follow" very well[229], i.e., vary their output to match immediate demand. That didn't become a serious problem until lots of wind and solar facilities were built and politicians insisted that their "renewable" power must be used whenever available which encouraged the owners of nuclear reactors to shut them shut down whenever Mother Nature was being especially generous with wind and sunlight.

Chapter 6. Today's more promising breeder reactor concepts

Let's begin this section with a description of one of the USA's oft-mentioned, fully demonstrated, but not very promising breeder reactor concepts.

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[227] If the desalination plant processes twice as much seawater as it produces fresh water and its breeder-type power plant's heat to electricity conversion efficiency is 50%, it would take about 3kWh's of fission heat to process each cubic meter of seawater. 3kWh = 1.05E+7 Joules requiring 3.28E+17 U atoms which ='s 1.3E-4 grams ^{238}U. One m^3 of 3 ppb seawater contains 3 milligrams of U – about 23 times more than that reactor would have "burned" to run that fast .

[228] The reason for that is that those countries have more effective governments whose leaders plan/govern/lead instead of pandering to perpetually quarreling political "bases", special interests, and lawyered-up activists.

[229] The situation was different in France after it had decided to build enough big reactors to provide most - not the USA's ~20% - of its electricity. Consequently, many of its reactors can and do vary their outputs between 30 and 100% of their nameplate ratings (IAEA 2018). Boiling water reactors naturally possess better load-following capability because recirculation water flowrates determine their moderation (more water vapor in the core (i.e., less hydrogen) lowers reactivity).

The USA's Shippingport Atomic Power Station was the world's first commercial atomic power plant (~60 Mwe – it was really a medium-sized pilot plant) devoted exclusively to peacetime uses. It served as the US Federal government's cost-is-no-object (designed by the Westinghouse Electric company's Naval Reactor division & Bettis Laboratory) demonstration of nuclear power's potential value. Its reactor reached criticality on December 2, 1957, and aside from scheduled stoppages for core changes, continued to operate until October 1982.

The chief differences between it and the solid-fueled, pressurized water reactors (PWRs) currently generating most of the world's nuclear energy included:

It possessed a "seed and blanket" type core comprised of seed fuel rod assemblies containing "bomb grade" fissile (93% ^{235}U for its first two cores) surrounded by blanket rod assemblies containing its fertile isotope (99.3% ^{238}U - natural U for those core loadings). The rationale for building it that way was (and still is) that a "seed and blanket" core configuration is intrinsically more fuel efficient (less natural uranium "burned"/useful output) than are those in which the fissile is uniformly distributed within and therefore diluted by its fertile component.

To further enhance fuel efficiency, that PWR's power output was regulated by pushing its seed fuel assemblies in and out of the core – not by poisoning its coolant with boric acid and/or inserting neutron-wasting (poisoning) control rods into it.

Back in those days the USA's "nuclear" decision makers were willing to admit that natural uranium represents a finite resource that shouldn't be wasted.

Consequently, about one-half of the energy generated by its first two fuel cores was produced by the fissioning of in situ-bred ^{239}Pu - roughly the same proportion as that generated by Canada's NU-fueled CANDU reactors and ~50% more than that of the USA's state-of-the-art commercial light water reactors.

Shippingport's third and final core converted it to a light water moderated, thermal breeder reactor via switching to a ^{233}U (oxide) starting fissile and substituting natural thorium for natural uranium as its fertile isotope[230].

Post-shutdown analysis indicated that it had indeed generated about 1% more fissile than it had consumed meaning that, in principle at least, it might[231] be possible to implement a genuinely sustainable nuclear fuel cycle in that fashion.

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[230]The primary reasons for doing so are that 1) for thermal (slow) neutron collisions ^{233}U has a higher fission probability than does either ^{235}U or ^{239}Pu and 2) the number of fission neutrons per neutron absorbed ("eta") averages 2.27 for ^{233}U, 2.06 for ^{235}U *1.84 for ^{239}Pu.

That's unlikely to happen because the cost of achieving such a happy outcome would be prohibitively expensive/difficult.

Rickover's heroic optimization of PWR concept resulted in a construction cost per kilowatt about ten times that of conventional PWRs. One of the reasons for this is that it was extremely complicated. His little breeder's core's thirty-nine discrete fuel assemblies contained ~3 million Zircalloy clad thorium oxide-based[232] fuel pellets within ~17,300, four-distinct-type fuel rods (seed, blanket, power flattening blanket, and reflector). To further enhance its efficiency, those rods possessed 29 different sizes, shapes, & compositions (Olson et al 1999

Running it a sustainable manner would have also required an exceptionally expensive to both build and operate fuel recycling (reprocessing/refabrication) system. Thorium oxide-based fuel pellets are much more difficult to dissolve (reprocess) and then refabricate due to its much higher melting/sintering temperature) than are their UO_2-based counterparts. That's important because that concept would require <u>lots</u> of fuel reprocessing/recycling – at shutdown, the Shippingport breeder's fuel burnup[233] was about 29.7 GWt/tonne which corresponds to fissioning only about 3% of its fuel's "heavy metal".

That's why any thorium-based nuclear fuel cycle capable of "saving the world" (i.e., sustainable) will likely invoke molten salt reactors.

Fourteen years ago, Japanese scientists reported that inserting a parfait-configured core (central high fissile core region surrounded with fertile blankets on the top, sides, and bottom with another in the middle - total U/Pu oxide-containing length of each of its core assemblies' ~195,000 fuel cladding tubes would be 1.2 meters) within an otherwise-standard, full-sized 1.35 $_{GWe}$ GE Hitachi BWR would just barely make it a sustainable energy source (Takada, Miwa,

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[231] "might" because Professor Jeri Krepel points out that after its uranium had been recovered/recycled several times, enough neutron-hungry ^{234}U and ^{236}U would build up in it to reduce the reactor's breeding capability.

[232] That reactor's fuel pellets contained about twenty-eight times as much fertile ThO_2 (14 tonnes) as fissile $^{233}UO_2$.

[233] "Burnup" is a measure of the amount of heat generated per tonne of the core's total actinides ("heavy metals" or HM) per "burn cycle". For example, let's assume that a state-of-the-art, 33% heat-to-electricity efficient, 1 GWe PWR generates 25 tonnes of spent fuel per year of which 20 tonnes was initially uranium (mostly ^{238}U enriched to about 5% ^{235}U).Total heat generated per year =1/0.33*1E+9 J/s*3.15E+7 s/a =9.56E+16 joules1 GWd =1E+9 J/s*3600s/hr*24 hr/day = 8.64E+13 joules. Its "burnup" in the usual units = 55.3 GWd/tonne HM = 9.56E+16/8.84E+13/20. HM consumed/year = 9.56E+16/3.2E-11 J/fission *235 g/mole /6.023E23 atoms/mole/1E+6 grams/tonne = 1.17 tonnes. Fraction HM burned =1.17/20 = 5.8% (100% heavy metal (actinide) burnup (FIMA=1) corresponds to ~949 GWd/t.)

and Moriya 2009)[234]. Their concept's internal breeding ratio (number of fissile plutonium atoms left within both of its fissile zones and the blanket sandwiched between them) of its discharged fuel to those in its initial fuel, would be 0.93 and its overall BR including top & bottom blankets, 1.01 (assuming 100% efficient actinide recycle, anything over 1.000 is sustainable/renewable). Start-up of each GW_e's worth of such power would require 6.60 tons of fissile plutonium and 0.96 tons of minor actinides derived from existing LWR spent fuel plus about 85 tonnes of natural, recycled, or depleted uranium.

Unfortunately, the nuclear industry's decision makers apparently weren't interested - likely because they were satisfied with the status quo and attaining sustainability would have required both them and their political/regulatory masters to admit that changes in how their businesses operate would be required.

Most of the more promising ways of implementing a sustainable nuclear fuel cycle take advantage of the fact that "fast" neutron reactors naturally possess better breeding (fissile making) potential and would require less fuel reprocessing/recycling to become sustainable. Hejzlar et al's cross comparison of several potentially renewable/sustainable fast reactor concepts utilizing different coolants (heat transfer media – helium, two molten metals, and a molten salt) is the best-written such document I've seen so far (Hejzlar et al. 2009 – read it, it's free). Its sole weakness as far as I am concerned is that no fluid-fueled reactors (genuine MSRs) were being seriously considered back then. However, I'll begin with two concepts featuring slowed-down (moderated) neutrons in minimally modified state-of-the-art power reactors.

6.1 Heavy water moderated thorium breeder concepts

Another way to begin the implementation of a much more fuel efficient (but probably not sustainable) nuclear fuel cycle would be to modify the world's ~293 already-paid-for pressurized water reactors (LWRs) by replacing their UO_2-based fuel with ThO_2 -based fuel and substituting "heavy" water (D_2O) for the "light" water (H_2O) currently moderating and cooling them (Permana 2008). The reasons to expect better performance include: 1) deuterium doesn't consume (waste) nearly as many neutrons as does hydrogen via neutron capture (which transmutes it to deuterium); and 2) ^{232}Th can efficiently breed its fissile "daughter" (^{233}U) with moderated neutrons while ^{238}U can't. The reason for this is that a thermalized neutron's collision with a ^{233}U atom results in the desired outcome (fission) about 92% of the time whereas it occurs only about 65% of the time for the ^{239}Pu bred from ^{238}U[235]. The same changes would

[234] However, not everyone is convinced that their conclusion was correct - in any case it's only barely-"possible".

[235] The other ~10 and 35% of the time, the collision creates a non-fissile actinide isotope – i.e., produces ^{234}U or ^{240}Pu.

likely enable the World's 32 CANDU-type reactors (**Error! Reference source not found.**) to achieve breakeven fissile regeneration (Greenspan 2014, CANDU 2019, Nuttin et al 2012).

Unfortunately, the neutron economy of a heavy water moderated, solid fueled, thorium-based "breeder" whether CANDU or originally light water-based may not be sufficient after the proportion of ^{234}U and ^{236}U in their repeatedly recycled fuel reach their steady-state equilibrium concentrations.

This long-term reactivity insufficiency may require addition of makeup fissile. Since ^{238}U should be avoided in any thorium-based fuel cycle[236], only highly enriched ^{235}U, weapons grade Pu or ^{233}U produced in another reactor(s) should be used for that purpose. A reactor (i.e., low) grade Pu starting fissile may not be sufficient for complete transition to a thermal spectrum, isobreeding, Th-U fuel cycle.

However, one of the more sensible things happening now is that that concept has been reinvented and if eventually implemented should require considerably less NU/GWh and less frequent fuel replacement than do traditionally fueled CANDU reactors. Clean Core Thorium Energy (Clean Core) recently announced that the "*Texas A&M Engineering Experiment Station's Nuclear Engineering and Science Center has successfully fabricated the first fuel pellets of Clean Core's proprietary advanced CANDU nuclear fuel technology in partnership with the Idaho National Laboratory (INL)*". It likely consists of 20% enriched UO_2 (HALEU) mixed with or surrounded by thorium oxide but could possibly be metallic or nitride based[237]. In any case, switching to such fuel would retain the CANDU concept's virtues while permitting much greater burnup/fuel assembly and further decrease its "raw" uranium demand/consumption/GWh.

In general, thermal spectrum breeders are much more affected by fission product accumulation than are fast spectrum breeders because…

[236] ^{233}U fissile "denaturation" with ^{238}U would greatly complicate both reprocessing and waste management because the reactor would generate far more plutonium and "minor" actinides.

[237] That fuel has been acronymed "ANEEL". Clean Core, in partnership with Texas A&M University and INL, has completed the fabrication of the test pellets which are to be inserted into INL's Advanced Test Reactor by the end of 2022 or early 2023 for high burn-up irradiation testing followed by post-irradiation examination, and fuel qualification. While that's going on, Clean Core with a Canadian partner will complete performance and safety assessments and a demonstration irradiation of full-size fuel assemblies in a CANDU reactor. Although the initial test pellets use HALEU supplied by INL, Clean Core plans to use HALEU from US enrichment company Centrus Energy Corp that's to be built at Piketon, Ohio, under a three-year, $115 million cost-shared contract signed in 2019 with the DOE, Clean Core said it expects to have ANEEL fuel assemblies in use at commercial CANDU reactors by the end of 2025.

1) the ratio of capture (transmutation)/fission cross sections (probabilities) are higher for the fissile isotope(s)
2) fast neutrons can directly fission some of the fertile isotope(s) and thereby contribute to power output
3) "poisonous" (wasteful) FP neutron absorption cross sections (probabilities) are much higher with slow moving neutrons.

Let us do a simple comparison of a hypothetical fast breeder reactor with a hypothetical thermal breeder. Let's also assume that the discharge burnup in the fast reactor is 10% FIMA (fraction of the total number of fuel atoms fissioned) and in the thermal reactor 5% FIMA and that one fifth of that fuel will be replaced upon each refueling. Based on these assumptions, the average share of fission products in the fast reactor will be 4% after the fresh fuel loading and 6% at the end of irradiation cycle. In the thermal breeder, the same values would be 2% after a fresh fuel loading and 3% at the end of irradiation. Accordingly, the proportion of fission products increases by 50% during each irradiation cycle.

A necessary condition for breeding is that the ratio of fissile and fertile isotopes corresponds to equal fission and capture rates. The proportion of fissile isotopes in a fast breeder's fuel is about five times greater (slightly above 10%) than it is in a thermal breeder.

Figure 53 depicts the ratios of primary fissile and fertile isotopes in equilibrated closed Th-U and U-Pu fuel cycles (fast reactors are on its right side).

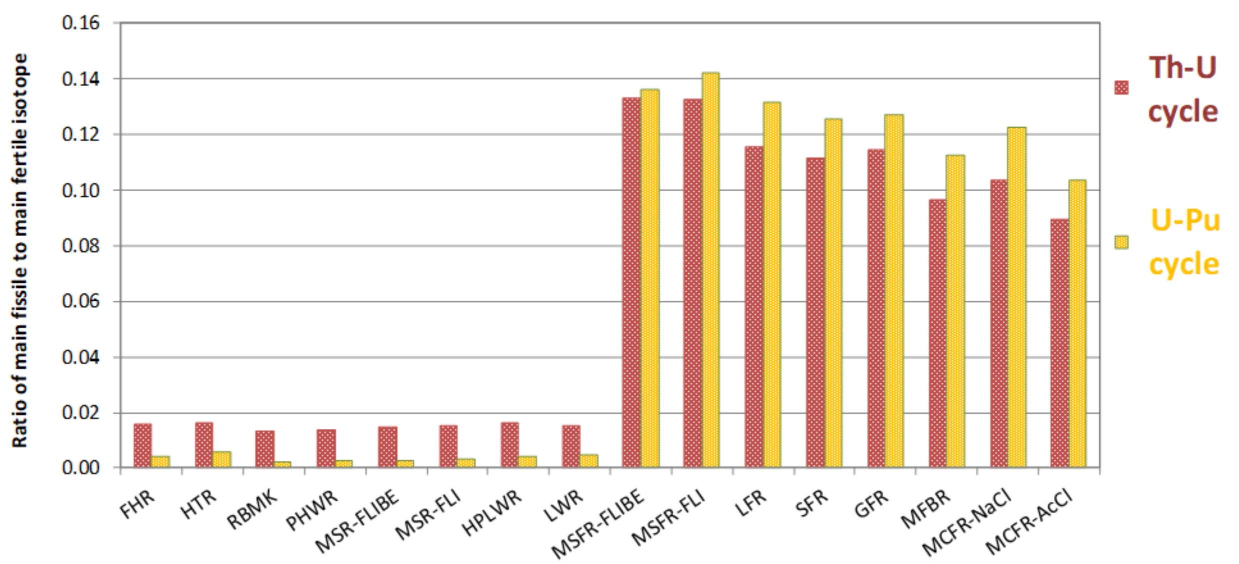

Figure 53 from Krepel & Losa 2019

Additionally, unless FP are removed continuously the amounts of fission products relative to the amount of the primary fissile isotope is considerably greater in thermal breeders rendering them more sensitive to both the absolute amounts and variation in the amount of fission products. To achieve the same relative share as in the fast breeder, the discharge burnup of a thermal breeder would have to be under 2% FIMA (Fissions per Initial Metal Atom) which translates to having to do a lot more fuel reprocessing/recycling.

This issue is exacerbated by the fact that fission products exhibit higher cross-sections for slow moving/thermalized neutrons. In classical LWRs (with the same 5% FIMA burnup and 1/5 core reloading scheme) the proportion of fission products increases between 2% and 3% percent mass wise accompanied by a similar reduction in fissile isotope proportion. In a breeder reactor, that proportion stays constant. The need for reactivity control is thus slightly lower for breeders than for burners.

Accordingly, another issue is that all of these concepts share the same weakness of LWRs and proposed High Temperature Gas (cooled) Reactors (HTGRs); i.e., in order to run for a fairly long time, their fresh fuel assemblies must contain extra fissile, meaning that its "beginning of life" (or BOL meaning initial) excess reactivity would have to be suppressed with control rods and/or burnable "poisons" both of which deliberately waste (absorb) neutrons that could otherwise serve to breed fresh fissile. Such waste translates to relatively little fuel burn up per cycle (~10 GWd/t), short refueling intervals, and lots of expensive/fussy solid fuel dissolution, reprocessing and fuel refabrication to achieve a conversion ratio ≈1.0.

To conclude, breeding with a Th-U-based fuel cycle and a heavy water moderator either in CANDU or heavy water PWR may be possible, but the question remains how high parasitic fission product absorption could be consistent with a practical frequency/amount of reprocessing. In any case, CANDU-type reactors featuring continuous refueling capability are apt to be superior because they don't have to be completely shut down to add or remove fuel which translates to more efficient steady state, not batch type, operation of the reactor and its attendant fuel reprocessing/recycling/waste management systems. That translates to a lesser fissile requirement and superior breeding because fewer neutrons are absorbed/wasted with control rods or burnable poisons.

6.2 Liquid metal fast breeder reactors (LMFBRs)

Another solid-fueled breeder reactor concept has already been implemented and more-or-less thoroughly tested in the US, France, Japan, and Russia (Cochran 2010). Russia's first LMFBR, the "BR-1", was designed in 1949 and commissioned at Obninsk in 1955 –four years after the world's first breeder reactor - the USA's "EBR I" - was first fired up and nine year's before its successor EBR II was completed at Idaho's National Reactor Testing station (NRTS then INEL/INEEL/INL). After that, two more Russian reactors, the BR-5 and BOR-60, were commissioned & tested, both there and at the Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad. These paved the way via an intermediate–sized (1000 MWt, 125 MW_e (most of its heat energy was used to desalinate Black Sea water, not make electricity) loop-cooled "BN 350", to Beloyarsk's first almost full-sized, pool-type, EBRII clone, the BN-600, which breeder reactor has been generating 600 MW of electricity since 1980. Based upon its success, construction of the still-bigger BN-800 began in 1984. However, after the USSR's genuinely disastrous 1986 bureaucracy-caused Chernobyl screw-up[238] had contributed to that socialist republic's subsequent collapse[239], the BN-800's construction was suspended until 2006, after which it was completed and brought up to a minimum-controlled power level for several years' worth of additional testing. In 2014, it was finally connected to the grid reaching full power (800 MW_e) by the end of 2016 thereby reclaiming Russia's ownership of the world's most powerful sustainable reactor.

[238] Which fiasco involved a totally different, much bigger, and rather primitive Russian-designed "RBMK" water cooled, graphite moderated reactor much like Hanford's first "production" reactors. As an early Generation II reactor based on 1950s technology built by a relatively poor country during the height of the cold war, Russia's RBMK design was optimized for speed of production over redundancy. It was designed and constructed with several design characteristics that proved dangerously unstable when operated outside their design specifications. The decision to use a graphite core with natural uranium fuel allowed for massive power generation at only a quarter of the expense of heavy water reactors, which were more maintenance-intensive and required large volumes of expensive heavy water for startup. Unlike Hanford's plutonium-producers, it was "dual purpose" – operated in a way (low fuel burnup/cycle) that generated electricity as well as "useful to Russia" bomb-grade plutonium, the latter being possible because, like Canada's CANDU reactors, its fuel is within pressure tubes meaning that individual fuel assemblies could be replaced without shutting down the entire reactor. Unfortunately, it was manned and locally managed by good team-playing, top down-managed, schedule-driven "operators" who inadvertently set up about the only situation that could have possibly caused that accident (Higgenbotham 2019). It wasn't really their fault though because their reactor's fatal weaknesses (large positive thermal coefficient of reactivity and graphite-tipped control rods) constituted state secrets too important to reveal to the lowly "operators" who became victims of excessive secrecy and lousy management. Boeing's current 737 Max travails and Japan's Fukushima-induced semi-seppuku demonstrate that that sort of management culture isn't unique to the USSR.

[239] Which, considering the world's currently deteriorating political/economic situation, is scary and may eventually prove fatal to billions of people if a technologically advanced nation's leader decides to initiate a "third world war".

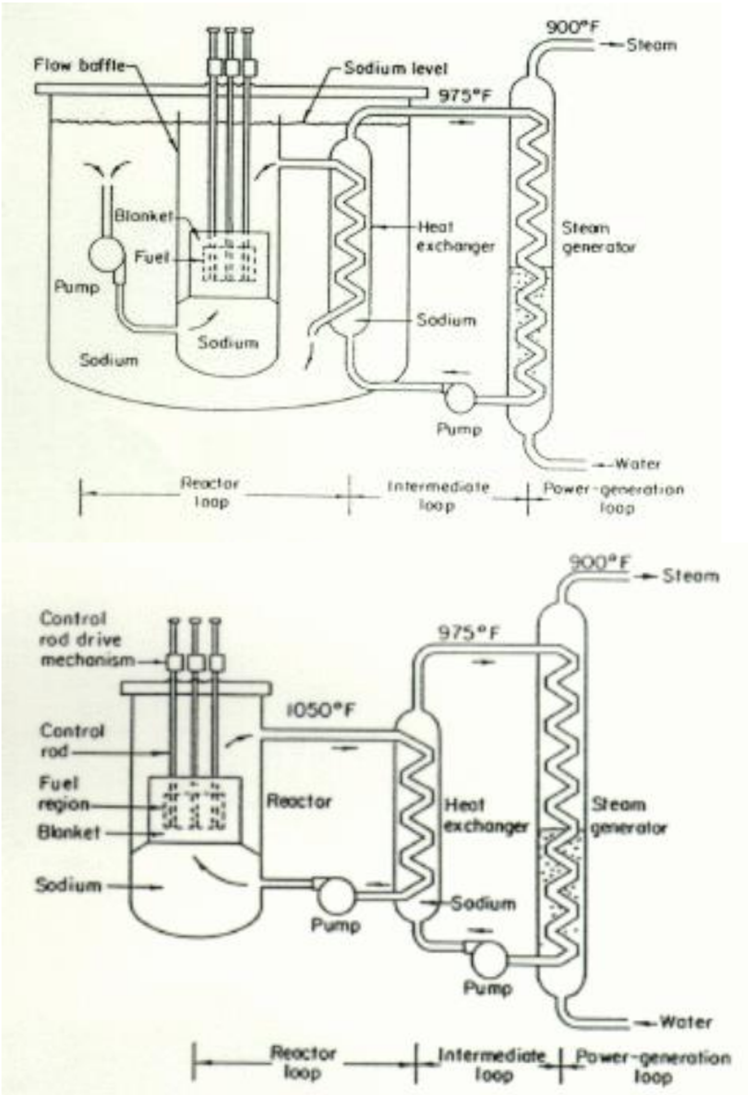

Figure 54 Pool (upper) and loop type LMFBRs

Overall, Russia's sodium-cooled fast reactors are like those "invented", developed, and utilized elsewhere. For economic reasons its BN reactors utilize enriched UO_2 fuel but were originally designed to use the same UO_2/PuO_2 mixed oxide (MOX) fuel assumed for most of the original French and U.S. designs.

Whether that or any of Russia's other LMFBRs were ever operated as breeders/suppliers of anything but weapons-grade plutonium is unknown to me but there's no reason to expect that they couldn't be operated in that fashion if it had made economic sense to do so at that time[240].

On the other hand, the USA's perpetual dithering about what nuclear reactors should be or do has left its last, best, hope of regaining the lead with its own, probably even-better designed[241] GE Hitachi PRISM ("Power Reactor Inherently Safe Module") concept LMFBR in nuclear purgatory for over two decades (Triplett 2012, Till & Chang 2011). By the time EBR-II was finally operating at its design power (60 MWt) circa 1969, the AEC's reactor division had developed a different vision for the USA's reactor program. Their idea was to choose one promising technology that could be achieved in the short term (Rickover's light water submarine reactor) and put all possible resources into implementing full sized commercialized versions of it as quickly as possible. That paradigm left no room for Argonne's tradition of developing forward-looking concepts. Like Russia's BN 600/800, GEH's s PRISM reactor is an upsized (311 $MW_{e)}$ version of the US DOE's pool-type EBR II[242], the main difference being that it would/did utilize metallic (not oxide)-based fuel. All of them would be inherently safe due to negative power reactivity feedback, large in-vessel coolant inventory, passive heat removal, below-grade siting, and exceptionally low (near atmospheric) operating pressure. The U.S. Nuclear Regulatory Commission has opined that, *"On the basis of the review performed, the staff, with the ACRS [Advisory Committee on Reactor Safeguards] in agreement, concludes that no obvious impediments to licensing design have been identified*." Unfortunately, none have been built and most of the people that had worked on developing both them and its electrometallurgical (aka, "pyroprocessing") fuel recycling system retired well over a decade ago (Till and Chang 2011).

However, a collaboration between Bill Gate's *Terrapower* nuclear startup, Bechtel, and GE Hitachi has recently (October 2020) given GEH's mid-sized breeder concept a huge shot in the arm. It's been rechristened "Natrium" and is to supply heat energy to a big molten salt storage tank – not directly power a close-coupled steam turbine Terrapower selects Bechtel as ear-news.org). Doing so would facilitate load following, energy storage, industrial process heat

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[240] Russia has never been rich enough to do things that don't make economic sense. Doing that now makes sense because demonstrating their reactor's sustainability would constitute a sales pitch unmatched by any other country's offerings.

[241] "Better" because it would use metallic, not oxide-type, fuel which should enable higher CRs and be simpler to reprocess/recycle.

[242] NRTS = National Reactor Testing Station (1949-1977); INEL= Idaho National Engineering Laboratory (I977-1997); INEEL = Idaho National Environmental and Engineering Laboratory (1997-2005); INL = Idaho National Laboratory (2005 -?)

applications, backing up a “clean” electrical grid’s intermittent power contributors, and boost maximum power output up to 500 MW_e for ~five-and-a-half hours. Many grids experience an almost 50% daily swing in power in the summer. Trying to follow that load with nuclear power alone would play hell with expensive-to-build energy sources that should be base loaded. We need at least enough internal storage to follow that demand – in other words, a system featuring reactors rated at 75% of peak demand that can swing from 67% output to 133% of the reactors’ average output. Furthermore, Natrium’s reactor wouldn’t need a super thick/expensive containment vessel, i.e., like a MSR it would operate at near atmospheric pressure. .

Because it separates the power plant’s nuclear and non-nuclear ”islands”, it should also simplify licensing and reduce construction costs (Forsberg 2021). Because its core is to be 90 feet underground and relatively small (“modular”), it could be passively cooled vial natural air convention (chimney effect) upon shutdown and thereby moot the post-shutdown cooling water boil-off issues responsible for Fukushima’s meltdowns and hydrogen explosions. That and the fact that it doesn’t have to withstand super high pressures (requires less steel and concrete) means that it should cost less to fabricate than a LWR - current projections assume an electricity cost of 5 US cents/kWh and a build cost of just under one $billion/per power plant (~$2.8/steady-state watt).

While many US communities balk at the idea of anyone building an experimental reactor near them that’s not been the case in Wyoming where many coal-fired power plants are scheduled to be shut down, each of which occasion would eliminate hundreds of jobs, raise electricity costs, and lower grid reliability . In November 2021 Natrium’s developers picked Kemmerer one of four such sites (others included Gillette, Glenrock, and Rock Springs) to house their first project. Once built it is to become part of Berkshire Hathaway Energy’s “Rocky Mountain Power” distribution system while generating ~250 permanent high-paying jobs. Its developers will establish training programs to help Wyoming’s coal miners and power plant operators transition from their current jobs to new roles at its nuclear facilities. Eleven months later they announced that they are looking at five more sites which when finished could provide reliable carbon-free power to customers across PacifiCorp’s six-state system. [Utah on the list for a possible nuclear power plant (sltrib.com)]

Best of all, there’s no question that Natrium’s reactor could be configured to breed (Triplett et al 2012) and therefore represents a way to generate genuinely sustainable power . That’s the key message presented in what I consider to be the best written recent compilation of the reasons for implementing this book’s nuclear renaissance, Barry Brook et al’s, “*Silver Buckshot or Bullet: Is a Future “Energy Mix” Necessary?”.*

In my opinion Bill Gate’s involvement is the chief reason that by the Fall of 2022 most of US DOEs nuclear laboratories - INL, Argonne, Oak Ridge, and Pacific Northwest National Laboratory (Hanford site) and their bevy of industrial and academic partners - Bechtel Power Corporation, GE Hitachi Nuclear Energy, Americas Pacifi Corp (a subsidiary of Berkshire Hathaway Energy), Energy Northwest, Duke Energy Carolinas, American Centrifuge

Operating, LLC (Centrus Energy Corporation), Global Nuclear Fuels Americas, Orano Federal Services, , and Battelle Energy Alliance, North Carolina State University, Oregon State University, and the University of Wisconsin - had all decided to get on Natrium's bandwagon TP_2022_Natrium_Technology.pdf (terrapower.com) .

Homework exercises 57-70 go through some of the details of a modern pool-type LMFBR.

6.3 General Atomic's solid-fueled, gas-cooled, fast reactor concept

… appears to be an especially attractive solid-fueled sustainable reactor concept. It's a "small" (500 MW thermal/265 MW electrical), modular, high temperature helium-cooled fast spectrum reactor (GFR) concept (Choi et al 2013). It is initially loaded with 43 tonnes of a low enrichment (6.1% or 2.6 tonnes of ^{235}U) uranium carbide-based fuel clad with a layer of silicon carbide. A great deal of physics modeling suggests that it would feature an ultra-long fuel cycle (32 years between fuel loadings), actinide burnup three times greater than a LWR's, and a compact size which should render it economically competitive with full-sized GEN III+ LWRs or the physically much bigger, unsustainable, graphite moderated HTGR concepts that DOE's lead NE lab has recently devoted much attention to. Since GA's modeling also indicates that there would be more fissile - primarily ^{239}Pu, ^{241}Pu & residual ^{235}U (total ~3.4 tonnes) in its fuel when FP buildup finally shuts it down than needed to restart it, coupling it with an efficient fuel recycling/reprocessing system should render its fuel cycle genuinely sustainable.

Figure 55 compares its first pass natural uranium fuel efficiency with that of several other proven and conceptual reactor concepts

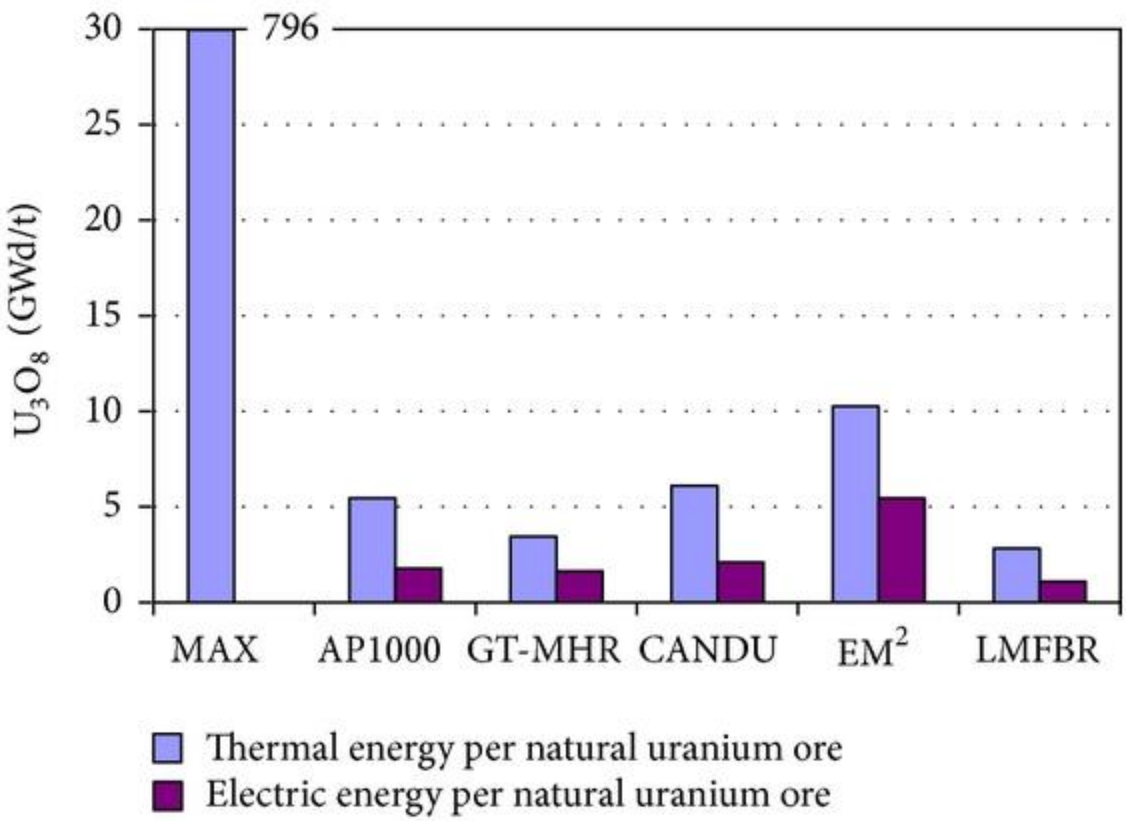

Figure 55 First pass natural uranium fuel efficiencies

Another feature rendering it especially attractive to an old chemist like me is that its spent fuel (uranium carbide mixed with misc. fission product carbides, etc.,) should be much easier to dissolve/reprocess/recycle than that of a conventional TRISO pellet-fueled[243], graphite

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[243] Tristructural-isotropic (TRISO) fuel consists of tiny spherical fuel particles (typically 500-micron diameter) comprised of a tiny kernel composed of UXn (usually UO_2 but may be uranium nitride or carbide) in its center, coated with four layers of three isotropic materials. From inside to out these coatings consist of a porous carbon buffer layer (to absorb fission products), followed by a non-porous inner layer of pyrolytic carbon (PyC), a physically strong layer of SiC to withstand gaseous fission pressure and give the particle more structural integrity, and finally another dense outer layer of PyC. TRISO fuel particles are designed to not crack due to stresses from differential thermal expansion and gaseous fission product pressures at temperatures up to and exceeding 1600°C and would therefore contain fission products in almost any accident scenario. Two of the reactor concepts based upon them are pebble-bed reactors (PBRs), in which thousands of TRISO fuel particles are dispersed within ping pong (salt cooled reactors) to tennis ball-sized (gas cooled) pyrolytic graphite “pebbles”, and “prismatic“ gas-cooled reactors in which the TRISO particles are embedded within large graphite blocks possessing channels through which the coolant gas (almost always helium) passes. All the major countries doing reactor research including the United States, Germany, France, Japan, and Britain, have put serious time and effort into developing high-temperature, gas-cooled versions of both types, e.g., South Africa’s PBMR. However, despite over five decades of such efforts, no genuinely successful grid-scale reactor utilizing them has yet been built.

moderated, HTGR (Bradley & Ferris 1961,Van Rooijen 2005).The reason for this is that while uranium carbide is also a hard, refractory (melting point 2350°C), ceramic like UO_2 it also purportedly readily reacts with hot water[244] to form easy-to-dissolve/process uranium oxide plus a mix of easily separated/destroyed gaseous hydrocarbons (mostly methane & acetylene).

Unfortunately, the EM2 concept has been even less "demonstrated" than were ORNL's MSRs meaning that there plenty of technical issues to address/resolve via performing potentially risky/dirty real-world experimentation before one could be built. In particular, uncertainties associated with fission product buildup during its >thirty-year fuel burn cycle combined with its marginal (low) excess reactivity throughout that time must be resolved. Other things requiring attention include additional transient and safety analyses to confirm the controllability of local excess reactivity and power peaking throughout its entire "burn" cycle.

Despite its rather high startup fissile requirement (about ten tonnes $^{235}U/GW_e$), in my opinion such work is worth doing.

The choice of which sort of reactor to develop/build/use will ultimately depend upon those characteristics deemed most important to future decision makers. For instance, if it remains verboten to have uranium enriched beyond 20% anywhere within a power reactor at any time, they would have to be much bigger (contain more uranium) than if higher enrichments were allowed. Similarly, if there can't be any sort of "bomb grade" fissile anywhere within them, reactor cores will have to be bigger and require more fissile to compensate for the fact that they cannot be surrounded by a blanket. If more-or-less continuous salt-seeking fission product removal (steady state operation) is deemed either too troublesome or too potentially "proliferative", it could be put off for a while by, again, increasing both the size of the reactor and the amount of startup fissile in it (breed and burn). Unfortunately, because startup fissile availability limits the rate at which a big-enough sustainable nuclear renaissance could be implemented, all of these alternatives unfortunately translate to just another way of kicking the same old can further on down the same old road.

6.4 Molten salt reactors

Over the long haul, it's likely that the best way to sustainably power the world with nuclear reactors would be to switch from solid-fueled to fluid-fueled molten salt (MSR)-type breeders[245].

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[244] That's not too surprising, acetylene – the fuel gas used in oxyacetylene welding/cutting – is made by adding water to calcium carbide.

[245] Professor Tom Dolan recently edited and wrote two chapters of a comprehensive (27 chapters, 58 authors, 840 pp) review of the status of molten salt reactor (MSR) research and thorium fuel utilization (Dolan 2017). Like my own nuke book, it's unfortunately too expensive for a poor old retiree like me to purchase but I've reviewed enough of it to have good reason to heartily recommend it.

The reasons for this were realized at the dawn of the nuclear age. Two of the Manhattan Project's "metallurgical laboratory's" Nobel Prize winners, Harold Urey, chemist, and Eugene Wigner (the Hanford reactors' engineer/physicist/designer), argued whether reactors should be considered mechanical engineering devices or chemical engineering devices. Both ended up agreeing with their then, junior colleague, Alvin Weinberg, that power reactors should be chemical devices in which liquids would replace solid fuel elements[246].

However, that never came to pass because 100% of the nuclear age's initial applications had to do with solving immediate military and political problems, not for sustainably powering entire civilizations. That and the fact that uranium turned out to be more plentiful than initially thought, established a business model that discourages anyone working in that industry to do the sort of thinking that inexorably leads to this book's conclusions/advice.

The reasons for Wigner, Urey, and Weinberg's conclusions have been enumerated many times since the 1940's one of the best-written of which is a freely-available ORNL report (Holcomb et al 2011). Those reasons are as follows:

• Since a molten salt reactor's fuel consists of a solution of already ionized (ionic) salts, it cannot be damaged by ionizing radiation. The lifetime of solid fuel assemblies is limited by radiation damage to both its fuel "meat" (e.g., solid UO_2) and whatever its cladding might be.

• Because molten salt reactors operate at temperatures well under the boiling points of their coolants, they have much lower operational pressures (water cooled/moderated reactors operate at >1000 psi, MSRs at under 100 psi) which translates to much-lessened explosion potential[247] and lower construction costs (less steel, concrete, etc.)

• Their higher operation temperatures (500–700 vs 250–300°C) translates to higher heat-to-electricity conversion efficiencies, more compact/cheaper gas turbines, less waste heat, and much

[246] This is ironic because starting in 1945 with Patent #2,736,696, Weinberg, along with Eugene Wigner, filed numerous patents on the light water reactor (LWR) technology that Rickover went on to power the United States' Navy's reactors with (a "little", cost-is-no-object, niche applications and then became dominant elsewhere. Dr. Weinberg never quit being honest, realistic, and great at explaining both the whys and hows of a nuclear-powered "Green New Deal", see Perry and Weinberg 1972, Goeller and Weinberg 1976 and Weinberg 1994

[247] For instance, a full-sized boiling water reactor (BWR) contains about 35,000 gallons of ~275°C water. The sudden release of that much superheated water would generate a ~0.04 kilotonne (40 tonnes TNT equivalent) explosion.

more efficient operation in water-stressed regions where air cooling might be necessary (Sienicki 2017)[248].

• It should be easier/simpler/cheaper to perform the "reprocessing" required to implement any genuinely sustainable nuclear fuel cycle because their fuel is already in solution and recycle would not require the refabrication of complex fuel assemblies. It would also facilitate the "burning" of the long-lived transuranic isotopes (TRU) currently rendering radwaste management especially "controversial".

• A "fast" (unmoderated) MSR's highly negative temperature reactivity coefficient translates to intrinsically safer operation and superior load following capability because as its heat exchangers extract more heat energy from its fuel salt, it produces more heat and vice versa[249].

• Because fissile can be added to a slipstream whenever it's needed, MSRs would not have to be started up with "excess reactivity" (extra fissile) which would then have to be suppressed with wasteful neutron poisons or control rods up until it had to be refueled. That would enhance its fissile breeding, efficiency, and overall safety[250].

• Molten salt reactors generally have thermal power to mass ratios 4 to 8 times higher than those cooled by sodium or helium, and are therefore more compact, which is why it's practical to design its core vessels and other high-temperature components to be replaceable.

Conceptually, the only things required of a molten salt reactor is that its fuel be brought to a critical configuration within its core and the resulting heat energy removed from it. Thus, they could be built many ways, which explains the diversity of concepts proposed during the past six decades.

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[248] One of the questions raised is, "*isn't the ~40 TW's worth of heat dumped into our environment by your nuclear renaissance apt to overheat Mother Earth*?" The answer is "no" because that figure represents only ~0.06 of one percent of the heat dumped upon Her by the sun. . More important is the fact that that's the only heat it would be adding, not eventually another ~50 to 100 times more due to a GHG effect.

[249] Pulling heat energy out of (cooling) a molten salt causes a volumetric contraction of 200-400 ppm/Centigrade degree depending upon its composition. Since the internal volume of the core tank containing it decreases considerably less per degree, salt cooling increases the amount of fissile within the core (fissile atoms become closer to each other) which, in turn, increases heat output and thereby constitutes a negative feedback mechanism. Conversely, removing less heat from the fuel salt reduces the reactor's power output by allowing its fuel salt to heat up.

[250] The reason for this is that gradually adding fissile (e.g., little pellets of $^{235}UF_3$) to a molten fuel salt slipstream would be both safe and simple. This characteristic would also render it easy/safe to initially fire up an experimental MSR. DOE's reactor gurus seem to want to do everything the hard way because it generates more stuff to study and be concerned about.

Heat removal is critically important for any powerful reactor. Many ways have been proposed to achieve it with MSRs including:

1. Pumping a non-miscible liquid coolant such as lead, mercury, or a volatile salt directly into the fuel salt to mix with and thereby extract heat from it (extensively investigated and deemed impractical)

2. Pumping a second molten salt or other coolant through pipes immersed in the fuel salt. The fuel salt would also be recirculated/pumped to enhance convective heat transfer.

3. Recirculating fuel salt through external heat exchangers

To date, only loop-cooled and integral-type[251] pumped fuel salt concepts have been considered sufficiently practical to justify further consideration (Holcomb 2011). "Fast" MSR (FS-MSR) concepts are more flexible in that they do not require moderating media within their core and can tolerate much higher fission product buildups which translates to lower fuel recycling/reprocessing costs.

Table 11 Properties of currently investigated MSR solvent salts

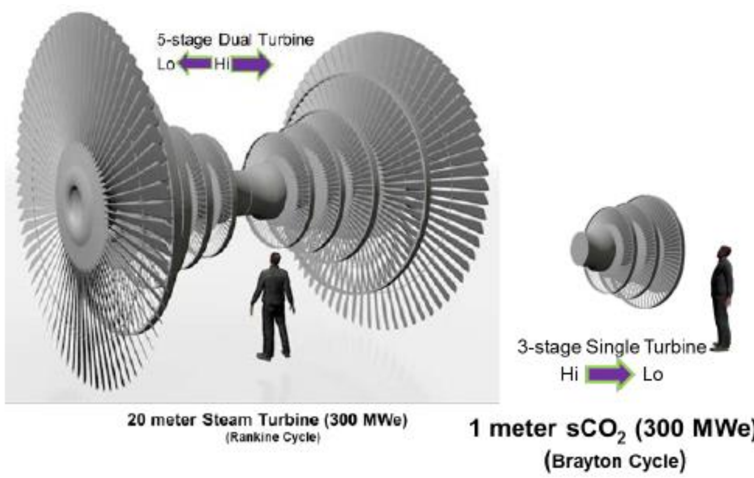
	Tmelt (°C)	Tboil (°C)	ρ (kg/m^3)	ρ Cp (kJ/m^3°C)
Li_2BeF_4(Flibe)	459	1430	1940	4670
59.5 NaF-40.5 ZrF_4	500	1290	3140	3670
26 7LiF-37 NaF-37 ZrF_4	436	*	2790	3500
51 7LiF-49 ZrF_4	509	*	3090	3750
Water (7.5MPa)	0	290 (BWR)	732	4040
Water (15.5MPa)	0	345 (PWR)	709	4049
Salt compositions in mole %.Salt props.at 700°C and 1atm (0.1 MPa)				
*The boiling points of the ZrF_4 containing salts are not well known.				

Fuel salt addition and salt cleanup introduce further configurational variability to MSR reactor concepts. Fueling options range from adding "virgin" TRU halide (fluoride or chloride) salts

[251] "Integral" means that the primary heat exchanger is within the reactor's containment vessel.

produced by an offsite centralized reprocessing facility to the local reprocessing of "spent" LWR fuel into such salts using with close-coupled infrastructure.

Because a MSR's fuel salt also serves as its coolant, if it's pump power supply should fail, its core temperature could rise to an intolerable point due to fission product decay even if it were to be scrammed via the insertion of a neutron poison. Consequently, most MSR concepts feature critically safe, easily cooled, fuel drain tanks into which it could be dumped. Each tank would include a pump bowl to accommodate any



excess of coolant salt volume each of which would be provided with overflow lines directed to the others. Their probably jet-type, pumps would also then pump the salt from those tanks back into the

Figure 56 Relative power turbine sizes

The maximum (initial) post shutdown cooling requirement of ORNL's 1 $_{\text{GWe}}$ reactor concepts would be about 130 MW_{th} (~6% of their steady state heat production) but their systems were designed to handle 300MW. Since power failure may have caused the initial emergency, its fluoroborate coolant would have been circulated by natural convection system when power has been restored. Once within those tanks, fuel salt would be cooled by either a low melting molten salt, liquid metal, or gas. In the case of ORNL's ~2.2 GW_{th} MSBRs, their secondary coolant salt was to flow through U-tubes extended into the tank through headers and that heat then dumped into the atmosphere via a liquid-to-gas heat exchanger powered by chimney-driven natural air flow.

Finally, another of the advantages that any of the molten salt or fast" reactors that I will describe relative to today's LWRs is that they could run efficiently with air rather than water-cooled turbines. LWRs operate at such low temperatures that condensing the expanded steam coming out of their huge, saturated steam Rankine turbines must be cooled/condensed with relatively cool water - not ambient-temperature air. The much smaller supercritical carbon dioxide (SCO_2) Brayton cycle turbines employed by such reactors that should replace today's could run efficiently (less than 2% heat-to-electricity conversion efficiency loss) with air rather than water cooling. This is important because even now some utilities (e.g., Central Washington State's Columbia Generating Station) must reduce reactor output during hot spells because the river/lake cooling them might otherwise become hot enough to kill aquatic wildlife (Sienicki 2017).

As of spring 2018, there were at least 13 different "nuclear startups" (companies/organizations) championing various molten salt reactor concepts. The best review I've seen yet of what's been going on is a Power Point Presentation made by ORNL's Dr. David Holcomb to UK Office of Nuclear Regulation (Holcomb 2019). While their potential economic, safety and operating features are extremely attractive, none of them have yet been licensed, built, or operated.

6.4.1 MSFR

One of the Generation IV International Forum's (GIFs) Advanced Reactor (World Nuclear 2018) potentially sustainable "Gen IV" concepts, EURATOM's EVOL program's "thorium burning" Molten Salt Fast Reactor (MSFR) is especially promising (Fiorina 2013, Merle 2017). EVOL started its study assuming the same graphite moderated single fluid (no separate blanket salt stream) MSBR that ORNL had left off with three decades earlier but soon decided that an unmoderated two fluid (separate fuel and blanket) system would likely be superior.

Due to the following factors…

- Not excessively high salt melting points
- High salt boiling temperature (i.e., generate little pressure at the reactor's operating temperature)
- Good thermal and hydraulic properties (fuel = coolant)
- Stable under irradiation
- Adequate solubility of both fissile and fertile components
- Low generation of tough-to-manage & politically charged radioisotopes
- Reasonable fuel/fertile salt stream cleanup/reprocessing options
- Low solvent salt neutron absorption and scattering cross sections[252]

…both its fuel and blanket salt streams would be a relatively low melting (565°C) eutectic[253] consisting of 77.5 mole% ^{7}LiF and 22.5 mole% total actinide fluoride(s). ~ 88% of the

[252] Cross section represents the probability of something (fission, scattering, or transmutation) happening to an atom's nucleus when a neutron collides with it expressed in terms of a geometric area. If that probability is high (e.g. the probability of ^{235}U being fissioned by a thermalized neutron), that nucleus acts like a big target – under those conditions, its cross sectional area in "barns" (1E-28 m^2) is large (e.g. ~750 barns).

actinides would ^{232}Th (natural thorium – its "fertile" material) and 12 % would be $^{233}U_4$ (its fissile). Its blanket salts' actinides would consist of ^{232}Th accompanied by much smaller amounts of in-bred ^{233}Pa and ^{233}U.

Thorium's advantages relative to uranium include:

Thorium (^{232}Th) is more abundant than uranium and could therefore satisfy world energy demands longer. It absorbs neutrons more readily than does ^{238}U, and its product fissile, ^{233}U, has a higher probability of fission (~92%) upon neutron capture than does either ^{235}U (~85%) or ^{239}Pu (~73%). On the average it also releases more "new" neutrons per fission. Neutron capture by ^{238}U immediately produces transuranic (TRU) "waste" along with the desired fissile, ^{239}Pu, but ^{232}Th only begins to produce TRU after five such captures, when its surviving progeny finally form ^{237}Np. 98–99% of the original ^{232}Th nuclei don't end up as TRU because that chain's intermediate isotopes ^{233}U and ^{235}U both readily undergo fission. Finally, thorium based solid oxide-type fuels result in a safer and better-performing reactor core because thorium dioxide has a higher melting point, higher thermal conductivity, and a lower coefficient of thermal expansion than does UO_2. It is also more stable chemically (and also tougher to dissolve) than is uranium dioxide because the latter tends to oxidize to triuranium octoxide (U_3O_8) thereby becoming less dense (expanding).

The problem with thorium in today's "demon-haunted world" (Carl Sagan's characterization) is that the reactor's fissile component is almost always "highly enriched" (mostly ^{233}U) meaning that an imaginary terrorist who had somehow managed to divert enough of its fuel could make a bomb if he could also somehow separate its uranium - no further enrichment would be needed.

Thorium's "breeding" reactions are as follows:

^{233}U+ neutron → two fission product atoms + 2.49 neutrons (Uranium 233, 2019)

One of the new neutrons +^{232}Th → ^{233}Pa (quick)

27-day half-life ^{233}Pa slowly decays to form ^{233}U

The MSFR concept's core is a 2.17 meter "square" (diameter = height =2.17 m) right circular cylinder surrounded axially by 1-m thick steel neutron reflectors, and radially by a 50-cm thick layer of fertile blanket salt, a boron carbide layer, and a thick steel reflector (Figure 57). It is filled with the fuel salt with no core internal structures. The fuel circulates out of the core through 16 external loops, each of which includes a pump and heat exchanger. A geometrically

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253 "Low melting" is a relative descriptor. High salt melting points represent the biggest showstopper and cause of MSR development delays (Jiri Krepel, personal communication).

safe[254] overflow tank accommodates salt expansion/contraction due to temperature changes. A salt draining system connected to the bottom of the core allows core dumping to passively cooled criticality-safe tanks to facilitate maintenance or quick response to emergencies. This system includes freeze valves melt as soon as electric power is lost or the salt overheats. The entire primary circuit, including the gas reprocessing unit, would be contained within a secondary reactor vessel. Fig. 11 is a schematic of its primary loop's layout and Table 7 summarizes its core parameters.

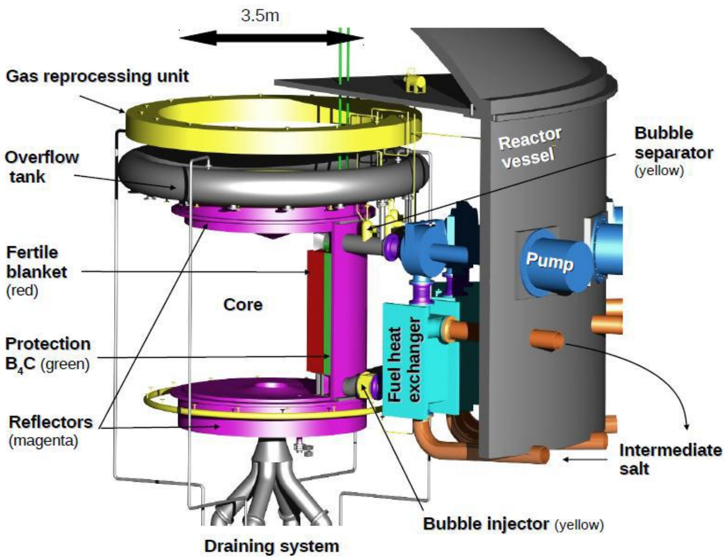

Figure 57 The EU's Molten Salt Fast Reactor (MSFR)

After pondering Dr. Fiorina's presentations at GLOBAL 2013, I wrote a paper (Siemer 2015) describing the especially attractive features of an "isobreeding" (generates only as much new

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[254] Geometrically safe means that the vessel is too small in at least one dimension to prevent so much neutron leakage that any amount of fissile within it could achieve criticality; i.e., enough of the new neutrons generated by each fission encounter enough other fissionable atoms to keep the reaction going before they can either "leak" out or absorbed/removed by some sort of fission product or control rod "poison". A spherical shape is "worst" in that respect because its surface area (leak area) is minimal relative to its volume. Another way to prevent criticality is to prevent enough fissile atoms accumulation in any one place regardless of what else might be in or around it. A third is to assure that whatever space containing the fissile also contains plenty of "poison", e.g., anything containing boron, niobium, silver, cadmium, etc. In this respect, pure water is especially "bad" because its high hydrogen content "moderates" the speed of freshly formed neutrons which greatly increases the probability that they will be absorbed by other fissile atoms before they can leak out of the vessel. For example, ORNL's LOPO aqueous homogeneous reactor (GOOGLE it) achieved criticality with just 580 grams of ^{235}U dissolved in about 14.6 liters of water. On the other hand, a critical mass of solid metallic ^{235}U (no moderator) would weigh ~52,000 grams & occupy about 2.8 liters (i.e., contain ~484 times more fissile atoms/cc).

fissile (^{233}U) from “fertile” ^{232}Th as it “burns” (CR=1.00)) version of that concept. Isobreeding constitutes an especially relevant ultimate goal/assumption because, at steady state, the world would not need extra fissile, which characteristic would simplify operation and mitigate proliferation concerns.

Table 12. MSFR core parameters (Fiorina 2013)

Thermal/electric power	3GWt/1.5We
Fuel salt volume	18m^3
Fraction fuel within core	50%
Number of heat exchange loops	16
Fuel salt flowrate	4.5m^3/s
Salt velocity , 0.3 m diameter pipes	~4 m/s
Blanket thickness	0.5 m
Blanket /volume	7.3 m^3
Boron carbide shield thickness	0.2 m

Isobreeding would simplify/cheapen reactor operation because very little “reprocessing” of its salt streams (6 to 10 liters per day) would be required to keep it running steady state fed with nothing other than dirt cheap natural thorium (see APPENDIX II).

It would operate at 700-750°C utilizing a supercritical CO_2 working fluid (not water) and [255] Brayton cycle turbines featuring an overall thermal-to-electric energy conversion efficiency of ~50%. Fluoride-based molten salts typically boil at around 1400°C and thereby possess low vapor pressures at their operational temperatures, possess volumetric heat capacities like that of water at a LWR’s >75 atmosphere working pressure, good heat transfer properties, low neutron absorption, aren’t damaged by radiation, chemically stable, do not react violently with air or water, compatible with graphite, and some are also inert to common structural metals.[256]

6.4.2 MCFR

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[255] These turbines would weigh about one-fifth as much as an equally powerful saturated steam (low temperature), Rankine cycle-based, LWR turbine.

[256] Many important people seem to confuse the fluoride anion (fluorine in its “happiest”, most stable, & therefore essentially inert state) with elemental fluorine (fluorine in its unhappiest, most reactive & most corrosive state) – those species are as different as elephants and oak trees.

Another concept apparently not formally considered by GIF, the Molten Chloride (salt) Fast Reactor (MCFR), should be simpler to build than the MSFR because its ^{238}U -to- ^{239}Pu "breeding" cycle's superior neutronics should permit isobreeding without a fertile isotope (^{238}U or ^{232}Th) containing "blanket" surrounding its core (Figure 58). This would mitigate proliferation concerns because at steady state neither the reactor itself nor its attendant fuel salt cleanup/recycling system would contain "bomb grade" fissile (>90% ^{239}Pu) that might tempt perforce suicidal terrorists to attempt its "diversion". Another of its practical advantages is that its core *could* be situated within a tank containing either a molten bismuth/lead "reflector" or a molten blanket salt containing a fertile isotope which would allow it to breed

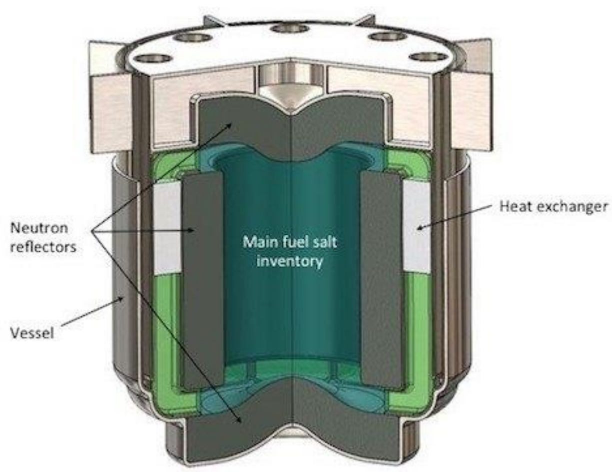

Figure 58: Terrapower's MCFR (https://www.energy.gov/ne/articles/southern-company -and-terrapower-prep-testing-molten-salt-reactor)

startup fissile for other reactors. Like most other MSR concepts, fission-generated heat energy within its fuel salt would be transferred to the working fluid (probably another molten salt) of an external heat exchanger (HX) and then to a secondary HX which then transfers it to its turbines' working fluid (e.g., water for steam/Rankine or carbon dioxide for supercritical CO_2/Brayton). Reprocessing (the recovery and recycle of U & TRU) invokes the chloride-salt based "pyroprocessing" technologies developed for the IFR (Malmback 2011). Since its reprocessing requirements would be small and sodium would comprise most of the cations in its raffinates, everything except the TRU, U, and chlorine in the salt so processed would be vitrified to compact, "best demonstrated available technology" (BDAT which means vitrification (glassmaking), waste forms suitable for eventual disposal. Its chlorine would be recycled to minimize waste volume, produce a better-quality waste form, and prevent escape/dispersal of the otherwise problematic ^{36}Cl.

These concepts would utilize chloride rather than fluoride salts because chlorine (a bigger atom) exhibits much less “moderating” capability[257] and the trivalent actinides serving as their fissile and fertile isotopes are more soluble in them than in their fluoride salt counterparts. Some of natural chlorine’s major isotope, ^{35}Cl (76%) is transmuted to ^{36}Cl (an environmentally labile, long-lived, energetic beta emitter)[258], which means that if the system’s fuel recycling system were to discard chlorine, doing so would further complicate waste management. However, since chlorine discard is both unnecessary and unwise (Siemer 2012), a more compelling reason to use ^{37}Cl–based salts is that ^{35}Cl exhibits significant moderating (via scattering) capability and would therefore reduce the reactor’s breeding (fissile replenishment) capability. ^{35}Cl’s transmutation would also generate some (not much) ^{36}S which also raises a potential corrosion issue[259].

In any case, these features along with the fact that researchers at Switzerland’s Paul Scherrer Institut had pointed out that a U/Pu chloride based breed & burner type MSR should work (Hombourger 2015, Hombourger 2019) is probably why the Bill Gates and Nathan Myhrvoldt-backed ***TerraPower*** nuclear startup has decided to split its development resources between its original solid-fueled, liquid-metal cooled, “breed and burn”, “Traveling Wave” reactor concept, a collaboration with GE Hitachi to build its first “real” LMFBR, and a ^{37}Cl salt-based MCFR, see Fig.14 (Southern 2018).

Another now defunct startup, “Elysium”, proposed what seems to be an essentially identical system.

Both describe unblanketed “breed and burn“versions of that concept to render them more attractive to regulators and utility owners[260]. The neutron economy of a “breed-and-burn”

[257] The faster that a reactor’s neutrons move, the better it can both breed and burn (fission) actinide isotopes not fissionable with slow-moving neutrons. Fission products possess relatively large neutron capture (transmutation) cross sections in the thermal (slow) energy range but much smaller ones at higher energies. Consequently, much greater fission product buildup is tolerable in an FS-MSR than in a thermal-spectrum (moderated) MSR. Since chlorine is a bigger, heavier, atom than is fluorine, it’s a poorer moderator which is why a MCFR would be “faster” (a better breeder) than its MSFR counterpart. In either, halide atoms would outnumber metals by about 1.8:1.

[258] The “danger” that any leaked ^{36}Cl might pose to exposed individuals is much overblown because the human body doesn’t concentrate ingested chlorine within especially vital organs & its biological half-life is both short (~10 days) and readily rendered shorter by counseling “victims” to eat lots of salted peanuts, potato chips, bacon, soy sauce, etc. & drink lots of anything.

[259] Such corrosion is unlikely because ^{36}S would likely be either stripped out of the fuel salt as a gas or converted to a non-corrosive and easily removed solid via reaction with fission product molybdenum.

[260] Breed and burn translates to a much simplified but less effective fuel salt cleanup system – salt seeking FP will not be continuously removed , which means that for the reactor to become a genuinely sustainable power/energy source, it will eventually have to be shut down and its fuel salt batch-wise “reconditioned” (see APPENDIX III).

reactor is high enough to breed more fissile (in this case ^{239}Pu and ^{241}Pu) from fertile nuclear reactor fuel (^{238}U) than it burns for many years. “More” is necessary because the absence of a close-coupled fuel reprocessing system allows salt-soluble fission product accumulation, some of which (especially the rare earths - lanthanides (REEs)) absorb/waste lots of neutrons which wastage must be compensated with additional in-bred fissile. To start off, the reactor must first be fed a substantial amount of fissile, ^{235}U and/or $^{239}Pu/^{241}Pu$. Thereafter, it may be able to sustain energy production for several decades without requiring other than periodic additions of additional fertile (depleted or natural U) along with more NaCl with the overflow salt going to “hot” storage. In principle, if FPs are eventually removed & 100% of the actinides recycled from everything within the reactor and its overflow tank, a breed-and-burn reactor-based nuclear fuel cycle could eventually “burn”100% of its fertile isotopes and therefore be genuinely “sustainable”. The trick of course is to keep everything in balance during a several decades–long “burn.

Terrapower’s initial blizzard of MCFR patent applications (e.g., Justia 2020) were mostly about how such balance might be achieved[261]. Its investors’ relatively deep pockets give it a huge – probably insuperable - lead over its US-based competitors because it can afford to hire/pay far more highly educated people (metallurgists, engineers, chemists, patent attorneys, etc.) and even perform experimental work that isn’t radiologically “hot”. As of 2022 its researchers have begun to publish the results of that work. For instance, Kelleher et al 2022 describes thermal gradient mass transfer corrosion rates obtained with a small-scale natural circulation loop (“microloop). By mid-2022, over nine flow-years of data had been accrued with forty-nine loops with nine different commercially available alloys and two chloride solvent salts: eutectics of NaCl-MgCl and MgCl-NaCl-KCl. Only pure molybdenum and tungsten were absolutely impervious to chloride salt attack. Of the alloys tested, only three evinced corrosion rates under 100 um/year alloy 600, alloy C-276, and alloy N, the lowest rate (45 um/a) was about 6 times worse than was observed with the MSRE’s fluoride-based system.

The first fast spectrum molten salt reactor and the first chloride salt fluid fuel reactor operated anywhere is scheduled to achieve criticality at the Laboratory for Operations and Testing in the United States (LOTUS) at INL around 2025. It represents a collaboration between Southern Company, Terrapower, and Idaho National Laboratory (INL) and has been named the Molten Chloride Reactor Experiment (MCRE).

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[261] Like most patent applications and, unfortunately, the ABSTRACTS of some of our most prestigious paywalled scientific publications, Terrapower’s were written to claim as much as possible while revealing as little “intellectual property” as possible (see APPENDIX III for a further discussion). For example, the MCFR concept described in one of its artfully written patent applications (Latkowski 2016) doesn’t specify the reactor’s shape (probably right circular cylindrical), size, or how it would be controlled.

Regulators will like breed and burn because: 1) since the reactor would not possess a blanket there wouldn't be any "bomb grade" plutonium anywhere for them to agonize about; and 2) they would only have to show up (actually work) during fuel exchange periods. Utilities would like it because it simplifies reactor operation and thereby save them money for as long as their decision makers are apt to be deciding anything.

Because "breed and burn" compromises reactor performance for the sake of convenience, implementing it would require more startup fissile to "save the world" than would genuine breeders coupled with efficient fuel stream cleanup/recycling systems.

Let's go through two of the examples described in Hombourger et al's paper (Hombourger 2019).

In all of them chlorine (Cl) means just its 37 g/mole isotope (24% of "natural" chlorine).

Three of that paper's figures and one of its tables are reproduced below:

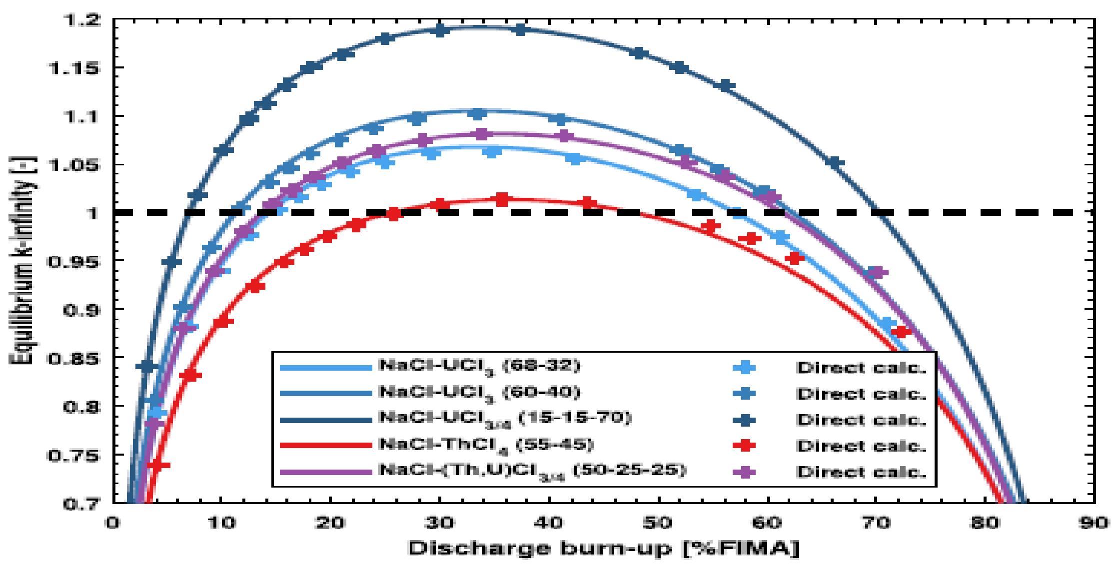

Figure 59 K_{eff} at equilibrium of fast spectrum chloride fuel salts

Figure 59 teaches us that a breed & burn molten salt reactor with a fuel salt consisting of 32 mole% U+$PuCl_3$ and 68 mole% NaCl could run until about 57% of its fuel's initial "heavy metal" (HM) loading is consumed[262]. The other case I'll consider is the one in which the fuel

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[262262] For example, if a reactor initially contains 10 tonnes HM and runs long enough to consume 5 tonnes of HM (not necessary the same actinide atoms as in its original fuel), its FIMA = 50%.

salt is 15 mole% NaCl, 15 mole% UCl_3 and 70 mole% UCl_4. In that case FIMA would be 71% of its initial HM loading before FP accumulation forced shut-down.

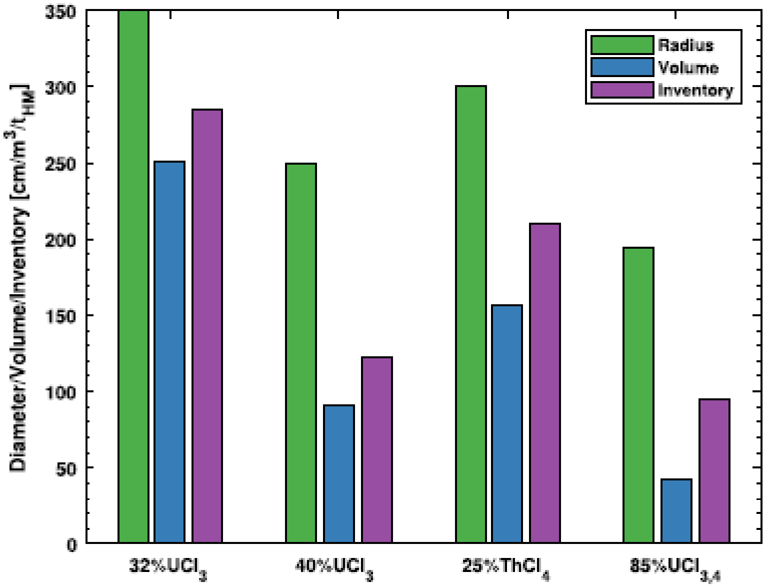

Figure 60 Radius (cm), core volume (m^3), and tonnes starting fissile of four fast breed and burn MSR concepts (cylindrical core with diameter ≈ height)

Figure 60 and Table 10 teach us that the first of the above-mentioned concepts' core would require about 250 m^3 of fuel salt containing 285 tonnes of uranium including ~ 31 tonnes of fissile. Their last example's core (85 mole% tri and quadrivalent U chlorides plus 15mole% $Na^{37}Cl$) would contain about 45 m^3 of fuel salt initially containing/requiring about 9.5 tonnes of fissile.

^{235}U or Pu fraction	LEU	LWRPu
$NaCl-UCl_3$ (32–68)	10.65%	11.3%
$NaCl-UCl_3$ (40–60)	10.7%	11%
$NaCl-UCl_3-ThCl_4$	23.6%	23.2%
$NaCl-UCl_3-UCl_4$	10.35%	9.85%

Table 13 Mole fraction fissile actinide (^{235}U or RGPu) in initial fuel

The final slide excerpted from that paper tells us how much make up salt would be added during the time that each concept "burns" before fission product poison build-up finally brings everything to a halt. That makeup salt would consist of depleted uranium chloride(s) - no additional fissile - and NaCl. The first concept's total fuel plus makeup salt volume would be

1.85 times its core's volume and the second's about 4.5 times its core volume. This means that the total HM fed to the first during its breed and burn cycle would be 1.85*285 = 527 tonnes & for the second, 4.5*95 or 428 tonnes.

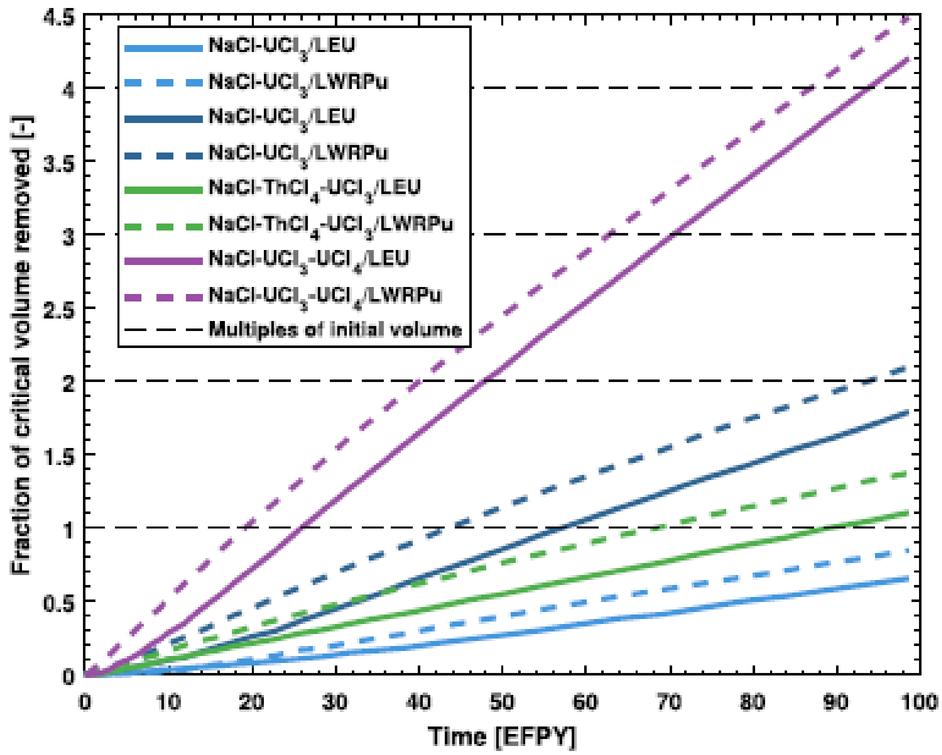

Figure 61 Total salt volume as a function of "Effective Full Power Years" (% total operational period)

In the first case, 57% (FIMA) of its initial HM loading is 0.57*285 or 162.4 tonnes - the amount of total actinide fissioned during its run. That means that it could generate about 5 times (162.4/32.2) as much heat energy per its initial fissile loading as do today's LWRs.

The second concept would fission 0.71*95 or 67.2 tonnes of actinides during its lifetime or over 7 times its initial fissile loading (in other words, most of its heat energy would be produced by "inbred" fissile.).

How long those reactors would run depends upon their power output. If we wanted to generate 1 GW_e worth of electricity and the overall system's (reactor & turbines) heat energy-to-electricity efficiency factor is 45%, we'd need to generate 1 GW_e/0.45 or 2.22 GWth. Since the fission of one actinide atom generates ~3.2E+11 J of heat, we'd have to split 2.22E+9/3.2E-11 or 6.94E+19 of them per second. Since there's 6.023E+23 (Avogadro's number) atoms per gram mole (238 grams) of ^{238}U, that's 0.0274 gram of it fissioned/second. At that rate we would be burning 0 .0274*3600*24*365 or 8.64E+5 g (0.864 tonne) of ^{238}U equivalent per year.

Consequently, in principle the first (bigger) concept could run for 162.4/0.864 or 188 years before FP accumulation shuts it down. The second could run for 78 years before shutting down.

Both of those reactors' reactivity would be maintained at k_{eff} =1 by adding a depleted U chloride /NaCl mixture which would push the same volume of its currently just barely "too-hot" fuel salt into a critically safe overflow tank.

Neither are real breeders but would nevertheless be much more fuel efficient than are today's power reactors with the exception of Russia's LMFBRs *if* the latter's fuel were to recycled via one of Russia's fuel reprocessing facilities. Additionally, since the reason that they would "die" after 78 or 188 years is because they would eventually become choked up with fission products, their "spent" salt would contain more than enough fissile to restart/operate the same reactor once that FP is removed. This means that in principle at least, breed and burn MCFRs do represent potentially genuinely sustainable/renewable power generators.

That plus the fact that "breed and burn" would enable our topmost decision makers to keep kicking the politically charged "reprocessing" can on down the road for another half century or so renders it especially attractive.

Again, I feel that breed and burn's main drawback is that it would require an excessive amount of startup fissile. Even the most compact possible B&B MSR concept's ~9.5 tonnes fissile/GW_e requirement would seriously limit the rate at which sustainable nuclear energy could replace fossil fuels and wind/solar (see APPENDIX III for details).

6.4.3 MOLTEX

Another promising MSR concept not considered by GIF is MOLTEX's "stable salt reactor" (Scott 2017, Moltex 2018, Scott 2020). Its primary technical distinction is that its core consists of bundles of thin-walled steel tubes containing the fuel salt immersed in a big tank of coolant salt. The fuel salt within those tubes contains a fissile isotope (any combination of trivalent ^{239}Pu, ^{235}U, and/or ^{233}U) in a molten chloride-based solvent salt containing a fertile isotope (typically $^{238}UCl_3$) and table salt (NaCl). Unlike the other concepts I've described, its fuel salt would be "static", not continuously recirculated between its core and external heat exchangers. Fission-generated heat energy would pass through the walls of those tubes[263] and transferred to a rapidly upward moving (pumped) fissile-free surrounding, fluoride-based coolant/blanket salt comprised

[263] This concept's "eureka moment" came when its inventor, Dr. Ian Scott, suddenly realized that within the Earth's gravitational field, a nominally static fuel salt contained within thin walled (~0.05 cm), ~1 cm diameter steel tubes like those of LMFBRs, could transfer their heat to an external coolant sufficiently rapidly (Scott 2014). The reason for this is that the density gradients caused by the fuel salt's heat generation (~50 kW/liter) would generate a great deal of local turbulence enabling rapid convective (not just diffusional) heat flow from the tube's contents to its inner wall's surface.

(in breeder versions) of a ThF_4-NaF eutectic[264]. The coolant stream's heat energy would be transferred to a third molten salt stream (e.g., "solar salt" a low melting (eutectic) mix of sodium and potassium nitrates) which, in turn, would exchange its heat with water or CO_2 to generate the high-pressure gas driving its power turbines. Both its fuel and primary coolant salt streams would be rendered non-corrosive to conventional stainless steels via redox buffering with divalent Zr – an extremely powerful reducing agent and therefore elemental fluorine/oxygen scavenger.

While I'm not exactly giddy about having thousands of fuel tubes within reactors, in this case there's so much to be gained in terms of practicality that a serious study of breeding capable versions of that concept makes good sense.

In my opinion, the MOLTEX concept's chief virtue is that it should be considerably easier and cheaper to implement a "first of a kind" (FOAK) breeding-capable version of it than either the MCFR or MSFR.

The reasons for this include:

1. Building and operating one would not require exotic materials
2. It's intrinsically "small and modular" (each of 150 MWe/module would weigh about 18 tonnes – see Figure 62) meaning both that its parts could be factory fabricated/trucked to a build site and that it could easily be scaled up to produce as much power as needed (stack additional modules side-by -side in a common coolant salt tank)
3. It's apt to be easier to convince governmental decision makers and investors that building one wouldn't be too risky
4. its most "fragile" parts – it's fuel tubes' metallic cladding – would be readily and regularly replaced
5. since its radiologically hot/contaminated fuel salt would not be pumped/circulated, a host of potential problems exterior to its core (e.g., leaky heat exchangers) couldn't happen
6. that same feature would also take full advantage of the inherent stability afforded by the fission process's delayed neutrons
7. like CANDU-type reactors it could run steady-state (no periodic shutdowns) because its fuel could be replaced/shuffled while the reactor is running

[264] MOLTEX's nonbreeding "waste burner" (SSRW) would utilize a NaF/ZrF_4 eutectic (minimum-melting mixture) coolant salt instead. Their fuel would consist of the low-grade plutonium recovered by a clever reprocessing scheme (see APPENDIX 1) from "spent" CANDU or LWR fuel.

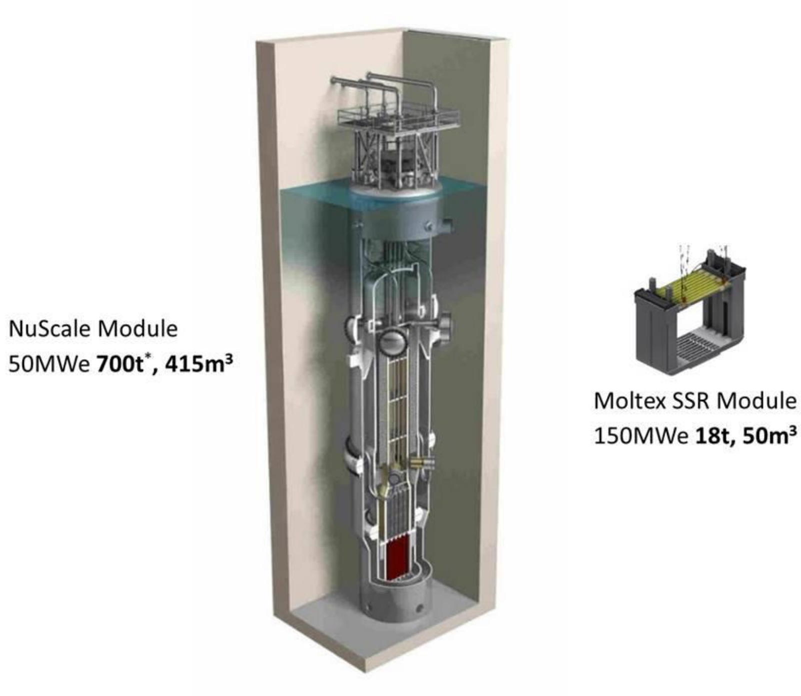

Figure 62 Relative sizes of MOLTEX (MSR- the original version) & NUSCALE (LWR) "small modular reactor" modules

Regarding point #3, regulators are apt to be comforted by the MOLTEX concept's simplicity (there's nothing mysterious about how it would work and it's not very complicated) and the fact that it couldn't possibly experience either a Fukushima-like meltdown (upon shut down, its core would be air cooled via natural convection – no huge water pools and pumps required) or a Chernobyl-like steam explosion (no water and nothing to burn). Investors are apt to like the fact that it should be possible to build the first one relatively quickly & therefore cheaply.

As far as I am concerned, another significant plus is that its developer seems to be willing to reveal more "technical details" than did most of his competitors in today's MSR startup sweepstakes (Scott 2014, Scott 2017). Credibility in this hyper-secretive technical arena is tough to earn and roughly proportional to the degree to which a concept's champions embrace "openness".

A 2020 press release announced that "Canadian Nuclear Laboratories (CNL) has entered into a collaboration agreement with molten salt reactor developer Moltex Energy. The agreement, funded though CNL's Canadian Nuclear Research Initiative (CNRI), includes work to support aspects of Moltex Energy's nuclear fuel development programme for its 300MW Stable Salt Reactor."

Unfortunately, it seems to me that several of the original concept's characteristics/virtues have been seriously compromised to satisfy Canada's regulatory experts and businesspersons see [PowerPoint Presentation (ornl.gov)]..

The MOLTEX concept's primary technical downsides are its large startup fissile requirement (my unverified calculations suggest ~12 tonnes/GW_e) and that each of its breeder version's reprocessing cycles would require the refabrication of roughly the same number of individual fuel tubes as would an equally powerful LMFBR. However, also like the LMFBR, its relatively high (~150 GWt/day) fuel burnup per cycle means that it would require only about 10% as much reprocessing/refabrication as would a breakeven-capable, thorium-burning, heavy water moderated PWR or BWR.

Apparently, a political (and therefore super important) downside as far as USA's DOE & NRC is concerned is the same characteristic that has rendered its own radwaste management issues so intractable; i.e., "*it wasn't invented here*".

Lizin et al have recently written a fine overview of the commonly proposed fast (unmoderated) MSR concepts (Lizin 2017).

Dr. Forsberg recently notified Dr. Pavlak's ZOOM group members (18Oct21) that two classes of MCFRs (Molten Chloride Fast Reactors) are currently being developed.

1: Ones in which the reactor's "hot spot" is a wide space in the fuel salt's recirculation loop where neutron leakage isn't too great to support criticality –TerraPower/Southern & Elysium with Pu/U-based fuels & INAP (China) with ^{233}U/Th-based fuel

2: Moltex's chloride-salt U/Pu-based fuel salt within tubes surrounded by a clean fluoride salt-based coolant: it's like a sodium-cooled fast reactor (or LMFBR) except its fuel would be much simpler to clean up/recycle (Moltex may eventually render it breeding-capable by adding thorium to its coolant salt)

Since there isn't enough spent LWR fuel-derived fissile (^{239}Pu +^{241}Pu) plus "excess" weapons grade-type ^{235}U or plutonium in the world (roughly 2400 tonnes total) to start more than 400-600 of any sort of fast breeder reactor, they would have to be configured to breed extra start-up fissile until enough of them were built (~20,000) to power everything.

6.4.4 Tube in Shell Thorium Breeder

The MSR concepts I've described so far are all "fast" because their cores would not contain a moderating material (e.g., liquid water, beryllium oxide, zirconium hydride, or elemental carbon) to deliberately slow the rapidly moving (fast; i.e., >1 MEV) neutrons initially generated by nuclear fission. As also previously mentioned (it bears repeating), "fast" enables superior fuel (fissile) regeneration capability, lessens minor actinide (Am, Cm, etc.) build-up, and permits operation with much higher fission product "ash" salt concentrations which, in turn, translates to a much-lessened fuel salt reprocessing (cleanup & recycle) requirement. No moderator also means that their therefore relatively small cores could be "modular" (transportable) and not generate ~75 tonnes of irradiated/contaminated/damaged moderator radwaste per GW_e-year as would ORNL's "classic" MSBR concept. To date, the world's graphite-moderated "production" reactors (of weapons grade plutonium and tritium) have generated roughly 250,000 tonnes of radiologically contaminated graphite, most of which lingers in "temporary" storage (TECDOC 2010). In principle, if they were to be operated properly (sustainably), any of them would convert almost all of their actinides, both that introduced and generated in-situ via neutron capture/transmutation, to relatively short-lived, simple-to-manage, fission products (FP). All of them would obviate the cost, waste, and safety-related issues inherent to potentially sustainable, solid-fueled reactor concepts such as the sodium-cooled "Integral Fast Reactor" (IFR), "Traveling Wave" concepts or General Atomic's helium-cooled "Energy Multiplier Module (EM2) (Rawls 2010). All of them should be cheaper to build than "advanced" versions of today's industry standard light water reactors because they would operate at much lower/safer pressures and generate more useful (higher temperature) heat energy. And finally, all of them could be started with fuel comprised of the uranium, plutonium, and minor actinides (TRU) extracted from spent LWR fuel assemblies which would also simplify/cheapen long-term management of such "waste".

Figure 63 depicts an especially promising MSR concept that no one else currently seems to be considering[265]. It's the "semi fast" (intermediate or "epithermal" neutron speed) tube-in-shell configured, two-fluid thorium breeder reactor conceived by David LeBlanc over a decade ago (LeBlanc 2007). Its internal core tube would contain a fuel salt comprised of a low melting 2 to 1 mole-wise solvent salt mix of ^{7}LiF and BeF_2 (FLiBe, SpG~2.0) containing a surprisingly small amount of fissile (about 0.16 mole% or ~6.1E+19 atoms/cc of ^{233}U) with no fertile ^{238}U or ^{232}Th.

265Even its inventor – Terrestrial Energy's chief engineer Dr. Leblanc – isn't "studying" these days because everything about it is so inconsistent with today's rules, regulations, and assumptions that he's concluded that it's not worth even investigating here in the western world. It's "epithermal" because its solvent salt's lightweight atoms (lithium, beryllium, and fluorine) slow but do not thermalize its neutrons. The reasons that I've depicted it with a vertically oriented core are: 1) a horizontal fuel tube would experience a huge bending force because its contents possess a much lower SpG) than that of the surrounding fertile salt (~2 g/cc vs ~4.3 g/cc), and 2) cranes lift upwards, not sideways. The latter is important because any such reactor should be designed to facilitate routine core tube replacement. The "accidental leak" supercriticality scenario is addressed by designing its blanket salt tank so that if the core tank bursts, its low SpG contents would float up to its geometrically safe (pancake-shaped) top, not collect into a compact ball.

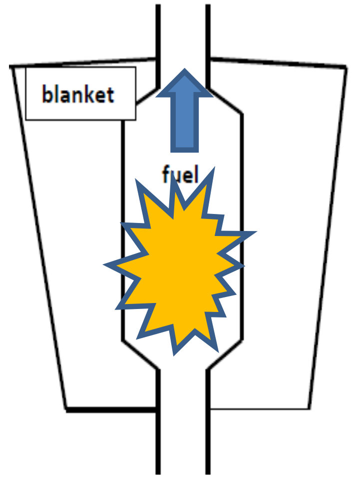

Figure 63 LeBlanc's tube in shell thorium isobreeder

The system's outer (aka, "shell" or blanket") side would contain a fertile salt comprised of 25 mole % ThF_4 + 75 mole % ^{7}LiF (SpG ~4.5). In other words, this concept is a "seed and blanket" MSR.

Virtually all of its heat-generating fission reactions would take place within the core but sufficient of the neutrons so-produced (>1/fission) would pass through the wall separating it from the surrounding blanket salt to regenerate at least as much new fissile as is burned (the fission of ^{233}U generates two fission product (FP) elements plus an average of ~2.48 neutrons[266]. About 1.1 of those neutrons are absorbed by other ^{233}U atoms within the core salt 90% of which fission thereby keeping the reaction going and producing a relatively small amount of ^{234}U (another fertile isotope) therein while the remaining ~1.3 are absorbed by the system's internals (core wall material, ^{7}Li, Be, F etc.) and the blanket salt's thorium.

It is a stretched-out version of the 4-foot core diameter, 2 fluid reactor (number 36) in Table 3 of ORNL 2751 (Alexander 1959). It is cylindrical rather than spherical with a diameter of 95 cm (48 inches x 0.78[267] relative to ORNL's original concept that emulates its neutronic characteristics. Its core is long enough (7.4 meters) to contain sufficient fuel salt (5.24 m^3) to limit mean heat generation within it to 400 kW per liter, which translates to a whole core heat

[266] What revived this concept to me is that 1) both fuel and blanket salt reprocessing would be much simpler than that required by any of the sustainable U/Pu based MSR concepts that I'm aware of, and 2) ^{233}U fission apparently releases about 10% more new neutrons than ORNL's researchers assumed six decades ago.(Uranium 233, 2019)

[267] 0.78 is an infinite length cylinder's diameter relative to that of a sphere's "buckling factor" (the relative sizes of different-shaped vessels possessing the same neutron loss/leakage probability).

generation of 2.1 GWt [4E+5*7.4*(0.95/2)^2*1000] or, assuming 48% efficient heat to electricity conversion, 1.0 GWe. Assuming ^{233}U, its within-core startup fissile requirement would be 124 kg [= 6.1E+19 *1000*5.24*233/6.023E+23] which, if it were to be connected to a total of 8 m^3 worth of external piping and heat exchanger(s), translates to a total startup fissile requirement of 312 kg [124*(8+5.24)/5.24] – well under 10% of that required by any of the "fast" reactors that I've described[268]. That's crucially important because startup fissile availability limits the rate at which a big-enough sustainable nuclear renaissance could be implemented.

Since this breeder concept's fertile material (^{232}Th) isn't mixed in with its fissile (^{233}U)…

> 1)…it would not have to be separated from REE-type FP - U is easy/cheap to separate from the rare earths (and Pu), Th isn't
>
> 2) Because fertile atoms would not be absorbing neutrons within its core, achieving criticality therein would require relatively little fissile - that's why it wouldn't require much startup fissile
>
> 3) Fuel salt cleanup/reprocessing would be much easier/cheaper than it would have been with the MSBR[269] or today's mysterious LFTR concept - simply fluorinate out/collect the uranium, distill off/collect the FLiBe, & throw away everything else. The remaining waste would be easy/cheap to vitrify and there wouldn't be much of it.

Another of this concept's advantages is that its "big" blanket could contain enough fertile Th to effectively shield freshly -reated ^{233}Pa from neutrons until it can decay to ^{233}U. The LFTR concept's (next section) relatively small blanket salt volume along with its slow-moving (moderated) neutrons, renders ^{233}Pa separation/storage necessary to achieve "isobreeding" which fact would greatly complicate its operation.

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[268] As is the case with everything else I've written about "other people's" concepts, this section was sent off to Dr. LeBlanc to review and, if necessary, correct. As is also usual, people cc'd on my note seized upon that opportunity to point out that unlike their own pet concept, it's "impossible" because inconsistentwith today's rules and customs. For instance: "*Main issue is …proliferation concerning reprocessing of both core and blanket. With the MSBR/LFTR required reprocessing system U fluorination system it is trivial to get pure HEU233 with absolutely NO U232 … 100% U233 critical mass is about the same as 93% Pu239, and far lower than 93% U235, the currently used weapons main arsenal materials.* ".In other words, in that reviewer's opinion, the purpose of NE R&D is to devise something that no "properly conservative" armchair expert could come up with a showstopper based upon today's notion that the future's civilian power reactors would be operated by unsupervised homo/suicidal idiots.

[269] MSBR = ORNL's graphite-moderated, breeding-capable, single-salt reactor concept (Robertson 1971)

This suggests another especially worthwhile experiment for DOE's lead NE R&D laboratory's experts to perform[270].

Its purpose would be to see if ORNL's especially fuel efficient, original two salt thorium breeder concept that LeBlanc's is based upon would actually work. To help understand what I'm talking about, read the following chapter from ORNL's iconic book "Fluid Fueled Reactors" (https://energyfromthorium.com/pdf/FFR_chap14.pdf) - especially its section having to do with their/its concept's configuration (spherical fuel salt tank within a bigger blanket salt tank), and neutronic performance with special attention to its "case numbers" 41 and 42 (three and four foot diameter cores, ^{233}U fissile and no thorium in the fuel salt)

Here's why the USA's lead NE R&D team should "study" it. :

- its "clean" core should require very little startup fissile thereby rendering a rapid sustainable nuclear energy build-out possible
- its relatively "pure" fuel & blanket salt streams should be far easier/cheaper to reprocess than any solid-fueled breeder's seed/blanket's rods, prisms, plates, or balls (save money & reduce out- of-core fissile inventory)
- if it does work (isobreeds or better), it shouldn't be difficult to scale up power-wise by switching to Leblanc's neutronically equivalent elongated configuration
- it wouldn't generate plutonium
- it wouldn't generate 75-100 tonnes of crapped up graphite moderator radwaste per GWe-year.
- it'd be uniquely simple to model
- it should be cheap to build
- it should be easy to start, operate, and shut down
- because MSRs are natural load followers, an electrical utility's customers wouldn't have to pay for, batteries, "peakers" or any other of Dr. Moniz et als' "all of the above" future energy scenario's contributors.

It's become too late to continue doing whatever sounds nice or fits current governmental and/or industrial biases and business models. In a finite world, time and money wasted doing unnecessary things is time and money not spent doing necessary things. No one can do "all of the above".

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[270] If DOE's experts "can't" study this concept because its core would contain bomb-grade fissile, maybe the US Navy's could – all its reactors do so because it makes good sense for its applications.

As far as its material requirements are concerned, the one good thing about DOE's approach to "waste" management is that it's terribly inefficient and therefore excruciatingly slow. The consequence is that several hundred kg of fairly pure ^{233}U probably still lingers somewhere within the DOE Complex because the AEC's contractors made roughly 10 times as much of it as this experiment would require to fuel its Shippingport thermal PWR breeder demo. Second, my ballpark calculations suggest that the salt mixture utilized for ORNL's MSRE demonstration contained about 470 kg of isotopically pure ^{7}Li which should also be more than enough to do those tests. Finally, there's been a great deal of materials science work done since ORNL's fluid-fueled reactor book was written (esp. in the ceramics and carbon-based composite fields) which ought to improve the concept's performance[271] & render modern studies relatively easy/cheap to do.

If those tests indicate that Leblanc's concept would likely work, another not-so-old report suggests that thorium blanketed, reactor grade Pu metal-fueled LMFBRs could quickly produce enough ^{233}U to start up lots of them (Chang et al 1977)[272]. That report's Table V indicates that a so-configured 1 GW_e LMFBR would generate about 384 kg of ^{233}U per year – more than enough to start up an equally powerful tube-in-shell thorium breeder; i.e., a single GW_e's worth of plutonium burned in that fashion could start up another breeder capable of generating the same amount of power "forever". On the other hand, it would take the ^{233}U generated by about ten such reactors to start up another such LMFBR.

6.4.5 LFTR (liquid fluoride thorium reactor)

Next, I'll describe another possibly sustainable MSR concept along with two others more suitable for niche applications.

The "Liquid Fluoride Thorium Reactor" (LFTR) is a revival of the graphite-moderated, graphite-constructed, two-fluid breeder (core fuel salt channels surrounded by blanket salt channels) described by ORNL's nuclear engineers <u>after</u> they had concluded that graphite's physical characteristics would render such a system virtually impossible to build (Robertson et al, 1970)[273]. The LFTR's chief advocate, Kirk Sorensen[274], has apparently come up with a

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[271] For instance, its CR (breeding performance) would be much enhanced (CR.1.00) if its core tube could be made of some sort of carbon or carbon-silicon composite instead of INOR 8 (aka Hastalloy N).

[272] A newer report suggests that a thorium blanketed LMFBR would breed about one half that much "new" ^{233}U (Liem 2008).

[273] Graphite is physically weak, can't be welded, and changes its shape/size when subjected to intense neutron irradiation.

proprietary way of getting around that issue. Like all moderated (thermal spectrum) MSRs its core basically consists of a big block of graphite with small salt channels through it, top-to-bottom. In its case, there are separate fuel (mostly $^{233}UF_4$) and fertile (ThF_4) bearing salt channels. Both salt streams would feature a low-melting (eutectic) solvent salt, FLiBe (67% ^7LiF, 33% BeF_2).

It's not getting much attention from most of the world's reactor experts for several reasons:

1) Like LeBlanc's concept it would be a genuinely sustainable, graphite moderated, two-salt MSR which means that its purpose, fabrication, and operation would be different than that of any of the reactors adopted/championed by the USA's industrial and government experts after Weinberg's downsizing. Consequently, their teachers didn't teach them much about MSRs.

2) Among those decision makers' beliefs is the notion that a reactor's owner/operators should not be responsible for running a close-coupled fuel cleanup/recycling system and properly managing the waste so-generated. Today's once-through nuclear power systems are admirably simple/convenient in both respects. Throwing empty beer cans out of your car's window is also admirably simple/convenient.

3) Because 27-day half-life ^{233}Pa has a relatively large thermal neutron absorption cross-section, any thermal spectrum Th/U fuel cycle presents a distinctive proliferation issue because achieving a CR ≥ 1 with a moderated LFTR-like MSR would be impossible if it were not continuously removed from its blanket salt and allowed to decay to ^{233}U somewhere not subject to the reactor's thermalized neutron flux. Consequently, a breeding or even breakeven-capable LFTR would require far more "reprocessing" than would any fast thorium-fueled, breeding-capable MSR like the EU's MSFR or Elysium/Terrapower's chloride salt-based concepts and would therefore be considerably more troublesome/expensive to operate[275].

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[274] Kirk has probably done more than anyone else to rekindle interest in MSRs. Circa 2006 he paid ORNL's document control people to "clear", copy, and then send him its MSR-relevant research reports which he then immediately posted on his "Energy from Thorium" blogsite. At last check, those documents along with a great deal of other such literature remain there freely available for anyone, "friend or foe", to sift through & learn from - Yeah Kirk!

[275] ORNL published several papers having to do with recovering most of the ^7Li & Be from salt streams via a relatively simple one-plate vacuum distillation (Scott 1966). It worked fine for that purpose but wouldn't be of much use for most of the other separations that sustainable LFTR operation would require (e.g., TRU from rare earth FP).

4) As would any graphite-moderated reactor, LFTRs would generate ~75 tonnes of “crapped up” waste graphite (moderator) per GW_e-year – fast MSR breeders would not generate such waste[276].

5) As would also be the case with the MSFR, it would be breeding-capable only if its fuel salt were made with isotopically pure ^{7}Li, not natural lithium.

6) As would that of any breeder’s blanket, its blanket would contain “bomb grade” fissile (almost pure ^{233}U) that a safety expert’s imaginary terrorists might “divert”.

7) And, probably the most important drawback here in the real world is that no one like Bill Gates, Elon Musk, or Jack Ma has yet been convinced to support LFTR development. I doubt that it will happen because more promising alternatives exist.

ORNL’s two-salt MSR’s advantages with respect to neutronics & reprocessing aren’t in question. Its real issues are “buildability”, durability, & maintenance. Its guts are made of graphite, very complicated, and therefore likely to leak like a sieve. That’s what killed both ORNL’s & my interest in graphite moderated, two salt, MSRs regardless of who is championing them. Sorensen’s refusal to reveal his LFTR’s secrets is why I’ve not considered it to be a serious contender for over a decade.

There’s been far too much of that sort of BS in this business.

The LFTR’s chief virtue is that ***if*** it could be made to work, it would require considerably less start up fissile than would the LMFBR (IFR) or any sort of equally powerful fast-spectrum MSR other than LeBlanc’s tube-in-shell concept.

6.4.6 THORCON and IMSR

Several other MSR concepts are currently vying for venture capitalist and governmental attention. From what I’ve been able to gather, their designs were apparently force-fit into compliance with today’s light water civilian reactor rules and assumptions resulting in systems little if any more fuel efficient than are LWRs[277]. In my opinion while it might be fun to think

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[276] “Crapped up” means heavily radiologically contaminated.

[277] Most of the USA’s nuclear startups seem to be focusing upon developing salable intellectual property (IP) rather than saving the world. That IP must of course be “protected” for as long as possible and I can’t really blame them - I used to have to “make a living” here vin the USA too (the good thing about getting old is that if you are not too dumb, you can eventually become comfortably “tenured” money-wise - Einstein took advantage of that too). From a broader point of view, there isn’t much evidence that patents are helpful, let alone necessary, in encouraging innovation. A 2002 study by Josh Lerner, an economist at Harvard Business School, looked at 177 cases of strengthened patent policy in 60 countries over more than a century, finding that “*these policy changes did not spur innovation*.” James Watt, Samuel Morse, Guglielmo Marconi, the Wright brothers, and many others wasted the best years of their lives in court defending their intellectual property, when they might have been busy improving their

about how we might go about turning ballerinas into hippos[278], it is a distraction that the best and brightest among us shouldn't waste time on due to the host of real issues that Hubbert, Weinberg, and Hansen identified a long time ago.

Reactor concepts that couldn't "save the world" by themselves would, however, be suitable for important niche applications; e.g., powering big ships or isolated small/medium-sized cities. If the fissile fueling them were to be generated by the breeder-type reactors powering everything else, they could constitute an important part of a sustainable overall system.

One such reactor would be THORCON's "doable" MSR (see http://thorconpower.com/ - A Youtube video of a lecture by THORCON's chief engineer, Lars Jorgenson, is the most efficient way of learning about the THORCON concept (Jorgenson 2020)). It is a high energy density, graphite-moderated, molten salt converter with a rather short (4 year) moderator lifetime when run at its full power rating. It's "doable" because it emulates ORNL's already demonstrated/proven MSRE (MSRE 2018) in a manner that wouldn't require exotic metals to construct or isotopically pure ^{7}Li to run. A land-based THORCON plant would consist of barge transportable 250 MWe modules, manufactured on an assembly line like WWII's liberty ships[279]. Each module would consist of two 400 ton "cans" each of which houses a 250 MWe primary loop including a "pot" (reactor), pump and primary heat exchanger. The cans are duplexed meaning that when one is operating, the other is in cool-down or stand-by mode. The plant is designed so that the change-out of a cooled-down can would be both simple and quick. At that time, it would be lifted from its silo, moved by the plant's crane to a disassembly area, and those portions of its primary loop requiring replacement remotely separated and stored.

The baseline THORCON would use a NaF-BeF_2 ("nabe") solvent salt mixture for both its radioactive fuel and non- radioactive secondary salt streams because its components are already readily available and reasonably cheap. Since nabe is less neutronically less attractive than is ^{7}Li based cousin (FLiBe), it would be only about twice, not >100 times, more fuel efficient than are

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wares. Furthermore, the expiration of patents often results in a burst of innovation, as with 3-D printing, where the lapse of three key patents resulted in rapid quality improvements and price drops.

[278] The problem with the "*doing something is better than doing nothing*" rationale for designing performance-compromised systems is that once we humans (esp. businesspersons) get used to doing anything in a particular fashion, everyone involved with implementing that business model resists change. Since people doing/supplying important things usually get rich, they also become able to convince politicians to support their business models which, in turn, engenders the rules, laws and bureaucracies constituting the "barriers to science" stifling change/progress.

[279] THORCON's CEO Jack Devanney, has just written an excellent little book (Why Nuclear Power Has Been A Flop – A Modern Gordian Knot (gordianknotbook.com)) that explains the whats and whys of nuclear power's "failure" and how policy changes & modularization (building 'em like ships) would address its cost issues.

today's LWRs[280]. The baseline version would employ a tertiary loop using solar salt (a low melting eutectic of sodium and potassium nitrate salts) to remove essentially all the tritium generated during operation. All the fluid loops within the system are designed to generate natural circulation driven by decay heat in the event of loss of power. Both the secondary and tertiary loops are located within an exterior-to-the-can steam generating cell designed to contain a massive rupture anywhere within these loops. Given a rational regulatory environment, it should be able to generate electricity for between 3 cents and 5 cents per kilowatt-hour.

Another well-publicized currently "doable" MSR reactor concept, Terrestrial Energy's "IMSR" would probably be easier to power ships with (https://www.terrestrialenergy.com/).   Like THORCON's concept,   it is "integral", compact, graphite-moderated, and no fertile-containing "breeding" blanket surrounds its core. However,   it's more conventional in that the fertile isotope accompanying the fissile (^{235}U) fueling it is ^{238}U, not ^{232}Th, which substitution renders it no more fuel efficient (of natural uranium) than are today's civilian power reactors.

"Little" reactors like these two compare favorably with the diesel engines currently powering large ships. Those diesels currently burn about 298 million tonnes of "oil" per year (ICTT 2019). The International Maritime Organization's (IMO) is targeting a reduction in the carbon intensity of international shipping of at least 40% by 2030 compared with 2008 levels and 70% by 2050. It is also targeting GHG cuts of 50% by then,

At 42kJ/gram, that comes to 1.25E+19 J worth of heat energy per annum. Since state-of-the-art ship-type diesel engines are a bit more thermally efficient than are THORCONs or ISMRs (~50 vs ~45%) , that's equivalent to ~1.39E+19 J's worth of nuclear-type heat energy.   When bunker fuel oil costs $600/tonne, that engine's fuel cost works out to about 10.3 cents per kWh or 3–5 times more than that reactor's power should cost. Each 250 MWe THORCON "can" weighs 400 tons[281] - about one sixth as much as a 50% thermally efficient Wartsilla 81 MW engine (currently the world's biggest and most efficient diesel engine). Each such can should be able to continuously power a big ship for about 12 years (250/81*4) which means that a "standard" two-can THORCON module could probably power it throughout its entire lifetime. Those savings would really add up: over a 24-year working lifetime: a 50% thermally efficient 81 MW diesel engine would consume 2.93 million tonnes of bunker fuel, which at $600/tonne would cost $1.76 billion of today's dollars – reducing that cost by two thirds would give that ship's

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[280] Several straightforward changes that would improve THORCON's fuel economy. Simply switching from NaBe to F^{7}LiBe would increase it by around 20%. Turning it into a genuine breeder would require EITHER running it with HEU (undiluted ^{233}U) and close coupling it to an onsite reprocessing plant or converting it to a fast reactor by eliminating the graphite (Jorgensen 2019 personal communication).

[281] The gas turbine powering the ship would weigh considerably less than the reactor.

owners/investors a very warm feeling. It would also let them honestly claim that their decision to so-power their ship reduced the amount of CO_2 that would have otherwise been dumped into the environment by 9.2 million tonnes. It would also address another of today's environmental impacts because bunker fuel is extremely dirty compared to the diesel fuels used by land-based trucks, cars, and tractors, which means that ships currently dump more SO_x into the environment than do any of Mankind's other fuel-burning machines and processes (see/do homework problems 96-100 for some examples).

Since the 22 TW's worth of breeder-type reactors powering this book's clean, green, and prosperous imaginary, but possible, future would also exhibit ~50% thermal-to-electricity efficiencies, they would be consuming 44 $TW_{thermal}$'s worth of fissile. That's' 1.39E+21 J [44E+14*3.15E+7] of nuclear heat per annum for "everything else" which figure just happens to be ~100 times that required to power today's shipping fleet with small converter-type reactors. This in turn suggests that if the future's big breeders generated at least 1% more fissile (CR>1.01) than they consumed, their extra fissile could sustainably power international shipping too.

Roughly 160 ships (almost entirely US and Russian military vessels) are now powered by ~200 small nuclear reactors. However, Andreas Sohmen-Pao, chairman of shipping company BW Group recently (28Oct2020) said during a decarbonization webinar sponsored by the Norwegian Business Association Singapore, that inquiries are coming in from privatized shipping companies as well

According to Sohmen-Pao, one of nuclear power's advantages is that "*You will have ships going maybe 50% faster because the fuel is essentially free once you have made the upfront capex investment.*"

Existing IMO legislation dealing with nuclear-powered ships, Chapter VIII of the International Convention for the Safety of Life at Sea 1974 should be updated to account for the development of small-scale molten salt reactors. Even more recently (2Nov2020 , London-based CORE POWER announced its participation with Southern Company, TerraPower, and Orano USA to develop Molten Salt Reactor atomic technology in the US https://www.spglobal.com/platts/en/market-insights/latest-news/shipping/110420-shipping-industry-should-consider-nuclear-option-for-decarbonizing-experts .

6.4.7 The history, whys, and hows of sustainable MSRs

All MSR breeder concepts save MOLTEX are at least 50 years old. In the USA no breeder concept other than the AEC's pet solid fueled, "liquid metal (cooled) fast breeder reactor" (LMFBR) ever received sufficient attention/funding to generate anything but "paper" (conceptual) reactors with, again, one exception – Dr. Weinberg's/ORNL's tiny graphite moderated "molten salt reactor experiment" (MSRE) operated for ~four years during the mid-late 1960's (MSRE 2018). However, that "experiment" couldn't breed because[282] it was too small (8 MWt) and its core wasn't surrounded with a fertile ^{232}Th-containing blanket. ORNL's breeder MSR R&D program ended circa 1973 because a financially strapped US federal government (the Vietnam War had been fought with borrowed money which ballooned its national debt triggering severe inflation) decided to fire the bothersome Dr. Weinberg (Weinberg 1994) and "study" only the LMFBR concept because it would be a much better bomb-grade fissile (plutonium) maker and had higher breeding potential (i.e., CR >1.3 vs the MSBR'S ~1.007). Meanwhile, the USA's nuclear industry was busy selling its first generation of much-enlarged versions of Admiral Rickover's enriched-uranium-fueled, light water cooled/moderated submarine reactor at cost so that it could then profit by servicing (refueling) them thereafter. Although several medium-to-full sized LMFBRs were subsequently built and operated in France and USSR/Russia, that concept never gained much traction with utility owners because they already possessed something meeting their requirements (mostly LWRs) and didn't want to deal with the issues revealed by the operational history of LMFBRs (e.g., mostly persistent sodium leaks/fires - Mahaffey 2014) or assume the greater costs of both those reactors themselves and the fuel recycling systems required to run them in a sustainable fashion[283].

"*sodium cooled reactors are expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair*"
Hyman Rickover 1957

The main reason that genuinely sustainable nuclear fuel cycles still don't get much attention in the USA is that most of its current political leaders seem to consider nuclear power to be a stopgap technology that with the "temporary" help of fracked natural gas, would enable us to "transition" to an imaginary clean/green world powered by conservation, biofuels, magically modified dams, wind turbines, solar panels/towers & huge banks of super batteries linked together by a zero-loss, world-wide electrical grid (Jacobson 2009, Lovins 2011, Jacobson 2017). Consequently, the US government's nuclear scientists/engineers have been encouraged to help their "industrial partners" render the latter's unsustainable nuclear fuel cycle more attractive for temporary niche-filling by championing "small modular" versions of their reactors

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[282] ORNL's MSR/MSBR program cancellation in 1973 was accompanied by the downsizing (firing) of its longtime Director, Dr. Alvin Weinberg. The rationale was, "*the USA could no longer afford to support two breeder reactor programs*". That was ridiculous because inn 1972 Argonne's LMFBR development work had cost US taxpayers 26 times as much ($123.2M/$4.8M) as had ORNL's MSBR studies - see Linda Cohen's, "The Technology Pork Barrel", Brooking Institution Press, 1991, p. 234. The real reason for those actions was that Weinberg had expressed doubts about the USA's approach to implementing the technologies that he had "invented".

[283] Utilities seek to keep things as simple/profitable as possible for themselves and their stockholders, not "save the world''.

even though they realize that such things they don't represent solutions to Mankind's long-term energy conundrum[284].

Another reason that the development of a genuinely sustainable nuclear renaissance continues to get short shrift is that implementing it would be impossible without first performing the "hot", hands-on research (not just paper studies) required to develop anything genuinely new. 750–900 kg of fission products would be generated within any fast MSR's fuel salt per GW_e year, all of which would have to be properly dealt with to prevent possible corrosion damage[285]. Similarly, the wall/walls of the reactor's core would experience extremely high neutron bombardment that might also cause damage. Convincing answers to the questions raised by these facts cannot be obtained until realistic testing is done under realistic conditions. Because the USA's national laboratories chose to replace their "hot" experimental facilities/capabilities and the people that worked in them with modeling/modelers several decades ago, it's become extremely difficult/expensive for anyone to perform such work (most NE-related "research" funding is currently spent upon new office buildings, "training", travel, maintenance, and other sorts of institutional overhead).

Successful implementation of any of the sustainable fuel cycles I've mentioned would satisfy 100% of Mankind's power needs "forever" fueled with abundant and readily accessible natural actinides – not just the 0.71% of natural uranium (^{235}U) fissionable in most of today's power reactors[286]. That would render clean/green nuclear power as "renewable" as is sunlight as well as

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[284] Here's the ABSTRACT of a recent critique of that policy: "Small modular reactors (SMRs) have been proposed as a possible way to address the social problems confronting nuclear power, including poor economics, the possibility of catastrophic accidents, radioactive waste production, and linkage to nuclear weapon proliferation. Several SMR designs, with diverse technical characteristics, are being developed around the world and are promoted as addressing one or more of these problems. This paper examines the basic features of different kinds of SMRs and why the technical characteristics of SMRs do not allow them to solve simultaneously all four of the problems identified with nuclear power today. It shows that the leading SMR designs under development involve choices and trade-offs between desired features. Focusing on a single challenge, for example cost reduction, might make other challenges more acute. The paper then briefly discusses other cultural and political factors that contribute to the widespread enthusiasm for these reactors, despite technical and historical   reasons to doubt that the promises offered by SMR technology advocates will be actually realized" (Ramana & Mian 2014).

[285] Redox control is necessary because fission of an actinide atom randomly generates a host of fission product atom pairs which may or may not possess the same net stable oxidation state as did the actinide itself. For instance, if the fission of a U^{+4} atom (atomic number 92) happens to generate a cesium atom (atomic number = 55) and rubidium atom (atomic number 92-55=37) both of which are stable only in their +1 oxidation state, the difference between those atoms before/after net oxidation state (4-2) will cause two of the anions originally accompanying the uranium atom (in this example, fluoride) to give up two electrons in order to restore electrical neutrality. That transfer would convert harmless, non-reactive, fluoride anions into one of the world's strongest oxidants (fluorine atoms) & therefore most corrosive species. A salt-soluble redox buffering agent (e.g., U^{+3} or Zr^{+2}) would scavenge up those fluorine atoms producing non-corrosive fluoride salts (UF_4 or ZrF_4).

[286] In the real world a significant fraction (typically 2/7) of the ^{235}U in NU is usually discarded during enrichment because it's cheaper to do so. However, in situ breeding of ^{239}Pu generally generates enough new fissile to compensate for that loss which is why state of the art LWRs require the mining/processing of "only" about 160 tonnes of NU/GWe year.

much cheaper, less environmentally impactful, and more reliable (Cohen 1983). For example, assuming 50% heat to electricity conversion (molten salt reactors run much hotter than do LWRs and would therefore generate roughly 50% more electricity per heat joule (GOOGLE "Carnot efficiency"), just the U within the topmost kilometer of the Earth's continents (i.e., 2.8 ppm of 4.2E+17 tonnes ≈ 1.2E+12 t U), could continuously generate 22 TW_e for 74 million years. Since the earth's crust contains 3 - 4 times as much thorium as it does uranium, let's say a total between them of ~12 ppm, breeder reactors could potentially generate ~2.7E+12 J's worth of heat energy from just one cubic meter of average crustal rock – that's about 56 times more energy than that provided by an equal volume of pure "banked" (in situ, dense & not chunked-up) bituminous coal.

Anyone who feels that such fuel mining would be too environmentally impactful should ponder the following realities:

- The USA's mountaintop-removal approach to coal mining
- Germany's gigantic brown coal strip mines (Figure 18).
- The fracking of the relatively "easy" (shallow) 1.6 to 3.2 km-deep shale deposits (Lallanilla 2018) currently being mined for both oil and gas, causes lots of mini earthquakes, occasionally pollutes ground water, and usually leaks some of its especially impactful GHG product directly into the atmosphere
- The ~100 ppm U in any shale so-mined potentially represents about 4000 times more clean energy as does its dirty ~5% of oil/methane/kerogen. This means that 4000 times less rock would have to be so-disturbed if its right constituent were to be properly "burned" to produce energy
- Huge amounts of phosphate rock containing a similar percentage of uranium have already being mined and processed – the resulting waste piles are already on the earth's surface and therefore easily accessed.
- Brazil's much heralded recent offshore oil discoveries are even deeper and covered with both rock and seawater (Presalt 2018).
- Nuclear power is far less damaging to both the environment and people than is the coal industry (Kharecha, P.A., and J.E. Hansen, 2013)
- The amount of mining required to fuel a breeder reactor-powered world would be much less than required to access the materials required to build a nominally equivalent clean/green and politically correct (non-nuclear) energy system
- Solar and wind power exposes people to considerably more radiation per kWh than does nuclear power due to the mining/processing (mostly in China) of the rare earths going into them (UNSCEAR 2016)

Chapter 7. Economics: The main reason that the USA's nuclear power industry is on the ropes

During the last decade, almost a dozen full-sized U.S. nuclear power plants have been prematurely "retired". Since clean energy commitments are expanding both globally and nationally, the value of existing nuclear power plants and those closures seem to be diametrically opposed. The US still plays an important role in the global nuclear industry because it pioneered that technology in the 1950s for naval submarine use and continues to generate more nuclear power than do the three next leading countries (France, China, and Russia) combined. . However, U.S. nuclear generation capacity peaked in 2012 when its utilities still possessed 104 operating nuclear reactors. As of 2019 US federal investment in nuclear research and development was the second highest among International Energy Agency members and international cost estimating guidelines are heavily based upon US reactor design and construction practice.

Because the International Energy Agency's (IEA) considers nuclear power to be essential to reduce carbon dioxide (CO_2) emissions, and that continuing to operate existing nuclear power plants (NPPs) beyond forty years is the most economical way to produce it, around the world, operating lifetimes of existing reactors are being extended. In the United States in particular, eighty-six of its still operating ninety-four reactors have obtained permission to operate for sixty years and six have already been approved for to run for eighty years.

However, as of November 2019, 23 of the USA's reactors were in various stages of decommissioning, and over half of the remaining are considered at risk.

The reason for this is that in a society that's "privatized" most of its government's responsibilities, an individual's personal security and therefore his/her behavior is almost entirely determined by his/her economic status. The same greed-based driver determines the behavior of people working for its governments and businesses. We are also strongly encouraged to live beyond our means which of course puts many of us in no position to challenge whatever system we find ourselves in. The USA's current energy marketplace does not sufficiently reward reliability and many of those nuclear plants' production costs (typically about 3 cents/kWh) often exceed the current "marginal" wholesale (not retail or total) cost of natural gas or wind-generated power[287].

Those factors are still driving the USA's energy futurists to embrace various combinations of wind + solar + combined cycle natural gas. Its southwestern region's (e.g., LA basin) high solar potential translates to lesser reliance upon natural gas but even there because building enough

[287] In the US both of those technologies often lose out to wind farms in wholesale dispatch stack bidding wars. Distribution utilities typically pay their suppliers about 2.5 cents/kWh) although the latter's lifetime "levelized cost of energy" (LCOE) is typically 8-9 cents/kWh. This can happen because subsidies more than make up for the difference.

battery capacity would be too expensive, over 30% of an adequately reliable grid's energy would have to be generated with reliable (dispatchable – not intermittent) sources. Due to the US Northeast's poorer wind and solar potential, its future cost-optimized power system would require even more natural gas.

Although public opposition certainly grew after it had happened, the common perception that nuclear power declined solely because of the 1979 Three Mile Island accident is wrong. Years of significant reactor construction cost overruns predating that accident had already tempered enthusiasm as had the fact that electricity demand growth turned out to be lower than anticipated due to policy changes that encouraged the outsourcing of heavy industry along with their good paying genuinely "middle class" jobs. By 1981, electric utilities, which operate the most capital-intensive industry in the nation, were paying 17 percent interest on loans for the construction of power plants that they had ordered a half decade earlier. That might have been a bearable escalation if not for the fact that their construction times were being stretched out from eight years to up to twenty thanks to the hordes of anti-nuclear "intervenors" making a profession out of tying up utilities in court. No company, no matter how solvent, could pay such interest rates, for two decades, while waiting to recoup the cost from the generation of power. That situation still obtains today.

In March 1981, Wall Street's Merrill Lynch recommended the cancellation of 18 nuclear plants, because of the financing costs. Utility bond sales were cancelled by financial houses. Six months later, Boston Edison's Pilgrim-2 plant was cancelled, as the cost had escalated from $400 million to $4 billion, simply because of the schedule stretch-out and high interest rates. The most prominent politically driven cost overrun was when the Shoreham, New York 0.82 GW_e nuclear plant originally estimated to cost US $350 million ended up costing $6 billion and then was never allowed to produce electricity. Falling oil prices during the 1990s along with the deliberate outsourcing of heavy industries (aluminum, steel, cement, silicon etc.) plus a demand to encourage the growth of "renewable" energy, incentivized utilities to build small, quick to start up/shut down, gas-fired power plants rather than nuclear power plants big, cheap, reliable, and "clean" enough to revive those industries.

A decade ago, here in the USA, President Obama declared, "*To meet our growing energy needs and prevent the worst consequences of climate change, we'll need to increase our supply of nuclear power. It's that simple. This one plant, for example, will cut carbon pollution by 16 million tons each year when compared to a similar coal plant. That's like taking 3.5 million cars off the road.... On the other side, there are those who have long advocated for nuclear power—including many Republicans—who must recognize that we're not going to achieve a big boost in nuclear capacity unless we also create a system of incentives that renders all forms of clean energy profitable. That's not just my personal conclusion; it's the conclusion of many in the energy industry itself, including CEOs of the nation's largest utility companies*". (Obama 2010)

President Obama was referring to an $8.3 billion federal loan guarantee for two new Westinghouse 1.117 GWe AP-1000 LWRs (numbers 3&4 –that site already has 2 older reactors) which were to be built at Plant Vogtle, Burke GA , with the reactors coming online in 2016 and 2017. Job creation was a key argument for it - projected 2500 temporary jobs during the build then 800 permanent. That project had originally been approved in 2009 and was expected to cost about $14 billion. In April 2011 after a good portion of that loan had already been spent, Environmental groups filed a petition asking the Nuclear Regulatory Commission to suspend the licensing process until "*more is known*" about the Fukushima nuclear accident. In February 2012, nine environmental groups filed a collective challenge to its design certification and a month later filed a challenge to the license that the Nuclear Regulatory Commission (NRC) had issued. In May 2013, the U.S. Court of Appeals ruled in favor of the NRC. By 24Sep18 that project's estimated cost had ballooned to $27 billion resulting in its being dropped "completely" (again) because the affected utilities simply couldn't afford to keep fighting an uphill battle.

In late 2020 that buildout was subsequently resumed and officially supposed to be completed sometime during 2021 and cost about $25 billion neither of which came to pass.

By the time that one of Vogtle's reactors had finally been started up (March 2023) that project's estimated cost was expected to come to about $30 billion. Meanwhile China had managed to buy, build, and start up four of Westinghouse's AP 1000s almost on time and budget[288] the first of which has been supplying power its electrical grid since 2018.

That project's dismal history demonstrates how costs quickly escalate when a project's cost drivers are poorly managed and/or the absence of a reliable supply chain, excessive litigation, slow regulatory interactions, excessive regulator billing rates, etc., become prohibitively burdensome.

Western-leaning countries' politicization of nuclear-related rules and regulations combined with exorbitant renewable energy subsidies, has rendered nuclear power a relatively poor investment thereby crippling it (Figure 74). Between 2013 and 2018, seven US already-paid-for nuclear power plants were permanently shuttered, and 12 others scheduled for closure through the mid-2020s. The USA is shutting down these well-functioning reliable power sources because their owners can't make money in its simultaneously "privatized" and deregulated electricity markets.

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[288]"almost" because cost overruns at both of its US build sites had led to Westinghouse's bankruptcy in 2017 which caused it to be unable to correct design deficiencies detected by its faster-working Chinese customers. Construction of the Virgil C. Summer Nuclear Generating Station's two other 1000 reactors was cancelled following Westinghouse's bankruptcy. The first pair of China's AP 1000s were originally estimated to cost CNY 32.4 billion yuan ($4.7 B) but ended up costing about 50 billion yuan ($7.3)B.

Technically clueless[289] journalists typically translate this to the much more attention-grabbing, "*nuclear plants cannot compete*" which is misleading in a cost per delivered kilowatt-hour basis. Today's nuclear plants are consistently among the least costly sources available, just above already-paid-for [290] hydroelectric dams. According to a paper entitled "Nuclear costs in context" (NEI 2017), the average total generating cost for a US nuclear power plant during 2016 was under $0.034 per kWh, 15% lower than 2012's when Japan's leadership's Fukushima-inspired "decapitated chicken frenzy" had already added another round of precautionary principled, "*just-to-be-safe*" overhead costs to US nuclear power as well.

The USA's most influential[291] decision makers don't seem to care that the cost of using fossil fuels is higher than the cost of transitioning off of those fuels, even in the short term before the resulting climate benefits kick in. That's because of benefits to human health, agricultural yields, and labor productivity. See https://www.pnas.org/doi/10.1073/pnas.2104061118

An updated evaluation of the social costs of carbon dioxide emissions estimates that every ton of CO_2 emitted costs human societies $185. That's several times higher than the $51/tonne figure that the US government's experts seem to have come up with - see . https://www.nature.com/articles/s41586-022-05224-9.

7.1 Today's "deregulated" electricity market –

> ***There is one fundamental lesson we must learn from this experience: electricity is really different*** *from everything else. It cannot be stored, it cannot be seen, and we cannot do without it, which makes opportunities to take advantage of a deregulated market endless. It is a public good that must be protected from private abuse. If Murphy's Law were written for a market approach to electricity, then the law would state 'any system that can be gamed, will be gamed, and at the worst possible time.' And a market approach for electricity is inherently gameable. Never again can we allow private interests to create artificial or even real shortages and to be in control.*
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> *S. David Freeman, re the "lessons learned"(?) from the ENRON debacle , https://www.commerce.senate.gov/hearings/051502freeman.pdf*

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[289] In a www-empowered world, "technical clueless" translates to intellectually lazy.

[290] In most of the world, hydropower is already nearly maxed-out because most of the locations suitable for big, powerful, dams are already so-employed, and Mother Nature provides only so much water to fill reservoirs. For instance, it doesn't make sense to build more conventional hydroelectric plants in California. Other dam-related issues include water stagnation, fish migration blocking, community uprooting, habitat loss, and species extinctions.

[291] They're the people paying for political lobbying.

Most of the world's nuclear power plants were designed and built back when electric utilities were heavily regulated vertically integrated monopolies with an obligation to serve and prices established via a government-approved, cost-plus rate of return algorithm. In this respect they were much like the single payer ("socialized") health care systems currently serving the USA's military personnel, most other Federal employees & ~100% of the EU's citizenry.

In the U.S., roughly five billion megawatt (MWh) hours of electricity are sold at the wholesale level each year (that's an average steady state power of ~570 GW_e), i.e., sold to a utility or another entity reselling that energy to residential, business, or industrial customers. There is no single national market for such wholesale transactions. In some regions, sales are conducted bilaterally through direct contact and negotiation, through a voice broker, or through an electronic brokerage platform, such as the Intercontinental Exchange (ICE). In some regions, specifically the Northeast, Mid-Atlantic, California, and the middle section from Texas to North Dakota, there are wholesale electricity markets operated by large entities known as regional transmission organizations (RTOs) and independent system operators (ISOs)—often collectively referred to as RTOs. Bilateral transactions can also occur in RTO regions, but through separate settlements and in compliance with complex RTO rules. These markets provide for the wholesale sale of electric energy (both day-ahead and real-time purchases), as well as ancillary services.

Public power utilities, state utility commissions, consumer- and low-income advocates, and industrial electric power customers have raised concerns about RTO-run wholesale electricity markets, which are not really markets in the traditional sense. The consistent theme I've observed while learning about those organizations is that they work better for their "service providers" than for its retail customers. The USA's citizenry experience more power outages than does any other developed country, its electrical grids are outdated, rundown, and neither its utilities nor its politicians are either incentivized to or willing to do much about it https://www.ibtimes.com/aging-us-power-grid-blacks-out-more-any-other-developed-nation-1631086 . The reason for this is that the USA has espoused policies that serve special interests and special people.

Such concerns initially revolved around high and volatile retail prices. However, more recently the leading concerns have been the cost and effects of the lack of transparency in RTO dealings and how some of the more consumer-oriented RTOs' ancillary "capacity markets" are hurting some of their power supplier-membership's bottom lines by "unfairly" undervaluing their systems' reliability".

The root cause of the USA's escalating electricity costs and faltering reliability is that industry's "deregulation" (privatization) which was sold to consumers with promises that it would lower the cost of electricity and provide them with "more choice"[292]. There never was a serious

[292] As is the case with the USA's health care and insurance systems, in the absence of at least one genuinely good alternative, providing more "choices" to customers doesn't benefit anyone except that business sectors' most lawyered-up providers.

discussion of what those individuals or businesses would be willing to pay for differing levels of reliability. The biggest concerns when deregulation became the law(s) of the land (circa 1996) were: (1) lower electrical demand than was anticipated before the Carter administration's "small is beautiful" policies[293], (2) the resulting overbuild of intrinsically reliable fossil-fueled and nuclear thermal power sources and (3) who would pay for all that spare capacity. The priority became transferring costs from wholesale ratepayers to the owners of power generation systems. The USA's problems now are (1) the reduced robustness and reliability of its current power system[294], (2) a large transfer of costs from wholesale rate payers to both retail ratepayers and taxpayers via government debt, subsidies, and deficits, and (3) a too-slow reduction in atmospheric gas emissions.

It's wrong to assume that privatized, market-based decisions will automatically solve energy, health, or environmental problems. Markets are good at identifying the lowest cost next/immediate step in addressing ongoing issues, not the best way to arrive at their best or lowest cost ultimate solutions. Markets would work if the product in question is fungible which while true with electricity itself, isn't with its production. Energy system reliability cannot be assured by substituting ineluctably unreliable power sources for fossil-fueled or nuclear-powered plants. The reason for this is that, as their degree of penetration increases, intermittent (unreliable) generators impose exponentially increasing transmission, storage, and backup costs upon the power system.

"*The ultimate test of man's conscience may be his willingness to sacrifice something today for future generations whose words of thanks will not be heard.*"

― Gaylord Nelson

In April 1996, the Federal Energy Regulatory Commission (FERC) issued two orders that changed the landscape of how electricity is generated, transmitted, and distributed throughout North America. Prior to then both the generation and distribution to customers by local service providers was owned and controlled by single entities (were "vertically integrated"). That constituted an impediment to entrepreneurs like Kenneth Lay's ENRON seeking to get rich generating, moving, and/or distributing electricity to the USA's retail consumers. Its Order No. 888 addressed "Promoting Wholesale Competition Through Open Access Non-discriminatory

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[293] The first step toward energy deregulation took place under the Carter Administration through a 1978 Act that gave small, "renewable" energy producers free access to the electric grid and forced utility companies to buy outrageously high-priced power. The multitude of low head hydro plants spawned by that act killed fish migrations in many of the West's erstwhile "trout" streams.

[294] The best description I've seen of the insider-dominated practices of the USA's "deregulated" electricity system is Meredith Angwin's latest (2020) book, "**Shorting the Grid**, The Hidden Fragility of Our Electric **Grid"** . It's a great read but may temporarily raise your blood pressure.

Transmission Services by Public Utilities; Recovery of Stranded Costs by Public Utilities and Transmitting Utilities." and its Order No. 889 added and amended existing rules "...establishing and governing an Open Access Same-time Information System (OASIS) (formerly real-time information networks) and prescribing standards of conduct."

The membership (not the so-served region's government) of each of the USA's wide area synchronous grid interconnections connect the combined outputs of the region's "all of the above" together to deliver well-synchronized AC power to millions of individual consumers. In North America there are four major interconnections each with many suppliers and distributors: the Western Interconnection, the Eastern Interconnection, the Quebec Interconnection, and the Electric Reliability Council of Texas (ERCOT) grid. In Europe one large grid connects most of the continent.

The USA's post-deregulation RTOs & ISOs are run like country clubs whose dues-paying members (mostly suppliers and distributors) establish loading order (bidding) rules that determine which electricity sources will be making their owners the most money over short, discrete - typically five to sixty-minute – time intervals. [APPENDIX XXXVII explains how a modern energy-based ISO/RTO 's bidding system works - it's too complicated to explain here without breaking up this chapter's narrative[295].]

Jobwise, "deregulation" has become another of the white-collar service industries that were supposed to replace the relatively grubby working-class jobs previously (pre-NAFTA) provided by the USA's heavy industries: e.g., its cement , steel, and aluminum industries along with the reliable power plants required to operate them. Jobwise, it has provided lots of white-collar work for the bean counters, analysts, lawyers, and lobbyists representing each of the "providers" in today's all-of-the-above energy supply systems but none for the horde of ex-industrial workers who've become uber drivers, store clerks, Walmart greeters, delivery persons, gutter guard installers, and "Proud Boys". Overall, deregulation has done more harm than good because electricity costs its consumers more and that industry's business models aren't preparing us for this century's (first oil, then gas, then coal) inevitable fossil fuel "peaks"[296].

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[295] Carmona et al's 28-page, densely illustrated mathematical masterpiece is a fine example of the level of expertise required to optimize an ISO/RTO's selection of energy sources in unregulated energy markets (Carmona 2013). It and a couple others like it helped me understand (but not appreciate) the reasons why there's an order of magnitude difference between wholesale and retail power costs in some regions.

[296] The March 2023 failures of both Silicon Valley Bank and Signature Bank demonstrate that Congress, the White House and banking regulators should reverse the Trump era's bank deregulation when they collectively caved to Wall Street and loosened the USA's banking laws.

The USA's electricity system is nominally regulated by a panoply of federal institutions and licensees (ISO's, RTO's, LSEs, FERC, NERC, NRC, State PSCs, federal laboratories…) each of which concerns itself with a small piece of the system, but none are either held responsible for assuring its overall reliability or punished if/when it fails. For example, NERC (North American Electric Reliability Council) is a voluntary, utility-managed, organization created in response to the hugely disruptive 1965 New York power blackout to improve US electrical system reliability. By design NERC is not a government entity to prevent it from "having too much power". The rationale was that if its analysts informed the USA's "Independent System Operators " about their issues, their members would be good little boys and girls and act in ways that would keep their systems reliable. The problem is that each RTOs' loss-of-load folks gradually become merged into "operations" which causes them to emphasize production costs, ignore reliability, and always go for the lowest cost, immediately available, energy. Any ensuing shortage problems would then be deemed force majeures (or "acts of God") by the authorities who had OK'd their paradigm and therefore thrown back on customers in the form of retail price spikes and/or blackouts.

Here's a great writeup about how crazy another "western world" country has become in pursuit of a market-based energy system. [Reality and Possibilities in Australia. Do renewables need their own grid? - Meredith Angwin]

Another of the downsides of today's deregulated electricity systems relative to the past's is that voters/ratepayers can't "fire" the people responsible for screwing up their lives and depleting their pocketbooks.

When the first power reactors were built, no one imagined a "what if" in which its electricity system would be deregulated and heavily subsidized "green energy" suppliers could capture additional market share by giving away their electricity whenever Mother Nature was cooperating with them - today's situation in the USA and other countries that have apes its deregulation initiatives. Those changes give unreliable energy suppliers a huge financial advantage meaning that the suppliers of more reliable power often "can't compete". I also suspect that no one back in the good old days ever imagined a "what if" in which nuclear power would not receive a financially relevant "carbon credit" for its zero GHG emissions. An analysis performed by the Brattle Group in 2016 concluded that simply granting zero-emission credits to nuclear power could secure its economic viability in competition with subsidized renewables and low-cost gas-fired plants. It said: "*A typical revenue deficit for a vulnerable nuclear power plant is around $10/MWh," which is equivalent to costing "the avoided $_{CO2}$ emissions... between $12 and $20 per ton of $_{CO2}$, varying with the regional fossil fuel mix that would substitute for the plant*". The USA's real commitment to lowering its GHG emissions is demonstrated by the fact that it still refuses to impose a carbon tax one sixth that of Sweden's.

An integrated, energy-only "all of the above", power grid must operate off the immediate dispatch stack. This means that an economic analysis of the cost of running a power grid with different supply mixes must account for all of its generators operating in a dispatch order determined by their marginal production costs which depend upon their capacity factors & maintenance, labor, and debt burden costs.

Everything is further complicated by the fact that different jurisdictions use different measures of system reliability. For example, one of ERCOT's independent analysts[297] (he's now become a gadfly) has volunteered the following explanation of its reliability-related considerations:

LOLP (Loss of Load Probability) is a measure of the probability that a system demand will exceed capacity during a given period, often assumed to be a full year :
LOLE (loss of load expectation) in days per year is the sum of the peak LOLP each day.
LOLH (loss of load hours) is the sum of the LOLP every hour for a year in hours per year. (NERC likes this measure).
LOLE/LOLH = the average duration of an outage in hours
LOLEV (loss of load events) counts events per year, can have two events in one day, and if only one event per day, will give the same value as the LOLE. The LOLEV is popular in ERCOT and CA and NERC. It's inferior to LOLE from convolution in my opinion.

"What I did is create a LOLE for the mornings before noon and an LOLE in the evenings after noon. I also only treat it as two events if the two events are separated more than 6 hours otherwise it's just one event. This makes the analytical LOLE come very close in value to the Monte Carlo LOLEV. The MC is inferior because it only has about 3 digits of significance whereas the analytical can easily have six digits significance and it runs a million times faster than MC. When taking differences between cases the accuracy of the LOLE calculation becomes critical. This is why you never see MC used very much. People who use MC don't know how to do the analytical convolutions although they are exceedingly simple.)
LOLF = loss of load frequency is identical to the LOLEV and is the number of occurrences per year in monte carlo
EUE or EENS (expected unserved energy or expected energy not served) same number. Australia prefers this.
PNW has an interesting definition of the probability in loss of load "

These sorts of decisions and calculations are extremely complicated which means that keeping the USA's chaotic "all of the above" power system working makes work for thousands of well-compensated financial, legal, statistical modeling, and IT experts all of whom add to its power systems' overhead and therefore retail costs. It also requires keeping lots of big fossil-fueled,

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[297] Since he is still consulting for ERCOT he'd prefer that his contributions to this book remain anonymous.

peaker-plant turbines idling so that they will be able to satisfy demand whenever Mother Nature decides to be niggardly.

A rational electrical energy system would supply reliable power at a reliable (predetermined) price in a dependable power market, not one that's subject to the whims of nature and financially incentivized by transitory dog-eat-dog competition and scarcities. Such a market must always possess at least 15% surplus capacity which condition can only be realized via long term, take or pay contracts[298]; i.e., one in which the purchasers of dependable electricity must pay for a predetermined amount of it whether they use it or not minus whatever the seller can recover by selling any surplus dependable-source power on an interruptible market.

Ideally, interruptible market prices should be determined by scarcity and marginal cost. However, from an administrative perspective it makes good sense to assign interruptible power a value, such as $0.02 / kWh which is periodically reviewed to ensure that it is simultaneously maximizing fossil fuel displacement while meeting marginal production costs. In today's world, liquid fossil fuel displacement should be more important than interruptible-type electricity revenue.

A dependable market based on consumer peak demand results in a high load factor. The incentive for demand minimization gives all consumers access to dependable generation at the lowest possible price.

From retail customers' perspectives, fixed known electricity prices are preferable and should be expressed in the simplest possible fashion; i.e., a peak demand charge plus an energy charge. That peak demand should only be measured at times when interruptible energy is not being supplied and reduced by a diversity factor[299] applicable to that market region.

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[298] These are the reasons for long term, take-or-pay, contracts.

- Any major energy transition will require large commitments for several decades
- Protects the sellers' stream of revenue.
- Convinces lenders to approve project financing.
- Facilitates decision-making and planning, particularly regarding budgets.
- Minimizes risk to the seller by transferring some of it to the buyer.
- Assists in mitigating other expenses, some of which are unforeseen and unpredictable.
- Eliminates competition for the term of the contract.
- Creates less of an impact on the credit-worthiness of the seller.

[299] Diversity factor is the ratio of the sum of the individual non-coincident maximum loads of various subdivisions of a system to the maximum demand of the complete system.

In jurisdictions with both privatized energy and properly run capacity markets like the US Northeast's PJM (*Pennsylvania-New Jersey-Maryland* I RTO, individual power plants get most of their fixed costs covered in the capacity market and all of their fuel costs and some of their fixed costs covered by the energy market. In such jurisdictions the dispatch order is less important for financial survival.

To decide which better fits a particular grid we should not just compare the cost of a >90% capacity factor nuclear plant with that of a ~50% capacity factor natural gas plant. The right way to end up with a clean power system is to start by figuring out what one should look like and then develop a plan to get there from here. Relying upon immediate market forces to determine each next step will lead to a dead end with ratepayers rebelling at high prices, stalled development, and saddle everyone with a high cost, still-dirty energy system that nobody is happy with. Germany and California provide "good" examples of such "stuck" systems.

Combined cycle natural gas plants are replacing coal-fired and nuclear in much of the world. Whenever possible they are operated as base-load plants with capacity factors like nuclear plants, 85–95%. However, they often aren't run that efficiently because more heavily subsidized zero fuel-cost wind & solar plants displace them in the region's dispatch stack. So, comparing the cost of nuclear doing base-load duty with a gas plant doing peak load duty to arrive at their operating LCOEs to choose between the two is not the right way to do it.

Our energy grids' decision makers need to stop thinking strictly about marginal energy costs because whenever the weather is "right" such energy can be nearly free from already-paid-for renewable sources. They should instead consider the cost of the *reliable* generation capacity required to meet their customers' peak power demands regardless of what Mother Nature happens to be doing. In a non-fossil-fueled world it should be such capacity, not immediate energy availability that determines the system's cost.

For instance, my "all-electric" Idaho home's energy demand ranged from a low of ~20 kWh/day in June when there's lots of sunlight and wind to ~95 kWh/day in Dec/Jan when the sun rarely peeked through the clouds and there was also relatively little wind.

A rationally operated RTO/ISO will usually assign negative marginal cost of production to inflexible (unable to rapidly load-follow) nuclear power plants (most PWRs but not BWRs) because of the high cost of any rule-mandated shutdown. So, provided there are no subsidies or fixed contract prices for any sort of supplier, such RTO/ISOs will always dispatch its inflexible nuclear plants ahead of all other sources which is why most of them still exhibit very high (~ 90%)capacity factors. Because this book's circa 2100 AD molten salt nuclear power plants are natural load followers they would be much better suited to a deregulated grid than are today's solid-fueled PWRs.

Of course, if there were enough of them, deregulation would make even less sense than it does now. From both environmental and cost perspectives, ensuring that a properly implemented nuclear renaissance's power plants are dispatched in the proper order, will require decision makers to revise subsidy policies (for example, Renewable Energy Credits (RECs), wholesale market rules and retail market rates). If we don't do that. a sustainable form of nuclear power won't be implemented meaning that meeting the world's emission reduction promises/goals will become unaffordable which in turn means that we won't honor/reach them.

The decision to subsidize hordes of wind and solar power suppliers caused two profound changes to the western world's power markets. The first is that wholesale (not retail) electricity prices got lower and, in some regions, went negative when demand is low and the weather is "right". The reason for this is that unregulated (privatized) wholesale energy markets are designed to constantly price electricity at its immediate (typically every 15 minutes) marginal production cost which for already-built renewable energy facilities (maintenance only, no fuel cost) is often close to zero. Consequently, as individual jurisdictions reduce their power grid's carbon emissions by adding more such heavily subsidized renewables, the average wholesale (but <u>not</u> retail) price of electrical energy drops.

In toto, today's electricity market is dominated by suppliers exhibiting the same sort of financial and political machinations that first made ENRON's investors rich & ultimately led to the world-wide 2008-2009 "great recession"[300]. Everything is apt to come to a head in the EU – another Minsky moment[301] - during the upcoming winter of 2022-23 due to its leaderships' collective refusal to wean their nations from Russia's natural gas, oil, and grain.

The second change is that clean reliable energy suppliers (primarily hydroelectric and nuclear) generation cannot compete in markets dominated by politically favored/subsidized renewable and natural gas unless that region's decision makers impose a "carbon price" much higher than that currently envisioned by most, but not all[302] of the Western world's leaders.

Canada's province of Ontario provides an example of what's happened. In 2016 its average wholesale market price had dropped to about 1.6¢ per kilowatt hour which was ~one-tenth of what its retail customers had to pay for it. Its low wholesale (but not retail) energy costs were a consequence of that province's success[303] at reducing carbon emissions achieved primarily by

[300] Which recession is apt to be dwarfed by the consequences of the USA's refusal to properly address the technical issues that inspired this book.

[301] A Minsky moment is a sudden, major collapse of asset values which marks the end of the growth phase of a cycle in credit markets or business activity.

[302] Sweden's "carbon" (CO_2) tax is now about $125/tonne. Consequently, its people are now clean & green as well as "rich".

[303] Ontario's electricity sector GHG emissions ropped by nearly 90% by 2017 compared to 1990.

replacing coal generation with base-load nuclear and peak-load natural gas. A great deal of additional politically correct "clean" (new hydroelectric, solar, wind and bioenergy) power generation capacity contributed to Canada's GHG reductions to a much lesser extent but ballooned total costs.

Another thing that nearly doubled retail prices over a 4-year period during the 1990s was that the cost of building its Darlington nuclear plant's four new CANDU reactors (3.51 GWe total) ballooned from an estimated ~$4 billion (mid 1970s) to over $14 billion by project completion (1993). The original schedule assumed ~10 years from initial approval to 4th unit startup – in reality, it took almost 18 years[304].

That project's primary cost inflators were as follows:

(1) Several re-schedulings due to unexpectedly low electricity demand (the same thing was happening in the USA).

(2) Unexpectedly high long term construction bond rates peaking out at around 17%/annum (ditto USA).

(3) Safety system software quality assurance regulation changes (ditto USA).

(4) Reactor cooling circuit hydraulic resonance problems.

(5) Further delays due to unfortunate management decisions (ditto USA).

Three of Canada's 2009 Green Energy Act's policies subsequently engendered another near doubling of retail rates.

(1) Replacement of old coal generation plants with natural gas plants and the refurbishment of 6 mothballed nuclear reactors.

(2) Deployment of ~5 GW of wind turbine capacity at high guaranteed (subsidized) contract rates.

(3) Deployment of about 2.5 GW of photovoltaic generation capacity at even higher contract rates (initially over 50 cents/kWh).

However, Canada did succeed in building its new reactors which means that its electricity is now both "clean" and reliable. It also means that most of its "new" wind and solar power is

[304]In contrast, due to its insistence upon tight scope and schedule controls, in 2002 China completed two CANDU 6 reactors at Qinshan, on-schedule and on-budget. https://canteach.candu.org/Content Library/20031701.pdf

superfluous and therefore must be dumped at a loss to US energy buyers but nevertheless paid for by Ontario's citizens.

One of the issues facing officials responsible for overseeing any all-of-the above regional power grid is deciding how much its unreliable energy sources contribute to overall reliability - in other words, what should their "capacity credit" be? That figure represents the fraction of a source's nameplate capacity considered firm for the purposes of calculating the system's safety margin. Consequently, it strongly affects the monetary value of individual suppliers' products which, in turn, means that determining the "right" credit for any such system's unreliable sources is a difficult, subjective, statistics problem generating lots of study, controversy, arm twisting, and lobbying – all of which overhead must be paid for by that region's retail customers.

The capacity credits of thermal power plants are usually >99%[305] with lower values assigned to intermittent energy suppliers reflecting their unreliability. Unfortunately, both typically and erroneously, those values are based upon average capacity factors, not the fact that those sources often do not generate anything.

In this discipline averages don't count any more than does the fact that a rotten old ship is perfectly safe 99% of the time but will immediately break up and sink during rare but nevertheless inevitable windstorms.

Capacity credits are system, not individual supplier-level statistical properties. Like standalone wind, a single natural gas plant deserves no capacity credit because sooner or later it will fail. However, assuming that plenty of natural gas will always be available (i.e., it cannot experience a common-mode failure), a system consisting of several natural gas plants is reliable because if one fails the others can take up the slack[306]. Individual generators contribute to system-wide capacity to varying degrees. Consider a system comprised 20 intrinsically reliable generators each with independent forced outages. While it is not impossible for all of them to randomly fail at the same time, its probability approximates zero.

On the other hand, the standalone wind power of any such system should get no capacity credit because wind generation drops to zero over large regions for many hours every year, everywhere. It's even worse with solar power because in addition to the unreliability caused by clouds, etc., on the average 100% of a every solar farm's output " fails" for a half-day, every day (nights). However, as components of a system including other generator types, solar panel

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[305] Other than for occasional equipment breakdown, a thermal power plant is as reliable as its fuel supply which is determined by the size of its fuel tanks or its reactor core's remaining fissile.

[306] However, if all its gas plants are fueled by a single gas line, they could all fail simultaneously.

arrays function like single big generators and offer some system capacity credit because their outages are more or less[307] independent of those of the other sources. Unreliable source contributions to system capacity are real but approach zero as their percentage-wise system power contribution increases. The question is by how much?

If regional power outages are deemed to be verboten, no practical combination of solar/wind/storage eliminates the need for some sort of reliable backup system capable of supplying 100% of whatever power is really necessary.

"I really do wish that we could constrain our 'renewables' advocates & sales folks to living with water supplies, transportation and toilets as expensive and flakey as their imaginary combinations of wind/solar/batteries and prayers would be"
Alex Cannara

Hydro, nuclear, coal, and gas power plants all possess turbines that act like huge flywheels and thereby provide grid-stabilizing synchronous alternating current (AC) power. Most of the world's existing nuclear power stations are PWRs whose outputs cannot be rapidly varied (possess poor grid load tracking capacity) and hence unsuitable for balancing wind and solar supplies. Thus, in the absence of storage reservoir-based hydropower (e.g., Texas's ERCOT) another issue raised by adding too much unreliable sourced power is that that region's thermal-sourced generators must be continuously grid synchronized and therefore run 24/7 to ensure grid stability. Their fuel consumption (currently mostly gas) while so-idling is relatively low but not zero which renders them extremely inefficient. In theory this issue could be mitigated by converting all of the region's renewable source generation to voltage source inverters and building lots of even less efficient fast start-type gas turbines.

The other function served by a region's fossil-fueled backup generators is to provide spinning (inertial) reserve. If W/S (wind/solar) generation is running unconstrained, its fuel-fed turbines will by default provide that reserve. As we increasingly overbuild unreliable sources, the grid's gas turbine-generated spinning reserve decreases meaning that its unreliable sources' output must be constrained or dumped[308] to keep the system's phase/frequency stabilizing turbines online.

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[307] "More or less" because regional 24-hour wind velocities usually correlate with sunlight intensities – they are not really independent variables.

[308] Most of Ontario's wind power is dumped into the USA's grid at exceptionally low cost to USA's utilities which doesn't provide much relief for its own rate payers or incentives to generate their own clean energy.

Overbuilding unreliable power sources reduces a system's fuel consumption but not its capacity requirements. Fuel consumption can be driven down to any arbitrarily low level depending upon the system's degree of its source and "battery" over build. Seasonal-scale electricity storage might work for a given year but sooner or later will become exhausted meaning that fuel-sourced backup will be required if its customers are not to be left in the dark. An announcement that a grid has only "0.1% fuel-generated power" does not mean that it has fuel-based power capacity equal to 0.1% of its electricity demand. It's far more apt to mean that that it maintains fuel-based generation capacity equal to its maximum power demand idling 99.9% of the time.

No realistic combination of solar/wind/storage eliminates the need for high-capacity reliable power backup.

Increasing any region's electricity system's inefficiency increases its inhabitants' cost of living and thereby lowers their living standards.

7.1.1 US Special case number one: ERCOT's characteristics, weaknesses, and strengths

The Texas Interconnection is an alternating current (AC) power grid (ISO) managed by the Electric Reliability Council of Texas (ERCOT). It serves roughly 30 million people and a coverage area larger than that of any single European nation. It is managed by and for its membership – mostly electricity suppliers and distributors - and maintained as a separate grid not subject to Federal Energy Regulatory Commission (FERC) regulation. However, it does "report" to NERC, the North American Electric Reliability Corporation, which "pretend regulator" (my term) cannot effectively punish (fine) ISOs that do not meet its "Loss Of Load Expectation" (LOLE) criterion of 0.1 days per year. Texas's law makers prohibited ERCOT's management from setting reliability standards or issuing fines to its membership. Its deregulated, energy-only driven marketing system possesses no mechanism to ensure that sufficient supplier capacity will be constructed and/or maintained to meet peak consumer demands when something goes haywire. ERCOT's leaders and membership have no business-relevant (i.e., financial) climate change related incentives despite its already large and rapidly growing proportion/penetration of weather sensitive supply "capacities". Because there are apparently no "sheriffs" left in Texas, ERCOT has become the "Wild Wild West" of the USA's electrical grids meaning that for the foreseeable future, its fracked natural gas is apt to remain "king" as far as its most of its electrical grid's energy supply is concerned.

That system can be accurately characterized with just two words: "*systematic unpreparedness*". The origins of its latest (February 2021) and most publicized major screwup included the lowest reserve margins in North America (NERC 2019), ignoring basic maxims of preparing for bad winter weather, and a market design that rewards shortages at the cost of consumers.

ERCOT's dispatch (loading) order for its supplier-bidders is determined by their estimates of marginal production during the next fifteen minutes. Its bidding rules do not financially reward the maintenance of reliable spare generation capacity[309] and therefore its managers maintain a razor-thin cushion to buffer unpredictable demand surges or supply failures. In other words, Texas's policy setters have built a house of cards which February 2021's weather-triggered system-wide power blackout collapsed. It is another example of what happens when "conservative" politicians permit a region's financial wolves to herd the rest of their more sheepish constituents.

Unlike North America's other electricity systems, ERCOT does not have a resource adequacy reliability standard or reserve margin requirement. Its reserve margin is determined by its suppliers' costs and willingness to invest based on market prices determined by market fundamentals and by the administratively determined Operating Reserve Demand Curve (ORDC) during tight market conditions. This approach is supposed to create a supply response to changes in energy market prices towards a "market equilibrium"; low reserve margins cause high energy and ancillary service (A/S) prices and attract investment in new resources, which investment is supposed to continue until high reserve margins result in prices too low to attract further investment.

About 15 years ago, Texas's politicians and investors decided to heavily invest in wind and natural gas which paired a notoriously unreliable, intermittent, energy source with a nominally dispatchable source – nominal because it relies upon just-on-time fuel delivery, not on-site storage. This ignores the fact that compressor-dependent pipelines aren't nearly as reliable as are big nuclear reactor cores, oil tanks, or coal piles.

For several years Texas's deregulated power market's customers have had to deal with instability during the summer. Its February 2021 cold spike disaster highlighted how its cold spells can cause them even greater problems. Winter storm "Uri" was a major **storm**, 2021producing snow and damaging ice from the Northwest to the South, Midwest and interior Northeast. Snow records were smashed in Texas. During the second week of that month (Feb. 12-16), that blast

309 In any deregulated ISO/RISO like ERCOT, "loading order" rules dictate which supply-resources will be profitable and therefore developed, not how they are dispatched (4.1 The Dispatch of Power Plants by an Electric Utility | EBF 483: Introduction to Electricity Markets (psu.edu) describes how a "dispatch stack" works). The reason that wind and solar is often dispatched to run full-out is because their owners can often offer distributors (utilities) zero or even negative prices if they are benefitting from a Production Tax Credit which most wind farm managers now choose over the federal government's 30 percent Investment Tax Credit subsidy. (Figure 71 lists some of the USA's" green power" subsidies.) That said, since the reliability of a system like ERCOT's (not much nuclear and no hydro) is totally dependent upon the availability of unsustainable, GHG-emitting, backup systems, (cheap but inefficient gas turbine "peaker plants"), it is "dirty", irrational, and uneconomic.

of winter weather (probably another manifestation of "climate change"[310]) dipped down from Canada to the Gulf of Mexico blacking out over 32 million US citizens from North Dakota to Texas's Gulf Coast, shutting down schools and grocery stores, causing lots of multi-vehicle pileups on iced-up highways, and killing lots of people, mostly poorer Texans (it's really rich and influential citizens flew off to places like Cancun to spend more time with their families).

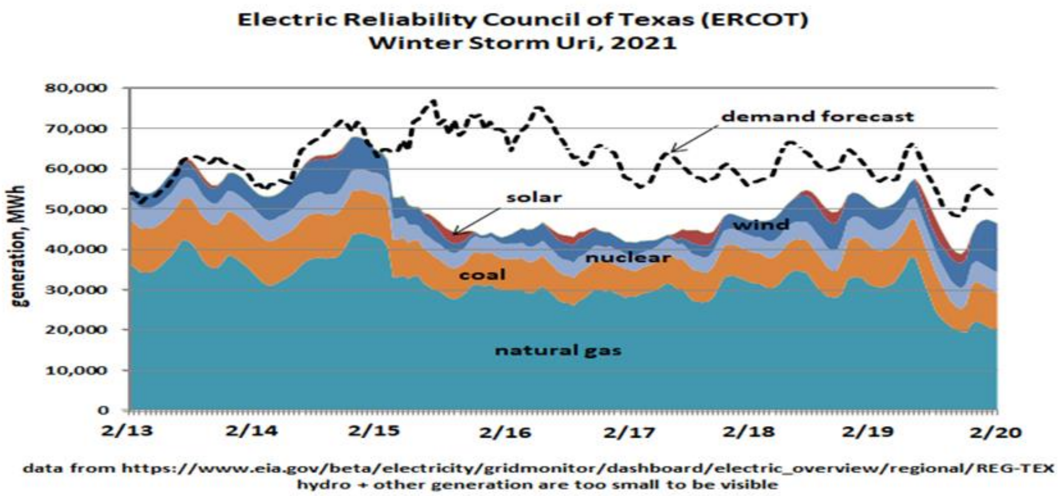

Figure 64 ERCOT supply, demand, and shortfalls third week of February 2021

Figure 52 depicts ERCOT's overall situation during that week. Note that the majority of Texas's electrical power is *always* produced by burning gas & that cascading failures of its much-vaunted gas supply system was the primary "technical" cause of that cold spell's extensive damage.

According to subsequent ERCOT press releases, its member-suppliers' wind farms did pretty much "meet expectations"- a statement which while both soothing-sounding and literally true is deliberately misleading because its weather experts didn't *expect* to get much wind power during much of that period – see Figure 65 (they knew that wind often dies down at the extremes - both high and low - of temperature changes).

310 Just a month after that black out, one of Austin Texas's senior TV weathermen said that having to forecast both snow and thunder in the same Texas Panhandle storm was a first-time occurrence for him. The Earth's weather is powering up because it is trying to levelize temperature differences between different regions. That is probably what also caused Iowa's hugely destructive summer-2020 derecho (straight-line inland hurricane).

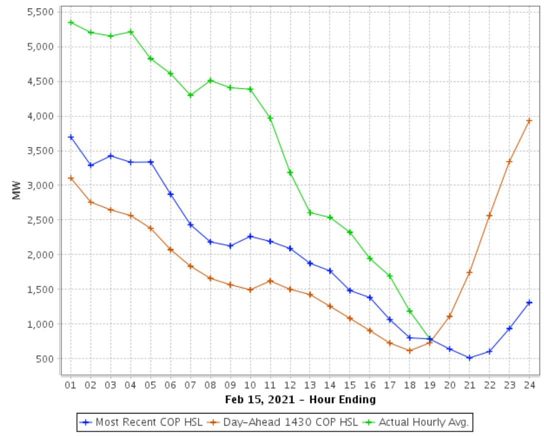

Figure 65 ERCOT's expected & actual wind power 15Feb21

This figure[311] (from www.ercot.com) reveals that Texas's much advertised ~28 GW's worth of wind power "capacity: could (& did) supply only ~2% that much power at a time when many of its gas-powered facilities had either frozen up or run "dry" due to reasons both technical and

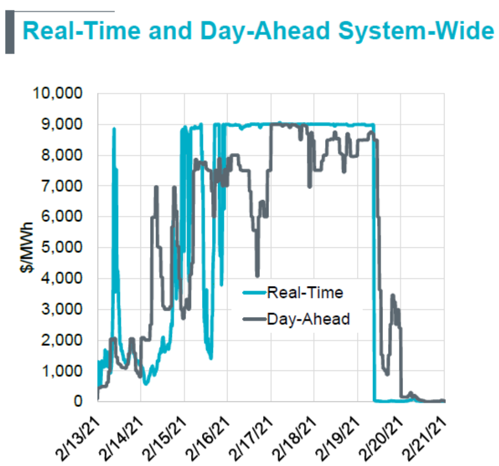

Figure 66 ERCOT's electricity spot prices during its February 2021 system-wide "Act of God"   (averaged ~$6.6/kWh for almost a full week)

political . ERCOT's managers called a Stage 3 emergency on the 15th of February and began nominally "rolling" power cutting that affected ~4 million of its customers. Its distributors shed up to 27 GW (~35%) of its forecasted total demand. Freezing conditions continued through 17 February, with a slight easing on the 18th when milder temperatures finally reduced customer

[311] In ERCOT-Speak, COP HSL means "Current Operating Plan High Sustained Limit.

demand. ERCOT had recently activated a program that pays Texas's large power users to reduce their consumption during emergencies - situations which usually occur during mid/late summer when much of the USA's Southwest would be uninhabitable without air conditioning. The difference between Texas's program and those of other regions is that its decision makers neither knew nor cared about what sort of businesses had volunteered to "help out" during its power emergencies. Unfortunately, several of ERCOT's ~450 volunteers were in the natural gas business (wells, pipelines, and compressor stations) the deliberate shutdown of which further reduced Texas energy supplies for both space heating and making electricity during that period. Over 4 million people were left without power for several days, billions of dollars' worth of property damage occurred (mostly water damage due to frozen pipes) and official records suggest that at least 150 people died, mostly due to hypothermia - other reports put the number of deaths at about 200[312]).

At least three of ERCOT's electricity distributors have since declared bankruptcy and several others are suing it regarding unexpected price spikes during the crisis. That bruhaha resulted in the resignations of several state and ERCOT officials and ERCOT's CEO, Bill Magness was fired.

On May 10, 2021, Brandon Young, CEO of Payless Power, one of the distributors of the ERCOT system's electricity, told an interviewer:

"*Now energy companies are on the brink of bankruptcy and the Texas Legislature has failed to act," Young said. "What happened wasn't a failure of industry, but rather interference by regulators that caused significant harm. ERCOT can review the ZIP codes of the facilities it shuts off which is how it avoids turning off power to hospitals and other essential facilities. New ERCOT and PUC commissioners need to review emergency protocols and work closely with current industry players to ensure this does not happen again. Further, the Texas Legislature must take steps to correct the pricing error which occurred to hold all industry officials accountable and ensure there are consequences in place moving forward."*

In response to that event, two of Texas's bigger energy suppliers have since proposed building new gas-fired power plants. These ~$8-billion proposals from Berkshire Hathaway Energy and Starwood Energy Group would build 10 and 11 gas-fired plants, respectively. In addition, ERCOT's recent Generation Interconnection Status (GIS) report reports that on March 30, 2021

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[312] As of 28Jul21 Texas's official estimate of the number of deaths caused by that storm is "from 150 to 200". Independent estimates based upon death records are much higher, more like 900. The total monetary cost of that storm's damage are now estimated to be ~$200 billion [Texas winter storm costs could top $200 billion — more than hurricanes Harvey and Ike - CBS News].

ERCOT approved Pro Energy Services' offer to have a new 306-MW gas-fired plant supply power to the Houston market.

The GIS report said that ERCOT has 151.3 GW's worth of projects in various stages of development, including 88.9 GW of solar, 30.3 GW of battery storage, 23.9 GW of wind, and 7.9 GW of gas-fired generation.

Unfortunately, unless Texas's energy business rules change, its new gas plants may not be able to deal with another such emergency because they may not be enough gas to burn - even in the short run, not after "peak" gas" has finally become an unescapable reality. https://www.forbes.com/sites/uhenergy/2021/03/05/getting-the-gas-you-need-was-a-key-problem-for-texas-in-storm The reason for this is that in Texas, pipeline companies control gas storage. Delivery of stored natural gas is prioritized to those with firm supply contracts, which its natural gas-fired peaker plant electricity suppliers are not required to hold. This means that those plants that the Texas grid was relying on during Feb. 2021's "Act of God"- could be last-in-line behind other natural gas clients. However, which of its customers did have priority is difficult to determine because unlike pipelines under federal jurisdiction, Texas's pipeline companies are not required to publicly disclose such contractual "details".

It is probably not just a coincidence that by <u>not</u> providing all the gas or electricity they could during such emergencies, spot prices will spike therefore permitting their members/suppliers to charge far more for what they do supply - that's how Texas's energy entrepreneurs can make the big bucks.

A related issue is that while Texas' pipeline authorities assured everyone that they still had plenty of gas (300 billion cubic feet) safely stored away when the grid went down, they didn't bother to also mention that that gas was essentially unrecoverable. The reason for this is that according to the EIA, the "working capacity" of Texas's 845 BCF of underground storage is 544 BCF which means that the gas pressure within its storage system when there's just 300 BCF left in it (845-544 = 301) would be too low to quickly pull back up out of the ground.

Texas's gas supply was also compromised by the fact that fresh-out-of-ground-stored gas often contains enough readily condensable stuff (heavier hydrocarbons and water vapor) that non-winterized near/on surface pipes and valves froze up during its mandated rolling blackouts.

ERCOT's representatives have said it is "*not clear*" how its "demand response" program's shutoffs to natural gas facilities affected supply to both residential customers and gas-fired power plants.

The Houston Chronicle reported that the Texas Oil and Gas Association, the state's largest oil and gas trade group, said it "*did not know*" whether its member companies had voluntary contracts with ERCOT to cut power or curtail operations during grid emergencies.

Such ignorance wasn't blissful for its customers but exemplifies the fact that to the USA's important-enough people, ignorance remains their last/best excuse for causing disasters for other people.

ERCOT has since published a CDR report (Capacity, Demand and Reserves) for the 20/21winter. It decrements ERCOT's installed wind & solar installed capacity to their average outputs excluding forced outages. It also published net power generation by source during that Act of God's three most critical days (2/15, 2/16, 2/17)[313]. Minimum generation in terms of percent CDR capacity for each of its power sources were as follows:

nuclear 75% (one of Texas's five nuclear reactor's cooling water temperature sensors failed which automatically "scramed" it for safety's sake)

coal 59%

gas 44%

wind 11%

solar ~0% (it was both cold and dark during much of that week).

Texas's February 2021 blackouts represent one of the biggest government failures in US history. Its residential electricity ratepayers — low-and middle-income citizens in particular — paid a hefty price for their leadership's mismanagement. First, they will have to pay outrageously high utility bills for quite some time due to the way that Texas's electricity and natural gas markets are managed/incentivized. Since the spot price of its natural gas also went up about 50-fold

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313 Texan decision making is especially faith-based (Godly?): leaders capable of remembering how He (She?) has behaved in the past would likely assign the blame for February 2021's weather-triggered disaster to human, not celestial, decisions. Several journalists (e.g., Looking back at some previous historic Houston cold snaps – Space City Weather) have since reminded us that there's nothing terribly surprising about that week's cold snap. For instance, during January 2018, Houston experienced 10 nights at or below freezing with a minimum of 19° F : In February 2011 Houston had another 12 nights at or below freezing with a minimum of 21° F: During December 1989 Houston had 14 nights at or below freezing with a minimum of 7°F: During December 1983, it experienced 12 nights at or below freezing including 11 in a row with a minimum of 11° F: January 1978 , 20 nights at or below freezing, minimum 21° F: January-February 1951, six nights in a row at or below freezing, minimum 14°F; January 1940, 11 nights in a row at or below freezing, coldest 10° F: January 1930, Houston's 8 nights at or below freezing included its coldest-ever recorded temperature (5°F): February 1899, nine nights in a row below freezing including two 6° F minimums : February 1895 12 nights at or below freezing over two weeks, minimum, 10° F.

during that episode, many households that were not totally blacked-out ended up with several-thousand-dollar combined gas/electricity utility bills[314].

Second, after courts get through establishing who gets the blame, they (or someone) will be on the hook for any defaults by ERCOT's market participants (suppliers & distributors). Finally, its consumers will be paying more for everything indefinitely because that state's lawmakers may finally be forced to insist that its public utility managers upgrade their systems. If sanity prevails(?) those upgrades will include winterizing power plants and gas lines, requiring some of its grid's suppliers to install on-site fuel storage systems, and paying suppliers to install sufficient reliable backup sources to dispatch power regardless of what the weather happens to be.

As far as Texas's future planning is concerned, let's first look at how its renewables normally perform during that part of the year when the sun is usually "out" during the daytime -see Figure 52. It depicts typical ERCOT intermittent source

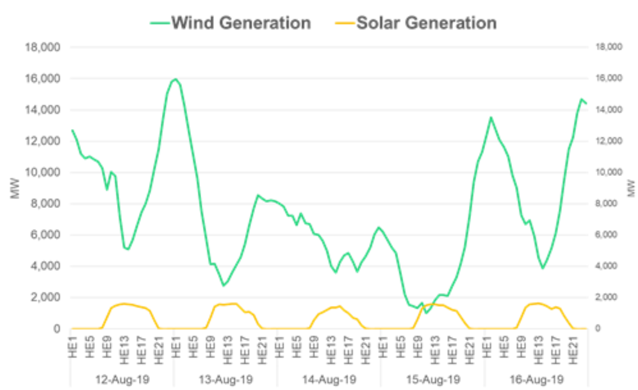

Figure 67 Typical summertime ERCOT wind and solar power production``

energy production during the summer of 2019. During that year, wind and solar power represented ~22 GW[315] and 1.5 GW of ERCOT's ~80 GW total nominal generation capacity. During that period, total system demand ranged between 75 GW (days) and 45 GW (nights).

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[314] For instance, ERCOT's rules allow so-subsidized suppliers to bid as low as negative (supplier pays the distributor) twenty-five cents and as high as $9/kWh (Figure 66). Profiteering during emergencies is another fine old US business tradition.

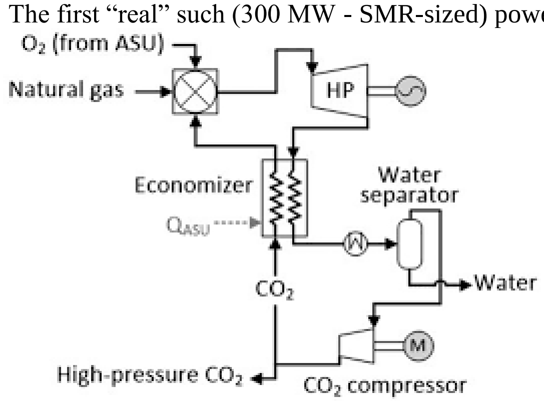
[315] By February 2021 Texas's total nominal wind power generating capacity had grown to ~28 GW because its energy entrepreneurs had rushed to add more windmills to qualify for a then soon-to-be-phased out renewable energy subsidy.

Note that even during "good" weather, Texas's renewables never satisfied over ~30% of its total power demand and often virtually none of it.

That's apt to continue for quite some time regardless of how many new windmills and solar farms are built because it's likely that a fresh round of subsidies and assurances will encourage Texas entrepreneurs to finally consider rendering the burning of its fracked natural gas "clean" via CCS (Meckel et al 2021).

That in turn suggests that when and if the USA's lawmakers ever do screw up enough resolve to properly tax carbon emissions, Texas is apt to succeed in implementing Mr. Biden's decarbonization vision well before California does. The reason for this is that wherever there's currently (not forever but who cares?) lots of "cheap" natural gas and good sequestration sites, methane reforming close-coupled with CO_2 sequestration represents the next best way after this book's hoped-for nuclear renaissance to produce both a pipe-transportable, "green hydrogen" fuel and clean electricity[316]. Texas could therefore decarbonize for less money per capita than

[316] To directly generate electricity, Texas's movers and shakers are likely planning to implement the Allam-Fetvedt ("Allam") Cycle -an exceptionally clean and efficient way of burning gaseous carbonaceous fuels and capturing the resulting carbon dioxide and water. It was first validated with a 50 MWth natural gas-fed test facility in La Porte, Texas, owned and operated by NET Power LLC, a privately held technology licensing company which in turn is co-owned by Exelon Corporation, McDermott International Ltd, Occidental Petroleum Corporation (Oxy) Low Carbon Ventures, and 8 Rivers Capital. The first "real" such (300 MW - SMR-sized) powerplant is scheduled to come on-line in the UK within 3 years.



The Allam-Fetvedt cycle is a heat-recuperated, high-pressure, Brayton thermodynamic cycle employing a transcritical-pressure CO_2 working fluid utilizing fuel combustion with pure oxygen (not air). It's begun by burning a fuel (usually natural gas) with oxygen diluted with a hot, high-pressure, recycled supercritical CO_2 working fluid within a combustor. The recycled CO_2 serves to lower its combustion flame temperature to a manageable point and dilute its combustion products so that the system's working fluid is predominantly CO2 (~95% by weight). The combustor's approximately 30 MPa exhaust enters a turbine-expander operating with a pressure ratio between 6 and 12. The turbine's discharge leaves as subcritical CO_2 comingled with combustion-derived water. Upon exiting an economizer's heat exchanger, it is further cooled to near ambient temperature by a central cooling system enabling condensation/removal of pure liquid water. The remaining nearly pure CO_2 working fluid enters a compression and pumping stage consisting of a conventional inter-cooled centrifugal compressor with an inlet pressure below CO2's critical pressure at which point, it possesses a fluid density over 500 kg/m^3. Most of it is recycled to the combustor after the addition of oxygen and fuel with the rest bled off as high-pressure, high density, and high could any state other than North Dakota--which is why most of Texas's big energy players are apparently rushing to get the required rules and technologies in place (Charles Forsberg, personal communication).

Regardless of whether they happen to "believe" in global warming or not, Texas's top dogs are perfectly willing to decarbonize[317] their region's power system if at the end of the day they've put together the USA's lowest-cost, game-winning, energy team--and right now they hold most of the high cards in that deck (fewer "environmentalists" and green politicians and more wind, sunlight, natural gas, and "technically" open minds).

Of course, on the other hand the cheapest option would be for Texas's most influential people to continue to take care of themselves while everybody else is learning to survive without power (oops - I meant to say, becoming more "resilient") by purchasing lots of "Generacs" along with the diesel/gasoline/propane-filled tanks required to fuel them.

Unfortunately, a note from Gene Preston[318] addressed to another member of Alex Pavlak's

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purity liquefied CO_2 suitable for sequestration or potential utilization as a fuel feedstock. Efficiency—the percent of energy inherent in the fuel that is converted to electric power—is the key measure of performance for natural gas plants, Rodney Allam, creator of the Allam Cycle, estimates that plants equipped with his technology can hit efficiencies of 59 percent while capturing 100 percent of the carbon dioxide generated—compared to 62 percent efficiency at the most efficient combined-cycle gas turbine plants (CCGTs), which capture no emissions. Carbon capture-equipped CCGTs cut that efficiency to 48 percent and capture only about 90 percent of the CO2 while still releasing CO, NOx, and other harmful pollutants into the air—in fact in higher quantities due to inferior fuel efficiency.

[317] Every time that a save-the-world scenario invoking CSS comes up, lots of PhDs opine that it would be impossible to pump that much CO_2 back down into the earth because it'd "just leak right back out again & suffocate everyone". That is unlikely - here are two things that I've just GOOGLED -up

1. "In 2013, the USGS released the first-ever comprehensive, nation-wide assessment of geologic carbon sequestration, which estimates a mean storage potential of 3,000 metric gigatons of carbon dioxide " [How much carbon dioxide can the United States store via geologic sequestration? (usgs.gov)]
2. "The U.S. Energy Information Administration estimates that in 2019, the United States emitted 5.1 billion metric tons of energy-related carbon dioxide"

Ratioing those figures suggests that the US could capture/store/sequester 588 years' worth of its current energy-related CO_2 emissions – longer if its energy were generated by burning just methane. Whether CSS could be safely done for 588 or 150 years doesn't matter anyway because if we just continue to keep doing what's easiest, we'll have burned up almost all of the world's recoverable fossil fuels within 100 years.

Most of the world's" technical" PhDs are amateurs in this arena & therefore voting with their "feelings". In this field, the USGS's PhDs are the real pros.

[318] Eugene G Preston, PhD/PE Electrical Engineering & CEO of Transmission Adequacy Consulting, 4710 Fawn Run, Austin, TX 78735

chat group (below) , suggested that there have been no "lessons learned" by Texas's most influential people. (Gene was addressing a question about what the situation is in Texas now a half year after February 2021's cold snap-caused power blackout.)

> *"Texas's grid has no capacity market, just a real-time, immediate production cost-based energy market. Its wind and solar power purveyors often bid in zero cost energy because they have out of market contracts and subsidies with the purchasers of renewable power. Gas, coal, and nuclear plants operating in the Texas market are less likely to have such bilateral contracts. The owners of the coal and nuclear plants that do have such contracts are still online and operating well and LCRA's coal plants fared well during February's cold spell disaster with no outages. Its nuclear plants have their capital costs covered by agreements predating deregulation. However, its grid's clearing price for just energy has dropped from an average of 40 $/MWh a few years ago to just 25 $/MWh and ERCOT's economics advisors now say that that's getting too low and puts its nuclear plants at risk of having insufficient revenue to pay operating expenses. Even some of Texas's gas plants cannot stay in business at those bid levels and are therefore being retired along with thousands of MWs worth of its coal plants. The feeble corrections being suggested/made in its energy-only market are not generating nearly enough revenue to attract new plant investments. There is no capacity requirement and no capacity market so ERCOT's drop in reserve capacity continues apace although it is doctoring up the data to make it appear that all is ok.*
>
> *ERCOT's new top manager is now in a lose-lose situation. If he corrects the data being released, it will show that Texas's totally privatized energy market is a failure. If he doesn't correct that data, he continues to hide that fact which might eventually come back and bite him like it did ERCOT's last CEO. The real problem is higher up: Texas's laws must be changed to hold everyone accountable for a minimum level of reliability and provide a way to pay for new reliable power plants. Until that happens its electrical system's generation capacity will continue to fall and rolling outages become more common and more severe. Climate change is making them both more frequent and more impactful.*
>
> *We are on a path that's leading us over a cliff. Those with parachutes may survive. Those without them will die in the heat or cold." Gene Preston 8/6/2021*

Dr. Charles Rhodes (another of Dr. Pavlak's group's members) summed it up this way.

The fundamental problem in Texas is that energy suppliers make more money by not meeting demand than by reliably meeting it. Until this issue is addressed no amount of contractual contortion will fix the situation.

However, since rumor has it that Texas's feedlots have created "mountains" of cow poo, it's more likely that one of its entrepreneurs will convince their best friends in government to either support the building of Raccoon-Mountain-like wind energy storage facilities for Texas's wind power or simply convert those mountains into methane via anaerobic digestors like those in most of the USA's bigger sewage treatment plants. That gas could be piped off to the nearest natural gas line & thereby used to mitigate the consequences of "Acts of God" like that caused by 2021's polar vortex. Since such gas would be both natural and "renewable" it should be eligible for lots of subsidies and therefore represent a "safe" investment.

All good Texans believe in gas & there's nothing quite so "green" as cow sh..-based biogas.

7.1.2 US Special case number two: California's CASIO

On the other hand, California's green policies and actions are based upon ideologies that render doing almost anything prohibitively expensive.

California's power elite disingenuously equate the environmental impact of electricity generated using emissions-intensive fuels with carbon-free nuclear energy and therefore are deliberately seeking to have fossil fuel businesspersons to replace Diablo Canyons' clean power with imported gas-fired electricity.

California Gov. Gavin Newsom recently signed into law Senate Bill (SB) 423 to accelerate the deployment of "firm zero-carbon resources" for electricity production.

It was one of 24 bills signed along with a $15 billion spending package focused on climate, clean energy, and wildfire/drought resiliency.

SB 423 defines firm zero-carbon resources as 'electrical resources that can individually, or in combination, deliver electricity with high availability for the expected duration of multiday extreme or atypical weather events and facilitate integration of eligible renewable energy resources into the electrical grid and the transition to a zero-carbon electrical grid.'"

The bill itself doesn't identify what the "firm baseload" sources required to reach CA's noble goals with the renewable sources that it does specify are, but recent history indicates that "in combination" means that CA's topmost politicians believe that burning more natural gas & dumping that CO_2 along with whatever leaks directly into the atmosphere doesn't add "carbon" to the atmosphere. This is another of the innumerable nasty things uniquely "known to the state of California" that the rest of us aren't enlightened enough to have realized yet.

PacifiCorp's - a subsidiary of Berkshire Hathaway Energy - Jim Bridger Power Plant in southwest Wyoming, provides coal-fired electricity for several Central Plains states. Though it is a significant source of revenue for Wyoming, "zero-carbon" it is not.

However, as long as they help to stabilize California's unreliable, renewables-heavy grid, fossil fuels now qualify as "zero-carbon" in that Golden State - even coal and oil

For most of the last decade, journalists have characterized "the California model" - high taxes, lots of environmental regulations, and aggressive climate change mitigation actions - as a progressive template for the rest of the United States. After voters elected Donald Trump, the media elevated California as leading the national resistance to his administration and agenda: after he had finally been "retired", they reported that "*California is emerging as the de facto policy think tank of the Biden-Harris administration and of a Congress soon to be under Democratic control*."

However, because of California's rising crime rates, excessive living costs, ever widening top/bottom wealth disparity, & burgeoning mentally ill and drug addled homeless population, its own citizens support for their leadership's "progressive" approach to governance is dwindling.

California's real problem is hyper-politicized, "liberal" faith-based decision-making that doesn't address its most important issues, not its politcians' "progressiveness".

US refinery capacity reductions are affecting diesel fuel output/cost. Furthermore, CA is again raising the intent to shut down diesel powered trucks and other vehicles near ports and transportation hubs where such traffic is high and the locals tend to be poor and suffer higher rates of pollution caused disease and mortality. The truck drivers are protesting because many of their rigs go home with them at night who don't yet have heavy truck-type EV's or the capability to charge their huge batteries. CA seems bent on economic suicide and working hard to eliminate all high-paying blue-collar jobs[319]. That is why California now has the highest poverty rate in the U.S. when adjust to the cost of living

If California's politicians push this agenda through ,cargo traffic will simply bypass CA. Several years ago, the expanded Panama Canal opened up enabling much larger container ships—from

[319] Germany too seems to be leading the EU back to feudalism. One of its government ministers recently suggested that Germans should only heat one room this winter and use no hot water except for sponge baths as he claims to be doing. Many of its big industries are shutting down or finding ways to reduce output. That is not sustainable. Maybe Germans will start emigrating to Texas too.

5000 to 14,000 units where a unit is a 20 foot long container. That shifts the economics and makes it much easier to bypass California ports and go through the canal to Texas or Charleston. China has also been busy building up port facilities in MX and other nearby countries and would be happy to reroute cargo around the idiots in CA.

The rest of the USA's "lower middle class" people find themselves in similar situations because they've chosen to elect "conservative" politicians whose primary faith is in the concept, "greed is good". Similarly, the EU's citizens have no one but themselves to blame for their burgeoning cost-of-living issues. Some of them may have to freeze in the dark during the upcoming winter to drive the point home that we humans cannot ignore "real" facts or become dependent upon ruthless energy potentates like Vladimir Putin. The EU's billionaire political campaign contributors aren't quite as rich as the USA's, but the flip side is that there's usually enough public money left over there to prevent as much starvation or freezing in the dark. Likewise, equality in public education and basic medical care are key Canadian differences that go a long way towards mitigating its other foibles. These are just two of the issues that the people we've elected to represent us have repeatedly failed to face.

The ostensible motive for President Biden's push to increase "renewables" is to lower "carbon" (mostly CO_2 and natural gas) emissions and thusly mitigate global warming. In most of the Western World, nuclear power can't be "counted" to meet such quotas, even though its total life cycle CO_2 emissions/kWh is lower than that of either wind or solar. To date, every nuclear plant that has been taken out of service including my new home state of Iowa's one and only Duane Arnold facility (Palo) has been replaced by fossil-fuel (mostly gas) burning substitutes – not the renewable "farms" that magical-thinking antinukes, green politicians, and energy businesspersons would have us believe. In the real world, unreliable power sources can't be backed up with other unreliable sources plus fabulously expensive imaginary batteries.

The only genuinely sustainable remedy for climate change is a vastly increased sustainable supply of clean energy. Due to electricity transmission instability issues and resource limitations at least 75% of that energy must be nuclear. At this too-late moment in time spending significant resources on almost anything else is a total waste of those resources.

We deserve the government that we choose to elect. California's especially environmentally concerned lawmakers have defined "renewable energy" in a manner that favors currently fashionable renewable energy sources, primarily ineluctably unreliable solar and wind. Because most of its ~300,000 "food insecure" citizens are being fed by the USDA's SNAP/WIC/etc. programs, Iowa's lawmakers also favor/subsidize the manufacture of food (corn & soybean)-based biofuels.

Real progressives like FDR and Bill Gates focus upon finding realistic solutions to real issues and were/are willing to do and learn from experiments. Hopefully, we here in Iowa will choose to do that too.

As of April 7, 2022 calls for extending the life of California's last remaining nuclear plant, Diablo Canyon, spawned a wave of new legislation seeking to derail progress toward that end. Because that plant has served electricity customers with reliable, carbon-free electricity for over 35 years and is now apparently supported by a majority of California residents, it's likely that that that legislation was motivated by out-of-state coal and gas interest lobbying – in particular those representing Berkshire Hathaway/PacifiCorp.

Senate Bill 1383 (SB-1383) would encumber that reactor's owner, PG&E, with onerous, expensive, and unnecessary reporting requirements. SB-887 and SB-1174 would enable offshore wind developers to replace Diablo Canyon's reliable support of California's electricity grid. Because offshore wind energy relies on natural gas plants for backup power, it threatens to guarantee gas a foothold in California energy for decades to come.

PacifiCorp is already building electrical transmission that would connect Wyoming coal plants directly to California's CAISO grid. Cost of the transmission corridor, estimated at $20 billion, would be borne in part by local ratepayers. After being led to believe their electricity will be generated from renewable sources, customers will instead be served dirty electricity from coal plants hundreds of miles beyond our borders.

"*California's fake-green 'energy transition' aims to export our emissions to other states, plain and simple, and all that's standing in the way is Diablo Canyon Power Plant*," says CGNP Legal Analyst Gene Nelson. "*With $billions in profit at stake, natural gas and coal interests are working to shut it down ASAP*."

Another especially important subsidy to California's most environmentally conscious and, of course, most well-off citizens is net energy metering, NEM (or net metering). It is a billing mechanism that allows consumers who generate some of their own electricity to use that electricity anytime, instead of when it is generated. It is particularly important with renewable, non-dispatchable sources like solar panels not directly coupled to an on-site energy storage "battery" (see Net metering - Wikipedia.) Monthly net metering allows those consumers to use solar power generated during the day at night, or wind from a windy day later in the month. Annual net metering rolls over a net kilowatt-hour (kWh) credit to the following month, allowing solar power that was generated in July to be used in December, or wind power from March in August.

In the Western world, NEM policies vary by country, state, or province with respect to; 1) their existence, 2) if and how long banked credits can be retained and, 3) how much they are worth (retail or wholesale). Most net metering laws involve monthly rollover of kWh credits, a small monthly connection fee, require a monthly payment of deficits (i.e., normal electric bill), and annual settlement of any residual credit. Net metering uses a single, bi-directional meter and can measure the current flowing in two directions. It can be implemented solely as an accounting procedure, requiring no special metering, or even any prior arrangement or notification.

California's Public Utility Commission (CPUC)'s policy NEM 2.0 compensates homeowners with credits to their power bill at retail rates. Net metering is highly controversial because it affects different interests/people differently. Utilities contend that distributed generation systems, like rooftop solar, present unique challenges to their future (profitability) and have therefore led a largely unsuccessful campaign to eliminate net metering because the owners of such systems do not pay the full cost of grid services[320] , thus shifting their share of that cost onto customers that don't own their own distributed generation systems. Most people who do own them still rely on the grid for power whenever their systems aren't producing because fuel-burning residential generators are too expensive[321].

A 2014 report rightly claimed that net metering in California produces excessively large subsidies for typical residential rooftop solar photovoltaic (PV) facilities which must then be paid for by other residential customers, most of whom are less affluent than are those being subsidized. In addition, the report points out that most of these large subsidies go to the solar leasing companies, not individuals, which accounted for about 75 percent of the solar PV facilities installed in 2013.

Consequently, the California Public Utilities Commission (CPUC)s recently approved another way for solar panel owners to receive credit for the energy their installations send to the grid. The new approach is called Net Billing, and will replace the older system called Net Energy Metering (NEM) for those signing up to participate after April 13th, 2023. Net Billing provides lower electric bill savings for solar owners than NEM because it credits rooftop panel owners

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[320] Since the 1990s, California's customers have been paid nearly the full retail price for electricity that they send to the grid. Since its residential prices are about twice those of any other western state, its regulators offer a sweet deal to solar households that keeps getting sweeter as utility rates rise. Those prices are 2-3 times higher than the actual costs avoided when a rooftop system pumps kilowatts into the grid because its customers must pay for massive, fixed costs that don't decline when some households export solar power to the grid. Those costs include most transmission and distribution costs, wildfire mitigation (cutting trees and bushes around power lines), compensating past victims of wildfires, paying for energy efficiency programs, subsidizing electricity for low-income customers, and, of course, investing in politically correct renewable technologies.

[321] According to its specifications, a typical state of the art home generator like Honda's " "EU3000iS Super Quiet Portable Inverter Generator" is only about 15% efficient at converting its fuel's (gasoline) heat energy to electricity. When run at its full-rated capacity (2800 watts) its 3.4-gallon fuel tank will run for 7.2 hours meaning that with California's $5.25/gallon gas, such power costs about 88 cents per kWh plus whatever the machine cost divided by the number of hours it'll run before "dying". (A bit of internet shopping in August 2021 suggested that one of them could be purchased for ~$2350).

with the wholesale, not retail, value of such electricity. Of course, the effectiveness of any such rule change depend upon the period when wholesale cost is computed which means that California's politicians, modelers, lawyers, and lobbyists will still be doing lots of "work" (overhead) that they must be paid for.

Another purely technical problem with net metering in a "privatized" energy market is that it incentivizes the addition of large, asynchronous, and highly variable (weather determined) amounts of power to the grid which reduce the fraction supplied by its synchronous generators. Since the demands served by the grid are also highly variable (both in magnitude and reactivity[322]), if too much of its power is asynchronous, the entire system becomes unstable which can and does lead to collapse (total blackouts).

In the USA Renewable Portfolio Standards (RPS) laws have been enacted by 29 states and the District of Columbia. California's especially aggressive RPS program sets continuously escalating renewable energy procurement requirements for the state's load-serving entities. Generation must be procured from RPS-certified facilities. A recent review of data compiled on characteristics comparing states that did and did not adopt RPS programs indicated that seven years after Program passage, a typical region's renewable generation share rises by ~1.8 percent while its average retail electricity cost goes up 11%. Twelve years after adoption, the renewables share goes up by 4.2 percent accompanied by a retail price increase of 17%. Retail cost inflation exceeds marginal operational costs reflecting costs assigned to ratepayers due to additional people-type overhead[323], stranded assets, intermittency, and additional transmission/distribution costs (Greenstone 2019).

Here's an example of why Mr. Gates feels that way.

California's Public Utility Commission has just released its final report on its August 2020 electricity grids flex alerts and brownouts. http://www.caiso.com/Documents/Final-Root-Cause-Analysis-Mid-August-2020-Extreme-Heat-Wave.pdf. A striking feature of that report is its similarity to a religious tract - its writers' "vision" isn't questioned even though readily observed/documented facts suggest that it is faulty. Another is its recommendation to double down on California's bet on exceptionally expensive short-term fixes like giant lithium-ion

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[322] "reactivity" refers to a load supplied by an alternating current (f =cycles/second) generating system in which its current and voltage are out of phase: total impedance ("load" in ohms) = $Z = -j/2\pi fC + j2\pi fL + R$) In this context, the -j term represents the 90-degree phase shift occurring between current and voltage in purely capacitive (C in farads) or inductive (L in Henry's) circuits.

[323] In the food sector, such wholesale-to-retail cost inflation is nominally due to the extra "value" that professional services add to raw commodities. It's hard for me to understand how that justifies the current retail costs of things like canning lids, peanuts, potatoes, carrots, onions, apples ($4.29/pound!!), & soybeans in the USA.

battery banks. There is no discussion of long-term reliability issues or mention of mitigation possibilities such as seawater-pumped hydro storage[324], reviving the “nuclear option”, or any of the other “obvious” options that would have been considered 50 years ago. I do not know if this is due to the same sort of stove-piped thinking that dominated DOE’s nuclear projects or simply that California’s PUC remains stubbornly clueless about their technical options. California's grid is failing because its decision makers listen to attorneys, fundraisers, and holistic make-believers about how to power an electricity grid, not to electrical engineers and the people who operate power systems none of whom believe that a reliable grid can be run with unreliable energy sources alone."

California’s "market language” suggests that it does not purchase dependable capacity either domestically or from neighboring power grids to ensure its citizen’s reliability needs. Its market participants only purchased energy on the spot market from their neighbors & its energy entrepreneurs spent billions on batteries so that they might play the spot market via energy arbitrage -an endeavor that would be self-defeating if implemented on the scale required to address that state’s long term energy issues[325]variability. Spot market energy prices are much lower than that of energy backed up with dependable capacity. The latter is typically three or four times more expensive.

Spot market energy imports are interruptible during capacity shortages. Since the recent heat wave affected California’s neighbors too, their energy exports were interrupted meaning it did not have enough dependable domestic capacity to meet peak demand. This is the fundamental problem with intermittent renewables like wind and solar. They are not dependable and adding enough battery storage to remedy that fact would be prohibitively expensive!

The underlying political issue is that no one seems to be responsible for assuring that Texas’s, California’s, or any other US region’s electrical grid is either reliable or affordable. Spot energy purchases should not be assumed to satisfy reliability requirements. Our decision makers must contract for dependable capacity, not just immediate “energy” to meet their systems’ reliability requirements.

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[324] Unlike most of the USA much of California’s coastline is lined with several hundred-foot-high cliffs upon which it’d be possible to site lots of Raccoon Mountain-like pumped storage facilities utilizing sea rather than fresh water. Of course, none of its politicians dare mention that because California’s technically clueless intermittent power-loving environmentalists always oppose building new dams, a necessary feature of any such project. They also oppose any other practical way to mitigate California’s energy-related issues or, for that matter, its housing affordability and most of its other real issues.

[325] If there were enough battery capacity to do that (that’s impossible with today’s batteries - too expensive), there would be little spot price variability which would eliminate arbitrage’s current profitability.

The USA's solar energy industry's champions are currently telling their Congressional supporters that they are finally willing to lose ***some*** of its subsidies. Solar power's current federal subsidy for solar is 30% of construction cost plus an additional 10% due to the especially rapid depreciation (short lifetimes) of solar power plants. That subsidy is now scheduled to ramp down to 10% by 2022 and remain there indefinitely. It's not a consequence of declining real costs because PV manufacture has become a mature industry which means that further such declines will be moderate. The real reason is that the industry's leaders realize that investment tax credits (ITCs) aren't their product's most important subsidy. Their real gold mine is the "renewable portfolio standard" (RPS) dictating that a certain percentage of a grid's electricity be produced by what they are selling. Moreover, technically clueless Green New Dealers are apt to ramp up those mandates over time creating a chain of events guaranteeing their profits for decades to come. If that   weren't enough, renewable industries' champions are trying to freeze such quotas into state constitutions to render it almost impossible cult for its consumers to escape the "green" trap being set for them[326].

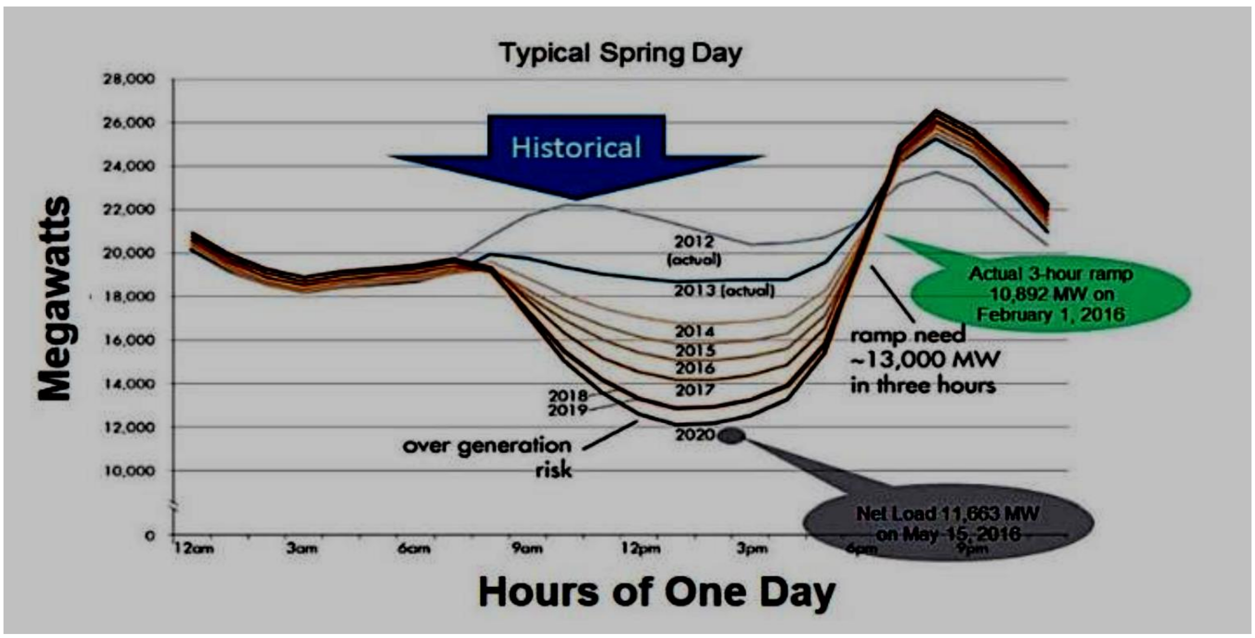

Figure 68 California's 'duck curve'   (Forsberg 2016)

Figure 68 depicts California's "dispatchable source" power requirements vs time of day during the decade that its citizens installed millions of rooftop-type solar panels. Note the following:

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[326] This paragraph is a 250-word rewrite of Norman Roger's essay (Appendix XVII), https://www.americanthinker.com/articles/2019/07/disentangling_the_renewable_energy_scam.html.

- Historically (pre solar) California's total power demand during a typical spring day varied about 25% (from about 18 GW_e to 24 GW_e) ~80% of which was provided by thermal-type (nuclear and fossil-fueled) power plants
- As more and more solar panels were added, the total amount of dispatchable energy (not "capacity") required was somewhat reduced
- However, more, not fewer, gas-fired dispatchable power plants had to be built/used because California's demand maxes out just as the sun is going down in the evening
- On the average its dispatchable power plants must still supply 100% of demand for about two thirds of each day and more when it's cloudy
- Those plants must also be able to respond very quickly when the sun sinks or clouds roll in - much more quickly than could/did California's "old" power sources. To respond quickly enough, today's backup gas burners are never really "off", but kept warm, their turbines spinning, burning gas, in "backdown mode" because it's both expensive and damaging to start a peaker plant's gas turbine quickly from cold.

Not depicted in this figure is the fact that California's deregulated wholesale electricity spot prices often go negative at the bottom of a sunny day's "duck curve", typically at about 1 PM[327].

Everything gets worse when a heat dome[328] like the one that fried southern British Columbia last year (2021) settles in along the west coast. In September 2022, widespread temperatures eclipsing 100°F exacerbated by tropical humidity smashed all-time records in the Central Valley and NorCal with a life-threatening 110°F+ heat wave.

One of the consequences of California's rolling blackouts & other energy-related precarities is a great deal of interest in high tech gadgetry that would render its most important homeowners more resilient.

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[327] When a market adds lots of solar capacity, the spot price paid by its distributors (not its retail rate payers) drops precipitously near the middle of cloudless days. The *incremental* cost of solar production then is about zero and producers receiving subsidies proportional to production will bid spot electricity prices down to negative values if their "production" subsidy exceeds them to continue sales. The same thing happens on windy days when there's lots of similarly subsidized wind power.

[328] A "heat dome" is a lid of atmospheric pressure that traps hot air beneath it. They form when an area of high pressure over the ocean moves over adjacent land and is then heated up by the sun for several . That area gets continually hotter which stops clouds from forming and therefore exacerbates heating which in BC's case caused temperatures to peak out at 122°F. These domes persist for as long as it takes for them to either fall apart or get dispersed by winds, such ais the jet stream.

One such gadget is an Australian tech startup's, " *hydrogen storage system for domestic solar systems. It is the world's first integrated hybrid hydrogen battery that combines with rooftop solar to deliver sustainable, reliable, and renewable green energy to your home and business*".

LAVO's 40 KWh energy "*storage system is about 1.68 m high, 1.20 m wide, and weighs a meaty 324 kg* (about the same as would a lithium battery-based storage system), *making it very unlikely to be pocketed by a thief. The hydrogen is stored in a patented metal hydride sponge at a pressure of 435 psi* and is converted back into electricity with an internal fuel cell.

LAVO's product (?) is admittedly very clever but will cost its owners about $25,000 and provide them with only as much electrical energy as would a $ 94* generator burning about twenty dollars' worth of gasoline.

However, it is eminently politically correct and will probably sell like hotcakes in California's more exclusive neighborhoods.

While the heat dome has been punishing everyone, it's been a life-threatening crisis for the state's unhoused population. Resources to provide cooling centers and crucial water supplies have been woefully inadequate. And though the heat wave seems poised to ease up over the weekend, our changing climate means we must be prepared to help those who are most vulnerable as these kinds of extreme events become more common.

Meanwhile as blackouts and flex hours roil California's citizens and economy its regulators and the local utility responsible for its last nuclear power plant, Diablo Canyon, continue to lobby for shutting it down.

This even though nuclear energy is clean carbon-free energy, and that the plant was built to operate for decades more.

Underlying the puzzling decision is a complicated morass of local politics, utility economics, and fear.

Diablo Canyon is now that state's only operating nuclear power plant; three others are in various stages of being decommissioned. Between them Pacific Gas & Electric's (PG&E)s two Westinghouse-designed 4-loop PWRs produce about 18,00 GW·h of electricity annually (8.6% of total California generation and 23% of its carbon-free generation), serving the electrical needs of more than 3 million (10%) of California's people,. It produces electricity for about 6 cents per kWh, considerably under the average cost of 10.1 cents per kWh that PG&E paid for electricity from its other suppliers in 2014. However, in 2016, PG&E announced plans to close both reactors in 2024 and 2025 because California's energy regulations give renewables priority over nuclear meaning that it would likely only run half-time thereby rendering it uneconomical. (Nuclear plants provide base load in order to spread their large fixed costs over as many kWh of generation as possible.) In 2020, the California Independent System

Operator's (CAISO) experts that when that plant closes the state will reach a "critical inflection point", create a significant challenge to ensuring grid reliability without resorting to more fossil fuel usage, which would jeopardize California's greenhouse gas reduction targets. Full decommissioning of the plant is estimated to take decades and cost nearly 4 billion dollars.

However, those facts don't matter in a state because it's another of those silly things uniquely "known to the state of California" which have collectively convinced many of its citizens to vote with their feet.

California's problem is that it has a non-functional government. It's not just the power sector. They have the highest rate of poverty in the> U.S.--great news for the politicians in Mississippi who can point to their progress. They decided 20 years ago not to use prison labor to remove underbrush--got the predictable forest fires. Same with the water problem. What California specializes in are reasons why it's not their failure--blame the climate, blame the feds, blame anyone. It is across the board which is why the state is losing population. Fifty years ago they would have found fixes to those problems.

Charles Forsberg (2022)

Here's another troublemaker's opinion of California's approach to becoming "green". https://www.manhattancontrarian.com/blog/2021-8-10-trying-to-see-if-californias-energy-plans-add-up iss a link to the March 15, 2021 Report of several California agencies charged with meeting California's 2045 zero carbon target, that Report being titled "Achieving 100 Percent Clean Electricity in California: An Initial Assessment."

Does California's multi-agency report provide either that Manhattan or this Iowan contrarians with reason to believe that its energy experts have a good idea as to how to get to a zero-emissions electrical grid?

The answer is "no" because a careful reading of their report reveals that 1) its authors don't know the difference between energy and power, and 2) they're unaware of how much "storage" their politician-customers' magic scenario would require (read both links)

I'll finish off this sad subsection with a Sept 1, 2022 (this morning) press release originating from Arroyo Grande, CA (there's still hope).

"*Early this morning California's Assembly reopened debate on a bill that would extend operation of the state's last nuclear power plant. Assemblymember and bill co-sponsor Jordan Cunningham began with an impassioned argument for approving the bill, and shortly thereafter it passed with resounding support (67-3). Narrow passage in California's Senate followed minutes later, with Gov. Gavin Newsom's signature expected later today.*

Though continued operation of the plant has only been granted through 2030, some legislators seemed to accept that a completely renewable "energy transition" might not be possible. Plant supporters, however, were ecstatic. "I'm in disbelief," said CGNP President Carl Wurtz. "This has been the culmination of a decade of work for CGNP, of thousands of hours of research, *filings, outreach, and testimony. It's unfortunate it took the lights going out for many to appreciate Diablo Canyon's value, but better late than never."*

CGNP Legal Assistant Gene Nelson was quick to credit the dedication of hundreds of other volunteers and professionals. "The last-minute passage of California SB 846 (Dodd) is the product of incredible teamwork, both within CGNP and many other groups," he said. "There were also those behind the scenes whose professional expertise proved critical to this legislation's success. All deserve our deep gratitude."

7.1.3 Other US grids

Dr. Alex Pavlak has performed an analysis of how best to go about assuring that the people served by the USA's northeastern-most regional transmission organization (PJM) would have 100% GHG-free power by 2040. That report points out that, while a great deal of effort has gone into trying to render such systems reliable elsewhere (e.g., Denmark and Germany's) without nuclear power, no one has actually succeeded (see APPENDIX XXXI).

As California's electrical grid's (CASIO's) pre-deregulation spare capacity disappeared, the cost of lowered reliability began to show its ugly head. Consumers were upset because they thought that reliability was an inherent part of California's electricity system assured by the rates they pay for its power. They did not realize that NERC[329]'s recommended reliability requirements could only be met in a "privatized" electricity market that adequately rewards firm capacity, not one that doesn't.

Some ISO markets did evolve to include capacity markets satisfying the NERC reliability requirements, but neither ERCOT's nor and CASIO 's moved sufficiently in that direction. The USA's sky-high per capita greenhouse gas emission rates, California's rolling blackouts, Texas's emergency alerts, the Northeast's gas supply shortages, and the relentlessly increasing precarity of many of its energy sector's job holders means that its current energy policies have failed.

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[329] The USA's independent electrical power systems are nominally regulated by a panoply of federal institutions and licensees (ISO's, RTO's, LSEs, FERC, NERC, NRC, State PSCs, federal laboratories…) each of which is concerned with only a small piece of the entire system, but none is responsible for assuring its overall effectiveness. For example, NERC (North American Electric Reliability Council) is a voluntary, utility-managed, organization created in response to the hugely disruptive 1965 New York power blackout to improve US electrical system reliability. By design NERC is not a government entity to prevent it from "having too much power". The rationale was that if its analysts informed the USA's "Independent System Operators "(ISOs) about their issues, they would be good boys and girls and act in ways that would keep their systems reliable. The problem is that these ISOs' loss of load folks gradually become merged into operations causing them/it to emphasize production costs, ignore reliability, and always go for the lowest cost immediately available energy. Any ensuing shortage problems are then thrown back on customers in the form of retail price spikes and/or blackouts.

There has never been a cabinet-level performance review of what the goals and justifications of electric utility deregulation were versus what actually happened. Federal and state governments defaulted on their fiduciary responsibilities to their citizens when they forced the breakup of integrated utilities thereby creating today's immediate energy cost-only market mentality. It should be straight forward to come up with the numbers required to complete such an audit. If doing so is not straight forward, that's just another characteristic of a system lacking understanding and control. The separation of generation, transmission, and distribution created a plethora of "small business investor" opportunities to screw customers. Deregulation was a strategy to rip off the public to benefit big-money investors.

FERC[330], etc. are tasked to see that electricity customers have reliable power, just as other agencies guarantee our water supplies, sewer systems, fire response, etc. collectively called "utility-grade services". Its purpose should be to advance the whole of society, not just its "investors".

Wind/solar cannot provide such service because both are time and weather sensitive, "use it or lose it", sources. Although batteries don't and can't correct for this (too expensive), regional decision makers infatuated by the 'renewables' fad, establish policies that shut down "clean" & already-paid-for nuclear plants (e.g., Calvert Cliff, Byron 1&2, Dresden 2 &3, Duane Arnold,[331] Indian Point, TMI-1, etc.) all of which did not receive emissions-related subsidies but did provide local jurisdictions with cheap (<4 cents per kWh) reliable power along with hundreds of good jobs. Existing nuclear power reactors still produce a third of the world's low-carbon electricity and more advanced reactors are being developed.

APPENDIX XXXIX is an OpEd piece submitted by Alex Pavlak to Marylandmatters.org about Exelon's proposed shutdown of the nuclear reactors that are providing most of that state's reliable, baseload capable, electrical power.

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330 "FERC's Mission: Economically Efficient, Safe, Reliable, and Secure Energy for Consumers. Assist consumers in obtaining economically efficient, safe, reliable, and secure energy services at a reasonable cost through appropriate regulatory and market means, and collaborative efforts." www.FERC.gov

331 Utility Dive reports that the replacement proposed for the reliable (cf ~0.95) 600 MW Duane Arnold nuclear power plant will be two unreliable solar projects of 50 MW and 150 MW maximum capacity backed up with a 300 MWh battery storage unit capable of providing 75 MW when the sun isn't shining. Consequently, Iowa's citizenry will be paying more for less reliable electricity. Power cost comparison: $0.04/kWh nuclear (Lazard)$0.21/kWh solar(Iowa Utilities Board agreement with NextEra).The reactor's owner/operators shut it down because its primary customer (power distributor), ALLIANT Energy announced it would be buying electricity from more highly subsidized sources.

We are failing because current policies don't recognize interdependencies (e.g., today's wind and solar farm energy suppliers aren't charging batteries, making synfuels, or desalinating water when their outputs exceed electrical grid demand and therefore must be "curtailed") which means that federal and regional energy/power governance policies must be reformulated to simplify a much needed and long overdue transition to a sustainable and reliable, zero net GHG emission energy system in a way that rationalizes supplier profitability and market operation.

Those policy changes must encourage everyone to behave in ways that would help reach those goals without the interminable delays and expensive mistakes currently characterizing many of this nation's big infrastructure projects–especially those related to nuclear energy. The USA's war-winning Manhattan Project, Apollo Project, and the buildout of its interstate highway & TVA/Bonneville hydropower systems all succeeded because their ultimate goals (not every detail) were clearly stated up-front and project managers saw to it that everyone involved in implementing them understood that it was in their own best interests to succeed - it wasn't just another gig.

We're not the only English-speaking country with windfarm reliability issues. Just a few months ago (15Oct2020) and barely a week after Prime Minister Boris Johnson had backed a huge expansion of offshore wind farms to power everyone in Britain, its National Grid was forced to issue another warning to its citizen-customers: *"Unusually low wind output coinciding with a number of generator outages means the cushion of spare capacity we operate the system with has been reduced*," resulting in "*tight margins*" for days to come. There was more to follow. During the first week of November 2020 Great Britain's National Grid issued two electricity margin notices, its most serious security-of-supply alerts since 2016, citing low wind farm output among the causes and urgently appealing for more power plants. To keep the lights on, Britain had to burn more coal (not just more of the wood that it's been importing from the USA) in dirty old power stations that are supposed to close within a few years https://www.thetimes.co.uk/article/warning-over-tight-electricity-supply-8qd7vc8s7 .

Oh well.

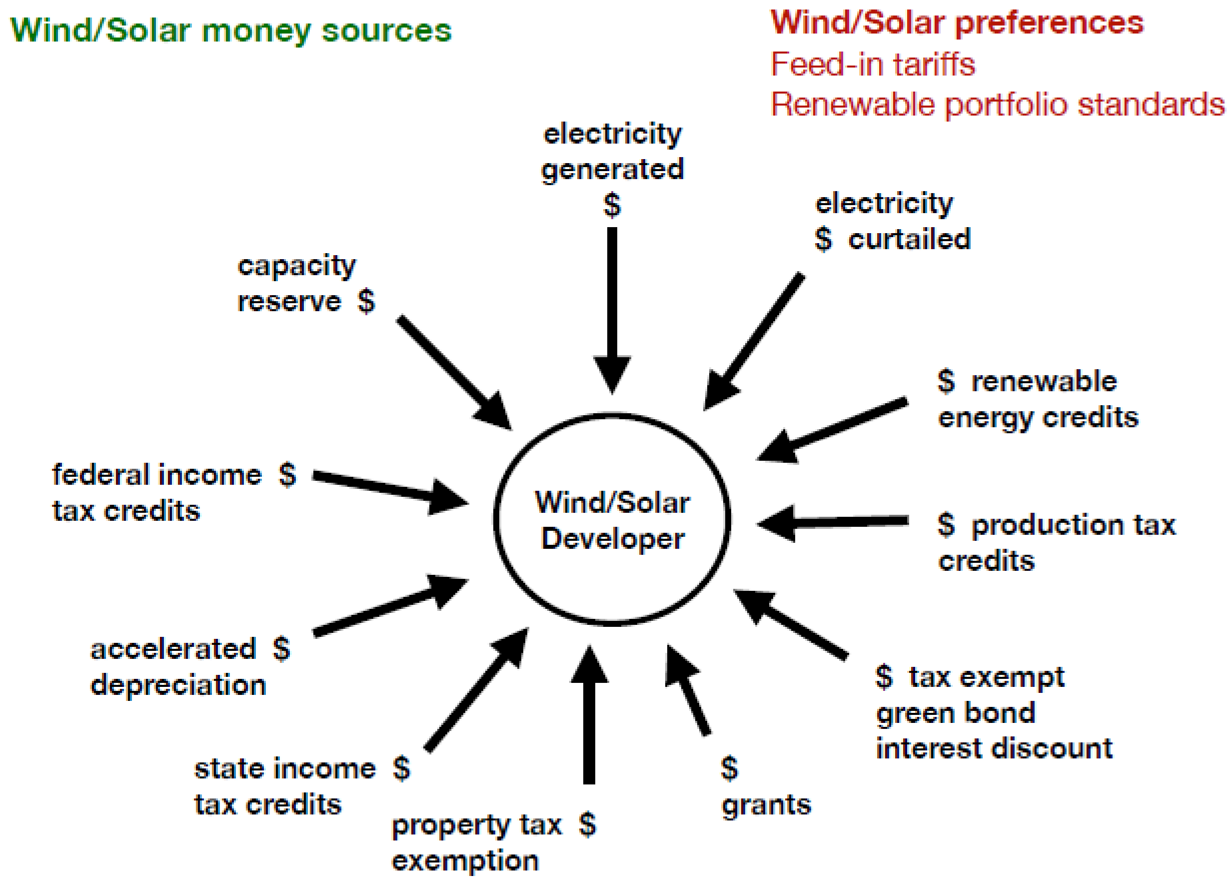

Figure 69 Renewable energy subsidies

Wind variability is a first-order parameter for the design of wind-electric power systems. “Curtailment” (temporary energy overproduction for which no market is available), defines penetration limits beyond which additional wind plants have too-costly system impact. Since aggregated system wide wind power productions typically drop below 2-3% of nameplate capacity for 50-100 hours per year, nearly ~100% dispatchable backup must be provided of such “capacity”. While wind variability drives system design, remarkably little effort has been directed at validating the wind models that purportedly account for it.

TABLE 8: ANNUAL WIND CAPACITY FACTORS

GRID REGION	ACTUAL	MODEL’S RESULT
MISO*	35%	45%
ERCOT**	31%	43%

*”**M**idcontinent **I**ndependent **S**ystem **O**perator”

** “**E**lectric **R**eliability **C**ouncil **o**f **Texas**”

The NREL’s Wind Toolkit is one such model (https://www.nrel.gov/grid/wind-toolkit.html). It is based on a reanalysis and interpolation of historical wind velocity from meteorological sites. While its companion “Validation Paper” (https://www.nrel.gov/docs/fy14osti/61714.pdf) does a decent job of validating wind velocities, its capacity factor data indicate that its model significantly overestimates electricity production (see Table 8). While it does identify plausible mechanisms, it doesn't parse out factors that might be improved via new technology and those that are an inevitable result of real-world operation (e.g., availability, imperfect siting, wakes …). There is also no end-to-end variability validation.

Section 3 of Dr. Pavlak's CARES report (Pavlak 2019) does a more thorough job of making that point.

To address today's electricity business model issues with nuclear power, NE Professors Charles Forsberg (MIT) and Per Peterson (UC Berkeley) devised an especially clever reactor concept[332] (**Figure 68**) featuring a

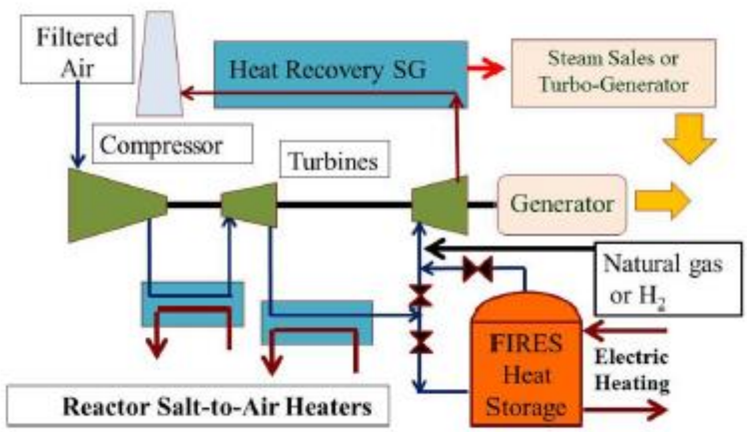

Figure 70 Air Brayton Combined cycle molten salt cooled reactor

conventional air Brayton gas turbine that receives its raw heat energy input from any combination of …

- Heat added to the "outside" air being fed to the turbine by passing it through a massive, well insulated "FIrebrick Resistance-heated Energy Storage" (FIRES) heat energy storage system.
- Heat exchange to either that or outside air from heat energy generated by a hypothetical ~700°C, 236 MWt, fluoride salt–cooled, high-temperature nuclear reactor ("FHR")
- Additional "peaker" heat generated by adding/burning natural gas to that air.

[332] I highly recommend reading Drs. Forsberg & Peterson's open access paper because it demonstrates that the USA's best and brightest are still capable of devising potential solutions to almost any technical problem posed by its political and financial leadership's business models .

In baseload configuration, no gas would be burned and the turbine operated at ~670°C producing ~100 MWe of 100% clean nuclear power @ 42% thermal-to-electric energy efficiency. When demand rises, gas is added/burned to raise the turbine's input air's temperature up to ~1065°C at which point the power plant's output would rise to its turbine's nameplate rating, 242 MWe. Finally, when power demand falls below 100 MWe, the difference between it and 100 MWe would go to heat its FIRES hot-brick "battery" via electric resistance-type heating of the brick itself[333]. Gas burned during its peaking mode would exhibit a heat-to-electricity production efficiency of 66% which is about 10% higher than that of a stand-alone combined cycle gas-fired power plant.

The reactor itself would be superficially like a helium-cooled, pebble bed-type HTGR in that its fuel would consist of golf ball-sized graphite spheres containing tiny TRISO kernels slowly circulated through the coolant (in this case a fluoride-based molten salt) being rapidly pumped through its core. Unfortunately, although molten salt cooled reactors (currently usually acronymed "FHUs") do possess some of the virtues of true MSRs[334], they also possess the drawbacks inherent to any TRISO-fueled HTGR; i.e., it would be difficult to implement any sort of sustainable fuel cycle with them because reprocessing such fuel is apt to be extremely difficult[335]. In principle they should be somewhat more fuel-efficient U-wise than a conventional or "small modular" PWR due to a higher operation temperature, but the difference isn't apt to be large.+

In my opinion, DOE's infatuation with TRISO seems to be akin to its insistence that its lead NE lab (INL) "steam reform" its remaining liquid reprocessing waste - a great way of spending lots of money and time trying to sell something that doesn't make much sense.

Nevertheless, another nuclear startup, "Kairos Power LLC", based upon Professors' Peterson and Forsberg's work has entered the USA's "advanced" small modular reactor sweepstakes[336]. The main difference is that its FHU would not be directly coupled to the turbine(s), its heat energy would be transferred to a huge molten salt storage tank big enough to store a day's worth of the

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[333] When chromium oxide-containing firebrick doped with nickel gets hot enough it becomes sufficiently electrically conductive to serve as a bulk (not wire-form) heating element (Stack 2020).

[334]For example, their core could/would be much more compact than a HTGR's because its working fluid/coolant, FLiBe, is a much better coolant (higher J/degree heat capacity -) than is any gas. Its high temperature turbo generators could also be much smaller/cheaper per kilowatt than those of a ~300°C water cooled/moderated reactor.

[335] TRISO's "heavy metals" (uranium & plutonium) are tough to recover because neither silicon carbide nor pyrolytic graphite dissolve in practical solvents.

[336] As of 2017 at least twenty-six different nations were investigating "advanced" reactor concepts (see chapter 26 of Dolan 2017).

reactor's heat. Since a larger fraction of the plant is associated with its relatively cheap power (not nuclear) block, a smaller fraction of it would have to satisfy today's ultra-conservative/expensive nuclear build specs.

In a traditional nuclear power plant, its turbogenerators' output matches its reactor's output. In Kairos' concept, its turbogenerators' maximum output could be much larger than the reactor's. Consequently a 300 MW SMR/FHU-based power plant could readily load-follow & possess a much bigger 1 GWe official "capacity". Isn't that clever?

"In the real world, the fast strategy for alternative salt systems is through the FHR—it's a big lift to a FHR and a much bigger lift to a MSR. If you have a FHR fleet, it is a much smaller step to Moltex fast-spectrum molten salt reactor with clean fluoride salt coolant with chloride fuel salt in tubes. It is also a smaller step to fusion machines with salt blankets—assuming the other technologies come together for fusion. It is a bigger jump to a MSR with the high inventories of fission products in the primary loop—particularly on the regulatory side. I will note that it was a big lift to get LWRs as reliable reactors. Hopefully that learning curve will be much shorter for the FHR that uses a proven coolant and fuel." Charles Forsberg

Unfortunately, Kairos' FHR would use small -fueled pebbles containing a graphite pit to get enough moderator volume. There is no thorium within the pebbles or the reactor, only HALEU fueled TRISO. The coolant is to be $LiF\text{-}2BeF_2$ w/ 99.995% enriched Li-7. That would make it the most expensive fuel and the most expensive coolant in the world, except perhaps USNC & BWXT's space reactor's TRISO fuel where a SiC matrix replaces the TRISO kernels' graphite.

Some of today's solid fueled nuclear reactors – mostly BWRs - can and do vary their output (load follow) at the rate that electricity demand changes but, of course, due to their fixed operational costs are more efficient when run steadily at their full-rated output. If forced to drastically reduce their output in response to today's (not the past's) much more variable "market forces" and then remain "off" for too long, enough of a high yield, short-lived, fission product (^{135}I) beta-decays to form enough of an especially strong gaseous neutron-absorbing "poison" (^{135}Xe) to completely "kill" the reactor for a day or two[337]. Being unable to immediately restart after a mandated shutdown is more detrimental to a reactor's profitability (financial viability) than is simply accepting low or negative pricing when demand is low and sunlight is especially bright and/or wind especially strong.

[337] The Chernobyl disaster was caused by a botched attempt to restart a recently shut down and therefore ^{135}Xe poisoned reactor. To do so, its operators withdrew all of its control rods which sparked a positive feedback loop that burned out its ^{135}Xe "poison" faster than they could fully reinsert its improperly designed (moderator tipped) control rods.

Despite this, during 2017, the USA's then ~100 nuclear power plants featuring well under 10% of its generating "capacity" supplied almost 20% of the total power provided/sold (unfortunately that's under the ~23% that they had supplied twenty years earlier). The average capacity factor of its surviving reactors exceeded 92% and generated ~800 billion kWh total electrical energy that year. However, in some jurisdictions their owners continue to lose money due to the USA's approach to "privatization" market forces/policies, which is not a sustainable situation as far as its managers & stockholders are concerned. This is the main reason[338] why several US electrical utilities have shut down their already-paid-for reactors and replaced them with thermally inefficient, natural gas-fired, "peaker plants" that dump lots of CO_2 into the atmosphere whenever Mother Nature isn't cooperating.

If we continue to build only unsustainable burner/converter type reactors, reprocessing doesn't make economic sense - especially if it would be especially tough to do as it would be with TRISO-based fuels. However, an upside is that "spent" FHU and pebble bed HTGR fuel balls are durable enough to be good "waste forms" as is. In a rational world (not DOEland) they would just be canned up and buried in a black shale deposit or somewhere else where oxygen isn't apt to get to them for millions of years.

Contrary to commonly held/expressed opinions, nuclear power is not nearly as heavily subsidized[339] as are today's most-favored renewable energy sources or fossil fuels. On March 13, 2013, Terry M. Dinan, senior advisor at the Congressional Budget Office, testified that federal (not total) energy related expenditure for that fiscal year were follows: Renewable energy: $7.3 billion (45 percent) Energy efficiency: $4.8 billion (29 percent) Fossil fuels: $3.2 billion (20 percent) Nuclear energy: $1.1 billion (7 percent). In addition, he testified that the U.S. Department of Energy would spend an additional $3.4 billion on "financial Support for energy technologies and energy efficiency" as follows: Energy efficiency and renewable energy: $1.7 billion (51 percent) Nuclear energy: $0.7 billion (22 percent) Fossil energy research & development: $0.5 billion (15 percent) Advanced Research Projects Agency—Energy: $0.3

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[338] Another "privatization" driver for nuclear reactor shutdown is that it's become considerably cheaper to "decommission" them than expected. Since the original owners of US reactors have had to collect/put aside several billion ratepayer dollars to decommission them and new owners get to keep whatever's left over when that's been accomplished, buying old reactors to decommission them has become more profitable than running them to generate salable electricity. Isn't unbridled capitalism great?

[339] With investment subsidies, the financial burden falls upon the taxpayer, whereas with feed-in tariffs extra costs are distributed across the utilities' customer base thereby raising everyone's power bills. While investment subsidies may be simpler to administer, feed-in tariffs (FITs) reward production/sales. Investment subsidies are paid out as a function of the nameplate capacity of the as-installed system and independent of its actual energy output thereby rewarding overstatement of power rating and the toleration of poor durability and maintenance. Some electric companies offered rebates to their customers, such as $2.50/watt of solar "capacity" installed up to $15,000.

billion (8 percent)   Electricity delivery and energy reliability: $0.1 billion (4 percent). That situation has apparently gotten worse: Wikipedia's current entry for "Energy subsidies" (Energy subsidies 2018 https://en.wikipedia.org/wiki/Energy_subsidies) includes the following figures: Foreign tax credit ($15.3 billion)   Credit for production of non-conventional fuels ($14.1 billion)   Oil and Gas exploration and development expense ($7.1 billion). The three largest renewable fuel subsidies were: Alcohol Credit for Fuel Excise Tax ($11.6 billion), Renewable Electricity Production Credit ($5.2 billion), and   Corn-Based Ethanol ($5.0 billion).

Summing up the numbers having to do with rewarding entrepreneurship in renewable, nuclear, and fossil fuel electricity generation and then dividing by how much energy each actually delivers (15% for renewables, 20% nuclear, and 65% fossil fuels), we see that nuclear power receives about 30% as much government "help" per kWh as do the fossil fuel industries and ~1.8% that given to the people being encouraged to sell us windmills, solar panels/towers, biofuels, etc..

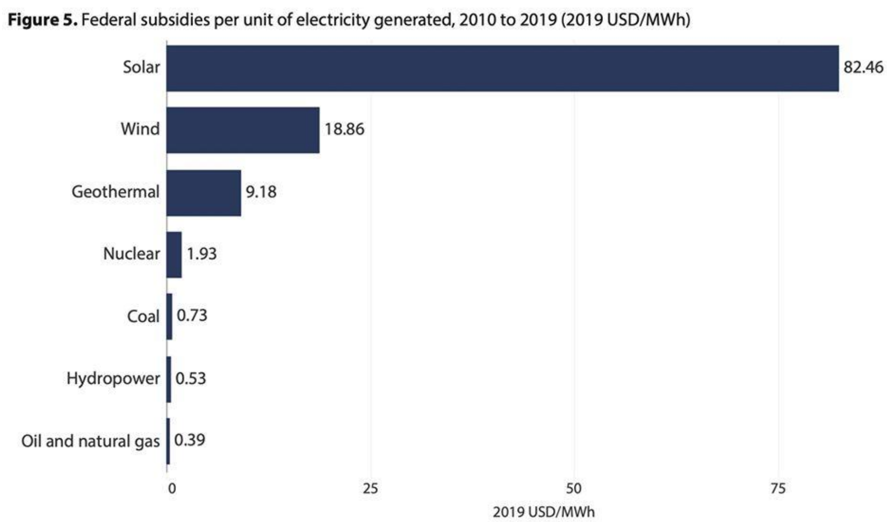

Figure 71   Ten year summary US energy subsidies https://files.texaspolicy.com/uploads/2020/04/23135621/Bennett-LP-Federal-Energy-Subsidies.pdf

It's now become obvious to a few of our leaders that this sort of governmental activism causes electricity prices to spike wherever it is most prevalent (for example, California (Figure 72) Germany, Denmark (Figure 73) and even Ontario - p. 306). It also increases GHG emissions because their policies/rules have incentivized utilities to substitute natural gas (and in Germany, lignite coal) for uranium[340].

When governments dictate that a greater proportion of "all of the above" must be renewable, today's marginal cost-based energy pricing polices tend to generate wholesale electricity prices too low to support any kind of baseload-capable, thermal (natural gas, coal, or nuclear) power plants. As more intermittent power is added, short term wholesale electricity rates drop below those required to support baseload capacity and thereby increases the system's precarity. Figure 22's dotted line illustrates that while average wholesale electricity prices (spot prices – what distributors pay for electricity) fell throughout Europe as additional intermittent sources were added, retail customer electricity rates ballooned. What's particularly interesting is the fact that in 2016, when wind & solar power constituted 8.3% and 3% of Europe's electricity respectively (Tverberg 2019) what retail consumers had to pay for it had gone up radically (Figure 73). Note what happened in Spain mostly due to its over commitment to concentrated solar power, and Germany mostly due to its infatuation with wind power - when even a relatively small fraction of their total power generated/consumed was from intermittent sources.

If security of both supply and cost is deemed sufficiently important, the intermittent nature of wind and solar power means they can replace only a relatively small fraction of that of baseload capable (dispatchable) power plants. Investment in renewable generation capacity is therefore in addition to, rather than replacement for the more reliable nuclear and fossil fueled thermal plants that used to supply most of our electricity. That's why retail power rates invariably rise as the percentage of it generated by wind & solar "farms" increases.

Even though US and EU's decision makers usually respond to such information by announcing 'intent" to address those issues, in practice they continue to subsidize/support the big 'local' companies installing/operating weather-dependent power sources in regions already requiring frequent "rescues" due to customer passivity, renewable industry lobbying, & environmentalist greenwashing[341].

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[340] A 112-page RPS Eligibility Guidebook, Ninth Edition Revised, details California's definition of renewable electricity. Its definition differs from the dictionary's in that it is a compilation of green dogmas (CAdotgov 2109)). Fossil fuels are taboo. Although hydroelectricity is naturally replenished by the rain, to California's rule makers, it is renewable only if it does not interfere with kayaking and fish. On the other hand, California policy makers love wind and solar power and act accordingly. Because their anti-nuke biases "Trump" their global warming concerns, carbon-free electricity generated by breeder reactors is unlikely to be officially deemed renewable without a great deal of "outside" arm twisting.

[341] Most of greenwashing's sundry definitions include: 1) not disclosing negative information related to a proposal or action's environmental performance, and 2) emphasizing positive information regarding such performance. Such behavior constitutes "selective disclosure" – one of Mankind's most characteristic behaviors, especially by anyone trying to sell anything.

Alternative/renewable energy companies have become especially politically correct "big businesses" with owners that employ many people and make especially generous contributions to

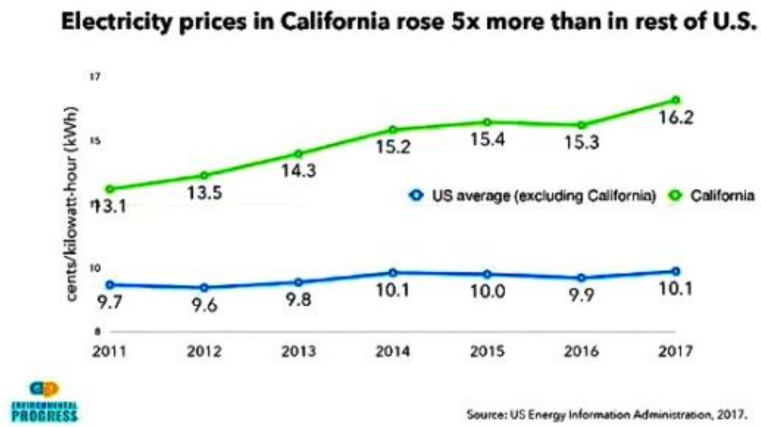

Figure 72 Effect of California's solar power mandates

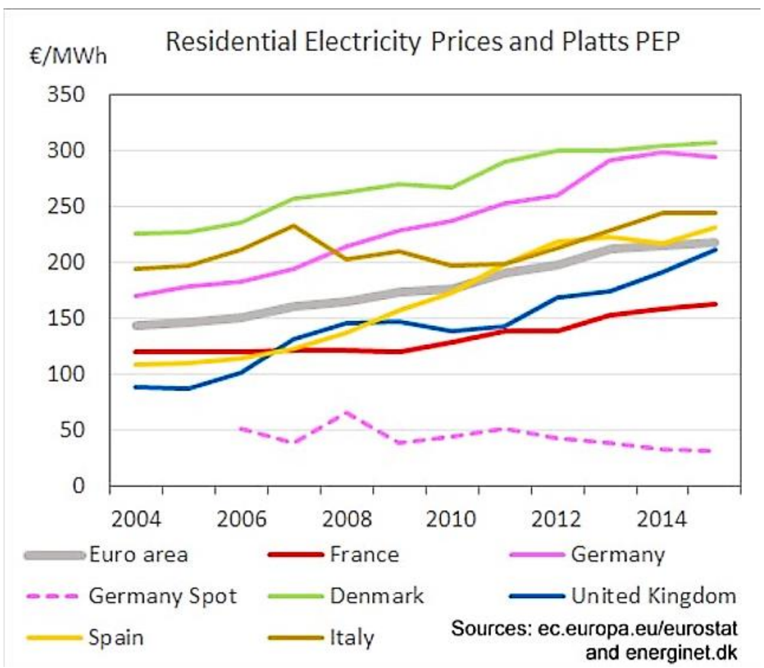

Figure 73 The effect of the EU's renewable power mandates (more W&S)

frequent periods of over supply whenever the weather is "right". Though those subsidies are repeatedly scheduled to expire, they are also repeatedly granted last minute extensions. These

reelection campaigns (see APPENDIX XVII). In this respect, they are like the USA's energetically/environmentally nonsensical, corn and soybean-based biofuel industries (SciAm 2014).

At first glance, some renewable energy technologies have higher energy returns on investment (EROI) than do fossil (e.g., new coal) fueled or nuclear power plants. However. fossil-type energy continues to provide the energy required to do the mining, extraction, transporting, dirt moving, building, etc. required to install any sort of politically correct renewable energy source.

"*Solar panels are 'rebuildable', not 'renewable'*" (Berman 2017).

It will take a long time to progress away from today's mostly privatized "all of the above" approach to electricity supply and even longer to generate enough of it to meet the needs of the future's hopefully bigger, richer, and fairer world.

Over the long haul, one of the biggest issues facing our descendants will be the unsustainable debt load that our generation's decision and law makers have left them. The USA's external debt - total public and private debt owed to nonresidents repayable in internationally accepted currencies, goods, or services – is currently much higher that than that of any other developed nation, >27 trillion dollars or ~$83,000 per capita. China's external total public and private debt is now about 1.8 $trillion or ~ $1300 per capita. The USA's stagnating economy's debt to GDP ratio is now ~1.3:1 - China's booming economy's ratio is ~0.48:1.

The difference between a country's external financial assets and liabilities is its net international investment position (NIIP). A positive NIIP indicates that the nation is a creditor, while a negative value indicates that it is a debtor. The USA, as recently as 1960 the world's largest creditor, has now become the world's largest debtor. With the rapid ascent of Hong Kong Monetary Authority's credit position, China (including Hong Kong and Macau) has recently been jousting with Japan for the top creditor position.

The fact that Professor Hubbert was right[342] about how long fossil fuels are apt to remain cheap enough to burn combined with the magnitude of the world's debt overhang means that any "green new deal" must be implemented with cost efficient, practical technologies – not with those with especially virtue-signaling names, eminent political correctness, and/or immediately profitable for especially well-connected entrepreneurs, and established businesses.

We hear a good deal of enthusiastic propaganda about how shale gas and oil can easily meet our energy needs for the "foreseeable future". If "foreseeable" means an election cycle or another decade or two, that's reasonable – if it means a first-world human lifetime, it is patent nonsense.

[342] Professor Hubbert rigorously defined the assumptions supporting his conclusion (see Figure 9) that fossil fuels could not indefinitely power a technological civilization. Since circa 1970, the fossil fuel industry's champions have repeatedly cherry-picked/changed his assumptions (e.g., how "tight" the oil in question might be) and time scales to "prove" that he was wrong. Since most of us prefer soothing lies to uncomfortable truths, those champions have apparently had an easy time convincing us that there's nothing to worry about.

Claims that a society can seamlessly move from fossil to 100% politically correct renewable energy without drastic changes in its peoples' consumption habits and lifestyles are equally misleading.

Most things we're told that sound too good to be true are untrue regardless of their source or possibly constructive intent.

What all this should be telling the world's decision makers is that it would make sense to develop/build sustainable power plants capable of generating power when it is needed, not just whenever Mother Nature decides to let the wind blow and/or clear away darkness and clouds.

I recently answered this QUORA question, "*How do the economics of wind and nuclear power compare?* with:

"*This question's answer depends upon what kind of "economics" you're talking about. If you're selling windmills in a state like California that heavily subsides any sort of politically correct (not nuclear) "clean" power source regardless of how unreliable (intermittent) it is and doesn't care a hoot about its citizens' electricity rates, wind power's economics are really attractive. On the other hand, if you're trying to make America great again by building a factory that requires electricity to make stuff, wind power's economics really suck because you can't depend upon being able to actually run it.*"

In conclusion, here's a tongue-in-cheek QUORA question that I recently posed myself. For some reason its Editors refused to post it. Can you guess why?

*Since "all of the above" is officially the right way to look at addressing the future's energy issues, what if instead of burying dead people**, we converted them to biofuels instead? Having recently attended Iowa's State Fair where its citizens were munching deep fat fried Twinkies while queuing up to see its world famous "butter cow", it seems to me that this suggestion invokes a very substantial renewable energy resource. Am I right? (I'm looking for answers backed up by calculations utilizing GOOGLable facts/data that put this suggestion into proper perspective, not answers based upon "feelings*

*In Harry Harrison's 1966 novel *"Make Room! Make Room*!" (basis for the 1973 film *Soylent Green*) deceased people were converted to value-added foodstuffs because in his too-crowded future world, "people food" was more important than biofuels.

7.2 Reactor build cost inflation

Another of nuclear power's issues in Western countries is grossly inflated reactor build costs. The miserable fate of the USA's Vogtle 3&4 demonstrates how project costs quickly escalate when their drivers are poorly managed and reflect contextual factors (e.g., lack of a prepared supply chain and experienced labor force, slow regulatory interaction pace, expensive regulator billing rates, etc.) that have become intractable burdens in the USA.

The USA's last-completed nuclear power plant is Watts Bar Unit 2, was started in 1973 and finally completed in 2016. The construction of Vogtle number's 3 & 4 GEN III+ (i.e., "super safe") 1.117 GWe reactors begun in 2012 has recently been rescheduled (again) for completion(?) in 2021 & 2022 for a total estimated cost of ~ \$12/W, ~80% over budget. US reactor-build schedules and construction costs are not predictable (risky investments) because it no longer possesses a healthy commercial nuclear power industry -we don't build reactors and can't fuel the ones we have. The adjacent chart from the "ETI Nuclear Cost Drivers Project" illustrates the dramatic cost differentials between nuclear power plants constructed in the West vs the rest of the world. While low-cost countries must adhere to the same international regulations, their nuclear industries possess mature supply chains, experienced labor forces, and good project management. The root cause of the USA's technical malaise in this arena is stakeholder inexperience/ignorance. If that isn't addressed, its response to the challenges serving to rationalize this book's recommendations will continue to be eclipsed by those of its Asian competitors.

Building one-of-a-kind reactors at each site – the way that the USA traditionally does it - is extremely expensive. Despite its high labor costs and generally low labor productivity, the USA could greatly reduce build costs by standardizing designs & moving as much as possible of each build into factories. That's the reason that I'm also enthusiastic about increasing "modularity".

In most engineering disciplines it is possible to accurately estimate a proposed project's cost utilizing information in the "economics" sections of discipline-specific tomes like "*Perry's Chemical Engineering Handbook*". However, that doesn't work with the USA's nuclear power projects because, even though the facilities themselves aren't especially unique, the costs of everything having to do with building them are uniquely and artificially high. It is difficult to come up with reasonably accurate build cost estimates because, like those of the USA's health care "system", there is little correlation between its "should" and actual costs due to sometimes unnecessary, usually self-serving, and often litigious overhead costs[343]. The effect of those cost

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[343] In the USA it's possible to make a very good (and very "easy"' because it's just paperwork) living generating "overhead" which explains why litigation, consulting, regulating, advising, and oversight have become among its best-paying white collar service industries. For example, in 2017 each of the USA's Nuclear Waste Technical

drivers is best illustrated by a figure (Figure 74 excerpted from a paper compiling historical construction costs of full-sized civilian light water reactors

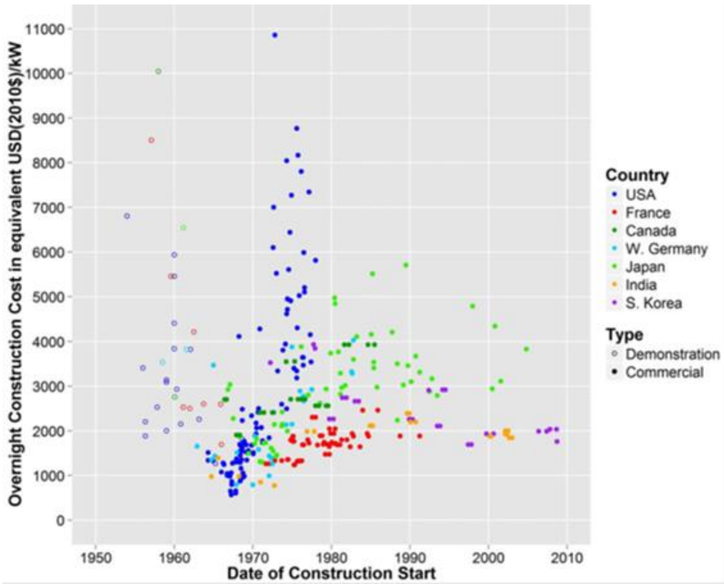

Figure 74 Historic worldwide inflation-adjusted reactor build-costs (Lovering, Yip, and Nordhaus 2016).

The USA's reactor build-cost/GWe (Figure 74's blue dots) started out at under one billion 2010-type dollars during the late 1960's but quickly ballooned by over an order of magnitude while those of better-disciplined countries (Japan, China, France and So Korea) remained at about $2 billion for several decades. They've moved up somewhat everywhere since then because today's GEN III and GEN III+ reactors are more "over engineered" than were their basically similar but not quite so "safe" predecessors[344] with respect to their containment systems– a rather surprising

Review Board's 14 FTE (full time equivalent) jobs was funded at $257,000 per annum. Each of the Defense Nuclear Facility Safety Review Board's (DNFSB's) 117 FTE's costs US taxpayers about $190,000. Neither of those "advisory" boards can force DOE to do anything constructive which is likely one of the reasons that both experience lots of membership turnover (board members recruited from the NAS are not much used to having their time/efforts/advice wasted/ignored).

[344] A reason for this is that we tend to blame technologies not ourselves for our mistakes, laziness, and incompetence. That's why accomplishing straightforward nuclear missions like waste vitrification, incineration, and repository siting, have become "impossibly" difficult/expensive. Another is that unnecessary additional redundancy (more "safety") costs money. During period 2 (1987–2017), a new containment design was adopted by Westinghouse (the AP-1000), and the resulting dimension, material usage, and labor changes drove up costs. Its switch from active to passive cooling to reduce the need for operator intervention during emergencies required the separation of the steel liner from the concrete shield building. This change enabled natural air convection between the two but also required thicker structures since structural layers that had previously acted together to resist pressures now had to hold up independently. The thickness of its new/improved steel shell layers, five times greater in 2017 than in 1987, represented the single largest contribution to that period's ~80% cost inflation.

factor in view of the fact we've been making big steel/reinforced concrete structures for well over a century now. ''Soft'' factors such as labor supervision, contributed over half of the cost inflation during the 1970s and 80's[345] - the labor productivity of recent builds is over an order of magnitude lower than industry expectations - see Eash-Gates et al., 2020 (an especially informative paper).

Like the costs of real estate, current reactor build costs are determined by "location, location, location"– high in western-world countries and much lower elsewhere. Consequently, as of 2018, most of the 58 power reactors under construction and 154 planned (220 GW_e Total) are in Asia. As of January 2019, another 337 of them have been proposed (World Nuclear 2019). The reasons that the Russians, Chinese, and So Koreans can build new reactors so much more cheaply than we can is a result of serial production of multiple identical reactors at each site because their leaders realize that more energy is desirable – our leaders stress "resilience"[346]) - and doing the engineering before, not during, construction as has become the norm in the USA. Their concrete crews pour concrete at one build site and immediately move on to the next – not sit around waiting (or "training") for forms to be reset on the same build. They may not be very efficient at the first pour but by the time that the same crew repeats the same on the third identical plant they've become very efficient at producing a top-quality product. Humans learn best by doing, not theorizing. Although the USA has lots of "experts" in the individual disciplines involved in building reactors, it no longer possesses an experienced work force or reliable supply chain.

Over the long haul, any reactor build cost under ~4 $billion/GWe (the norm in Asian countries) is economically justifiable because its product will surely be worth much more than that. For example, at 3 cents per kWh, the electricity generated by a one GWe reactor over a 40-year lifetime would be worth $10.5 billion [$0.03/kWh*1E+9 J/s*3.15E+7s/year*40 years/3.6E+6 J/kWh].

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345 "*Indirect costs caused most (72%) of the cost increase during period 1 (1976–1987), the indirect expenses incurred by home office engineering services (engineering design, purchasing and expediting, estimating and cost control, planning, and scheduling), field job supervision (salaries and relocation expenses), temporary construction facilities (materials and labor to construct and manage temporary buildings needed during construction), and payroll insurance and taxes".* Most of these costs are ''people'', not hardware-related.

346 "Developing more resilience" means learning to live with less electricity. For instance, Lebanon's people have had to become more resilient because its rolling blackouts typically provide them with only a few hours of electricity/day. Many of the world's other poor people are in similar or even worse situations. While the USA's policy setters are still championing small, low output, reactor concepts, the Chinese plan to upsize their next "AP-1000" clone to 1400 MW_e (the CAP1400) and may then further upscale it to 1,700 MW_e.

percentage	Assumes $4B mortgage 40 years + 250 employees 200$k/a & 1 mil/kWh overhead					
interest	Mortgage	mortgage	labor			total
rate	payment/a	cost/kWh	$/kWh	overhead	sum/kWh	cost/a
1.5	1.33E+08	0.0152	0.0067	0.001	0.0229	2.00E+08
2.5	1.58E+08	0.0181	0.0074	0.001	0.0265	2.32E+08
5	2.32E+08	0.0264	0.0095	0.001	0.0369	3.23E+08
10	4.08E+08	0.0466	0.0145	0.001	0.0621	5.44E+08
		at 1mil/kWh annual waste- related cost is 8.76$M				

Table 14 Nuclear Power's Maximum "should costs"

I've characterized these figures as "maximum" because the future's reactor build-costs should be well under $4/watt. While my $4B/GW$_e$ build cost estimate has been characterized as "aspirational", it is also reasonable, see https://world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx

6.3 Sustainable reactor should-costs

In 1970, a paper written by two of ORNL's senior-most nuclear engineers (Bettis 1970) included an analysis of what the power generated by a full-sized molten salt breeder reactor should cost. Their figure included the costs of construction ($0.159 billion 1970 dollars), fueling, and operating a one GW$_e$ breeder. Applying the USA's subsequent otherwise-official ~6.46 x inflation factor for most of the things we need, to their conclusion ($0.0041/kWh) generates a current should-cost figure of $0.0265/kWh – about 40% of today's average wholesale electricity cost. This suggests that if the USA's ~320 million citizens set out to power themselves at the rate I've assumed for the future's 11.2 billion people (2 kW$_e$ average with a 40% peak) with one GW$_e$ molten salt breeder reactors, building the 857 [30000*0.32/11.2] of them so required should cost about $860 billion of today's dollars [857 *6.46 *$0.159 B], To put that figure into perspective, it is only ~35% [860/634 =1.35]) greater than the USA's current annual "discretionary" (nominally) military spending (OMB 2017). Similarly, since the USA's national debt as of 1Apr2019 was ~$22 trillion and the interest rate on its 10-year treasury bonds was ~2.49%, it seems likely that its taxpayers are/were paying someone (?) ~$1.5 billion per *day* just to service their country's "conservatively" managed (privatized and under regulated) economic system's debt, not to address the technical issues threatening their children's futures.

Fast MSRs should be cheaper to build than the graphite-moderated LFTR-type reactors that ORNL's engineers were envisioning circa 1970 because they would be smaller, simpler, and require less much fuel cleanup (reprocessing). For instance, their cores could be so small (7-10 m^3/GW$_e$) that it should be possible to design them so that components subjected to especially high neutron flux would be cheap/simple to replace. This is a key point because any product's durability and affordability is as much determined by its maintainability as by its frequency of failure. Maintainability is determined by cost of parts and the difficulty of replacing them[347]. For example, for the MSFR, the key high maintenance part would be the annular tank containing the blanket salt surrounding its core. The volume of that tank would be about 7 m^3 and its surface area about 50 m^2 meaning that if it were 1 cm thick (reasonable) and made of an ~8 g/cc transition metal alloy, it would weigh roughly 4 tonnes. Real world prices of that "super alloy" would be roughly $25/kg, meaning that its cost should be about $100,000 or ~10% of one day's worth of its product @ ~$0.03/kWh .

The secret to making nuclear energy inexpensive has been known ever since France proved that it's possible over 40 years ago. One design is licensed for a generation and standardized copies built across the entire grid. South Korea is apparently still able to do that now. In that fashion, all of the logistics plus an experienced construction workforce is ready for every new order that comes in. I'm also convinced that THORCON's "build 'em like ships" philosophy is the right way to do things[348]. However, it should be easier/cheaper to build and ship the "guts" of a MSFR, MCFR, or MOLTEX reactor than an equally powerful graphite-moderated MSR like THORCON's because they would be considerably smaller and weigh much less. ORNL's single salt MSBR's core contained about 300 tonnes of graphite (Robertson 1971) and the "almost breed and burn" denatured (politically correct) MSR concept ("DMSR") that succeeded it (Engle 1980) contained about 2400 tonnes of graphite. Calling any such system "modular" or "transportable" requires the same sort of faith-based conviction responsible for the outcome of the 2016 US presidential election[349]. The "fragile" parts of a FS-MSR or tube-in-shell type

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[347]I didn't feel insecure about buying a rebuilt-engined 1954 Volkswagen "beetle" in 1970 even though I realized that its engine would at best, last only another 50 000 miles because I also knew that I could quickly/cheaply change out whatever wore out whenever I had to. One of its successors, an '84 Nissan Sentra wasn't nearly as simple to work on, but I managed to keep it going for ~440 thousand miles because at ~150 k miles I'd de-computerized its carburetion & ignition systems & made it a new of carburetor jets by drilling right-sized holes through two metric screws. Keeping a machine running isn't rocket science unless it's been designed by people that don't give a heck about maintainability. Today's cars cost 15 times as much and must last for at least 150 k miles 'cause they are built so that "*when that check engine light comes on, it's game over*" (Iced T, 2021).

[348] South Korea currently builds/sells ships bigger than was the RMS Titanic for ~$30M (US) each. The USA no longer even tries to compete in the civilian ship building arena which is another of the reasons that its young people can't find good jobs & therefore vote for same sort of no-nothing xenophobes that Germany's did circa 1932. We here in the USA seem to have become hapless, helpless & hopeless. If we can't get our heads straight about things like this we might just as well tell our grandkids to move to the Far East where they've got a better chance of living long, happy, productive, and prosperous lives.

[349] I respect God in the sense that I take his "work" so seriously that I can't bring myself to believe in Him. An especially memorable quote in Alexis de Tocqueville's book, "Democracy in America" (published 1835), is "*Religious insanity is very common in the USA*". Their "*thoughts and prayers* "don't solve technical problems but I

reactor core would be much more compact consisting of 2–4 tonnes of "hard metal" that could be readily crushed to make very durable ~half cubic meter disposal/waste forms when they were removed/replaced.

Unfortunately, utilities have become leery of building any sort of nuclear plant because they represent long term investments suited only for a stable (predictable), rational, economic system. The stability required to properly implement a nuclear-powered future would require cooperation at all levels including political leaders able to look beyond the next election cycle, a better educated populace that doesn't readily succumb to the whims of fears and fashions, and investors that believe that a rising tide should lift all boats, not just theirs. The lower that interest rates become and the longer that investors can be confident that their money will keep coming back to them, the lower that energy prices can be for everyone. I don't mean just "competitive" with natural gas - I mean low enough to render every other source uneconomical.

If we could build a one GWe breeder/isobreeder for $2.5 billion as can South Korea their intrinsically equally expensive CANDU-type reactors with 2% (interest) dollars then its electricity could be sold for $0.024/kWh for 80 years or for $0.068/kWh for 10 years and then $0.0165/kWh for the remaining 70 and still reliably afford its investors a 2% annual return. Unfortunately, many western countries can't seem to do such things because electricity generation/distribution has been both "privatized" and politicized. This has encouraged people who must work together to implement a system capable of addressing this book's problems to bicker with other instead. The reason for this is that their governments' policy setters haven't evinced sufficient maturity, courage, and foresight. Nuclear isn't "too expensive" because of its real costs[350], it's too expensive because our policy setters don't act like leaders should.

The way that things are now, if the USA decided to install its share of the world's nuclear reactors circa 2100AD (~3.3 TW 's worth), it'd make lots of sense to import "modular" factory-made reactors from a country that's not crippled itself with excessive regulatory, legal/safety, labor-rule overhead costs. Factory-labor costs are covered by different agreements than is construction labor and its rates tend to be considerably lower. Furthermore, productivity is generally much higher in factory settings than at construction sites.

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can sympathize with Mr. Trump's "deplorables" who had apparently concluded that any change would probably be better for them than were the likely outcome of previous US administrations'- privatized approach to problem solving.

[350] On the other hand, China's policies reward cooperation which has led to more progress in addressing its and the rest of the world's technical issues. The best explanation I've seen yet of the factors that determine the costs of supply the western world's electricity was volunteered by Paul Acchione a few days ago (23Jan2020 , see APPENDIX XXV.

As far as what that labor might cost is concerned, it's risky to hazard guesses about what that might be well off into the future.

For instance, although "naked" labor costs are still (circa 2020) about 4x higher in the US than China, ~half of that is because China's living costs are ~one-half those of the USA's. This currently makes its average construction worker about one-half as "rich" as are ours. Furthermore, China's labor costs are rapidly rising while ours seem to be shrinking.

A chart of labor rates as a function of time can be seen here

https://acetool.commerce.gov/cost-risk-topic/labor-costs

(Data source: Economics and Statistics Administration analysis of data from The Conference Board, International Labor Comparisons program and National Bureau of Statistics of China.)

China's ~260% rise in labor costs between 2000 and 2015 corresponds to a compounded annual inflation rate of 6.5%. On the other hand, US labor costs deflated at an annual rate of about 0.85% over that period. (It's no wonder that some of the USA's worker-natives have become "restless".)

By the time that the US finally decides to get serious about embracing its own full-sized nuclear renaissance, China might decide to outsource "dirty" jobs like reactor building to "cheap labor" countries like we may have become by then.

7.3.1 Materials

"Special" materials that wouldn't be required by any of this book's preferred reactor concepts include the China-sourced rare earths in make the relatively light-weight generators within the nacelles of many of today's most affordable (Chinese) wind turbines. Because there is no such weight requirement for ground-sited dynamos, nuclear power plants don't need super magnets.

7.3.1.1 Concrete, steel, etc.

Generating a kWh's worth of energy (not "capacity") with any sort of nuclear reactor requires far less building materials than does doing so with today's more politically correct power sources. (Figure 75)

Table 10.4 Range of materials requirements (fuel excluded) for various electricity generation technologies[52]

Materials (ton/TWh)	Generator only				Upstream energy collection plus generator			
	Coal	NGCC	Nuclear PWR	Biomass	Hydro	Wind	Solar PV (silicon)	Geothermal HT binary
Aluminum	3	1	0	6	0	35	680	100
Cement	0	0	0	0	0	0	3,700	750
Concrete	870	400	760	760	14,000	8,000	350	1,100
Copper	1	0	3	0	1	23	850	2
Glass	0	0	0	0	0	92	2,700	0
Iron	1	1	5	4	0	120	0	9
Lead	0	0	2	0	0	0	0	0
Plastic	0	0	0	0	0	190	210	0
Silicon	0	0	0	0	0	0	57	0
Steel	310	170	160	310	67	1,800	7,900	3,300

Key: **NGCC** = natural gas combined cycle; **PWR** = pressurized water reactor; **PV** = photovoltaic; **HT** = high temperature

Figure 75 Materials requirements for different energy sources DoE's 2015 Quadrennial Review https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter10.pdf

A recent (August 2021) "Technology Brief" Nuclear power brief_EN_0.pdf (unece.org) produced by the United Nations Economic Commission for Europe (UNECE) concluded that nuclear power produces far less CO_2 emissions over its lifecycle than do any other electricity sources including wind, solar, gas, and coal . It also concluded that nuclear has the lowest lifecycle land use, as well as the lowest lifecycle mineral and metal requirements of all the clean technologies.

The bottom line is that wind farms impose much greater environmental impacts than do nuclear power plants.

Since a modern technological civilization requires reliable power and wind turbines produce only when the wind blows, neither they nor solar panels can replace thermal and/or hydroelectric power plants unless we're willing to pay for lots of backup and/or storage along with the additional "capacity" required to charge it when Mother Nature is being generous. That of course means that adding a good deal of intermittent sourced to a region's production portfolio invariably raises the cost of its electricity - often precipitously. Nuclear power's capacity factor –

average power delivered/nameplate capacity - is currently about 92%. That's about 1.5 to 2 times higher than those of typical natural gas and coal-fired power plants, and 2.5 to 5 times higher than those of wind and solar power plants[351].

Second, a wind "farm" requires far more land (has a bigger physical footprint) than does a nuclear power plant. Depending upon the terrain, optimal wind turbine spacing should be 3-15 propeller-sweep widths to prevent them from "starving" one another (Ford 2011). Given that an average sized 2 MW turbine sweeps out a ~139 m diameter circle and is taller than the Statue of Liberty, big windfarms cover enormous amounts of land. Depending upon turbine spacing, the area covered by the approximately 1200, 2 MW nameplate capacity wind turbines required to generate the same amount of useful energy per year as would a one-gigawatt nuclear power plant would be from ~100 to ~900 square miles including that covered by the wind turbines along with their access roads, maintenance sheds, & power lines. An equivalent-output nuclear power plant would occupy under one square mile. For instance, the area covered by the 4.7 GW_e Fukushima Diachii power plant is about 1.6 km^2 which (assuming 90% CF) works out to about 2700 watts/m^2 of land so utilized.

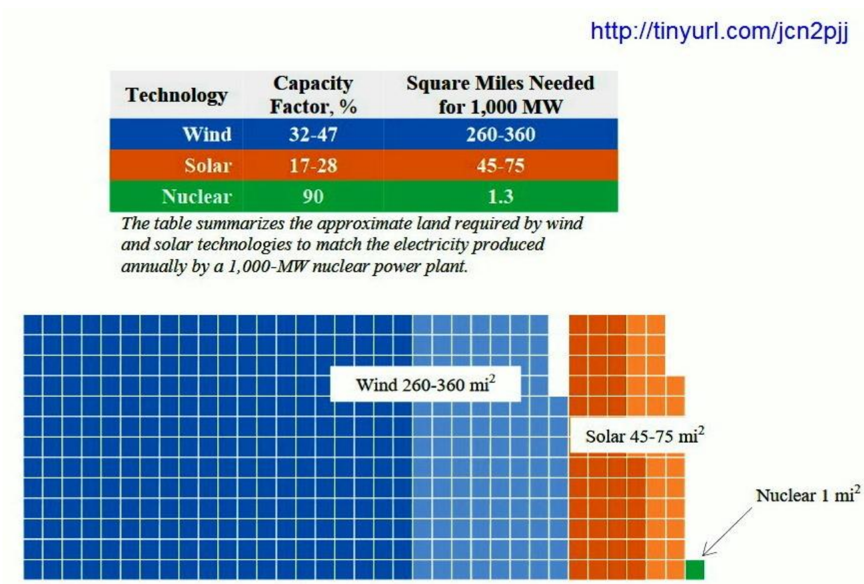
Technology	Capacity Factor, %	Square Miles Needed for 1,000 MW
Wind	32-47	260-360
Solar	17-28	45-75
Nuclear	90	1.3

Figure 76 Relative clean energy source land requirements

Assuming a capacity factor of 0.3, properly spaced wind turbines generate an average of 0.3 watts/m^2 of landscape so blighted – about ten thousand times under that generated by the Fukushima Diachii power plant.

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351 More importantly, a conventional nuclear reactor's operators can choose their "down" (refueling) times within wide (several-week) limits. With wind & solar renewables, we are absolutely subject to Mother Nature's whims.

In regions with high solar irradiance, solar power plants can generate an average output of 5-10 watts.m^2. For instance, according to WIKIPEDIA California's 550 MW (nominal) Topaz solar plant's 9 million solar panels cover 19 km^2 and generate an average of 1282 GWh of electrical energy per year (4-year average). That's an average power output of 147 MW [1282E+9*3600/3.15E+7] which translates to 7.74 watts/m^2 [147E+6/19/1E+4]. That's not an impressive power/unit area efficiency figure because that region's average solar irradiance of ~5.5 kWh/day/m^2 corresponds to 229 Watts/m^2 [229=5.5*3.6e6/24/3600].

Topaz's build cost per GWe was $16.3B ($2.4B/0.147)

Third, the total amount of materials required to generate wind farm energy is far greater than that required by nuclear reactors. According to the OECD (https://www.oecd-nea.org/ndd/reports/2011/ndc-2011-15.pdf) building General Electric's Gen III^+ 1.38 GWe "ESBWR" reactor would require 110,000 m^3 of concrete and 44,000 tonnes of steel[352]. Assuming a 90% capacity factor and 60-year lifetime, that works out to 169 m^3 of concrete and 68 tonnes of steel per terawatt hour (tWh) of useful energy (electricity). Assuming a wind farm comprised of 2 MW, 34% capacity factor, 20-year lifetime, *w*ind turbines (typical onshore US), the amount of concrete[353] and steel required to generate that same TWh's worth of energy would be 4070 m^3 and 2080 tonnes respectively.

According to WIKIPEDIA, the average amount of CO_2 generated to make a tonne of steel is currently ~1.9 tonnes, almost all of which ends up in the atmosphere. Making one tonne of Portland cement (which represents about 20% of the weight of high-quality concrete) dumps another ~1.25 tonnes of CO_2 into the environment. Altogether that's 5150 tonnes of CO_2/tWh for the wind farm vs 171 tonnes of CO_2/tWh for the Gen III^+ nuclear power plant.

Another "material" issue is that far more metallic wire (a limited resource) must be used to link widely dispersed, relatively low power (mega not giga watt), low-capacity factor sources to the grid. Wire costs money as does stringing it as do the plethora of discrete electrical gadgets required to keep everything synchronized and safe. A recent NEW MATILDA post/article identified another "environmental" downside to wind farms, i.e., they're apt to cause more of the sorts of wildfires that have been recently devastating much of the world's remaining forests. The reason for this is that most of those fires are started by downed/shorted power lines & overheated transformers both of which are more numerous in regions infested with lots of wind turbines

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[352] Today's Gen III^+ LWRs are a long way from being the "best possible" nuclear power plant++.

[353] https://www.forconstructionpros.com/concrete/article/10886050/ohios-first-largescale-wind-farm-uses-lafarge-cement-for-turbine-concrete-foundations)

https://newmatilda.com/2020/01/15/greener-power-comes-with-its-own-increased-risks-of-bushfire/ .

Let's go through another example[354] assuming that we wish to replace Vermont Yankee's medium sized (620 MW_e) 46 year old LWR with 310 MW (average) wind power, 155 MW (average) PV solar power, and 155 MW (average) of Concentrated Solar Power (solar tower/mirror combo).

Building the solar and wind power facilities would require:

~450,000 tons of steel (0.6% of current U.S. total annual production).

~1.4 million tons of concrete (0.2% of US production/a).

The CO_2 emitted in making the wind/solar renewable energy facilities would be about 2.5 million tons

The cost of building that much wind/solar generation capacity would be about 12 billion dollars

The land required to build it would be about: 73 square miles (larger than Washington DC)

Here's a more reasonable suggestion:

Replace Vermont Yankee's old 620 GW_e GEN 2 boiling water reactor (BWR) with two of GE Hitachi's' new super simple/safe BWRX-300 natural circulation Small Modular Reactors (BWR-type SMRs).

If GEH's new SMRs were to exhibit a CF of 90% (its engineers expect 95%), they'd be generating an average of 540 MWe over ~80-year lifetimes which adds up to a total reliable energy production of 378 billion kWh.

If these SMRs cost $5/watt to build (GEH currently (2020) estimates a NOAK (Nth of a kind) BWRX-300 has an overnight capital cost (OCC) of US$2,250/kW, meaning an investment of $675 million would finance a 300 MW nuclear power plant (NPP).cost of $2.25/W), that'd be an up-front build cost of $3.0 billion/ for both of them.

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[354] Some of this example's numbers are from Chapter 10 of George Erickson's,"*Unintended Consequences: The Lie that killed millions and accelerated climate change*", web version is free at http://www.tundracub.com/htmls/unintendedconsequences.html. A more detailed compilation of build costs for GHG-free electrical energy sources may be found in "*Critique of 100% WWS Plan* "(Maloney 2018).

Since a US state, not for-profit private investors would be buying them, it could probably get a ~1.5% federal loan (today's official loan rate) which would cost Vermont's citizen rate/taxpayers a total of about $3.48 billion over twenty years.

Let's also assume that GE's super safe, same site, pair of SMRs could be run/managed with just 200 full-time employees each earning $150,000 per year

Over an 80-year lifetime, that would add a labor cost to their product/service (electrical power) of $2.4 B

Total energy cost (build+ interest +labor) over 80 years = $5.88 B

That's a breakeven nuke power cost/kWh of $ 0.016 for Vermont's frugal but far-seeing citizen tax/ratepayers and their representatives.

Neighboring MD's currently promised tax/rate-payer-paid wind power incentive for its persuasive "green"-but-unreliable wind power entrepreneurs is 13.1 cents/kWh

(it'll likely end up higher than that for the owners of its/their proposed swarm of intrinsically more expensive to both build and maintain offshore-sited windmills)

Which of these options is apt to make the most sense to Vermont's (not Texas's) citizen tax/ratepayers?

If we assume that building this example's ~600 GW's worth of reactors would require as much stuff as would a ~1100 GWe Westinghouse AP 1000, they'd collectively require ~10,300 tons of steel and *~165,000 tons of concrete* (about 1.8 % and 12% respectively as much as would the less reliable wind and solar alternatives).

Making their concrete and steel would emit   ~204,000 tons of $_{CO2}$ - about 9% that required to build an equivalent amount of wind and solar energy generating facilities.

Assuming my Nigerian example's solar panels and my previous hometown's (Idaho Falls, ID) mean solar insolation value (1891 kWh/m^2), solar panels would generate a yearly average of about 41 watts/m^2 - under 10 watts/m^2 during the winter's coldest months.

Another thing that our decision makers should consider is that nuclear power plants are far less apt to be destroyed than is any solar or wind farm by the USA's increasingly frequent/severe floods, tornados, derechos, and hurricanes[355].

[355] http://www.theweatherjunkies.com/single-post/2017/09/28/Puerto-Rican-Solar-Farms-Heavily-Damaged-By-Hurricane-Maria

7.2.1.2 Other Metals

The future's molten salt breeder/isobreeder reactors must be made of materials able to retain sufficient physical strength at temperatures up to ~750°C.   Those materials must also be sufficiently resistant to high neutron fluxes and the corrosive components of their salt stream(s). A great deal of experimental work performed at ORNL between circa 1955 and 1973-4, suggested that for the fluoride salt-based concepts that it was considering, a molybdenum/nickel/iron/chromium alloy, "Hastelloy N", would likely work[356]. Subsequent Russian and French work agreed with that conclusion. "Alloy 617" is another commercially available especially promising high-nickel alloy (see http://haynesintl.com/docs/default-source/pdfs/new-alloy-brochures/high-temperature-alloys/brochures/617-brochrue.pdf?sfvrsn=a27229d4_16) that ought to be subjected to (tested under conditions expected in fluoride or chloride based MSRs. Unfortunately, because we have refused to build such a test facility, only God(?) knows how well it would behave in practice (Ni-base alloys tend to crack upon neutron irradiation due to in situ He generation via the transmutation of ^{58}Ni and/or traces of boron. However, there's no reason to believe that it wouldn't work as well - maybe better - than would the materials that the Russians, French/EU, or ORNL have proposed for their MSRs[357].

In any case, a primary goal of engineering any such system should be to design it so that its "quickly wearing" parts (the tank containing or surrounding the reactor's core) could be replaced/maintained whenever that need arises. That's the sort of work that engineers are supposed to good at doing.

Providing that the redox state of their salt streams were to be buffered at a highly reducing state with something like Zr^{++}, MCFRs could probably be built of either 316 stainless steel or the austenitic (heat treated) "HT 9" stainless steel that Argonne's researchers /INL concluded would be suitable for its   LMFBR's fuel assemblies[358]. Neither metal is particularly difficult to work with nor fabulously expensive (not another of INL's now-traditional "unobtaniums").

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[356] The people designing the THORCON reactor plan to use the five-fold cheaper 316 stainless steel. The EU's MSFR's internals are to be constructed of an alloy similar to Hastelloy N with the exception its molybdenum would be replaced with tungsten –according to Alibaba's listings its cost should be about the same ~$20 US/kg.

[357] The best material to make MSRs of is unobtanium. The problem is that it's only available on a ***thole planet inhabited by feisty, ten foot tall, blue-colored, foreigners with funny looking tails.

[358] Another possibility that I haven't heard about yet is that it seems that the core "tank" of a MSR would be a natural candidate for "cathodic protection". Cathodic protection stops the corrosion of a metal's surface by making it the cathode of an electrochemical cell. One way to do it connects the metal to be protected to a more easily corroded "sacrificial metal" which acts as the anode (sacrificial metal corrodes instead of the protected metal). For

Yosika et al have recently summarized MSR materials state-of-the-art (Yoshioka 2107).

Let’s come up with another example:

How often would we have "maintain" our little molten salt test reactor (e.g., see Fig. 26) by replacing its core tank?

A recent Lawrence Laboratory report addressed radiation damage to steels exposed to high flux fast neutrons within the cores of fast reactors (Caro 2012).

“ *HT-9 steel is a candidate structural and cladding material for high temperature lead-bismuth cooled fast reactors. In typical advanced fast reactor designs fuel elements will be irradiated for an extended period, reaching up to 5-7 years. Significant displacement damage accumulation in the steel is expected (> 200 dpa) when exposed to dpa-rates of 20¬30 dpa Fe/y and high fast flux (E > 0.1 MeV) ~4 x* 10^{15} *n/cm*^{2}*s. Core temperatures could reach 400-560*^{o}*C, with coolant temperatures at the inlet as low as 250*^{o}*C, depending on the reactor design. Mechanical behavior in the presence of an intense fast flux and high dose is a concern. In particular, low temperature operation could be limited by irradiation embrittlement. Creep and corrosion effects in liquid metal coolants could set a limit to the upper operating temperature.*”

Note that steel embrittlement (damage) is more important at low temperatures than it would be at a molten salt reactor’s operating temperature. Note too that as is the case with Argonne’s sodium cooled fast reactor, MOLTEX’s concept subjects its fuel tubes’ cladding metal to the maximum possible neutron flux because it is only a few millimeters away from where each fission takes place. With the exception of its concept, the steel comprising any fast MSR’s core tank wall is at its periphery well away from its especially “hot” center – typically by at least one meter. This means that the neutrons impinging upon it would be less numerous & not moving as quickly.

If for the sake of conservatism, we choose to ignore that fact and assume that the reactor’s steel’s wall flux would be the same as that at the center of a lead-cooled fast reactor, we could expect a HT9 core tank to last 200 dpa/20-30 dpa/year or from 6.6 to 10 years before we’d have to shut it down, drain its core tank, & replace it.

If that core tank were to be made of the more chemically resistant & higher temperature-rated 316 SS steel or Hastelloy N instead (~100 dpa limit see IAEA 2012), it would likely require replacement about twice that often.

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other structures an external DC electrical power source provides sufficient current to protect the surface. Properly investigating ideas like these will require a MSR-type test reactor.

7.2.1.3 Isotopically pure salts

The most expensive component of any breeding-capable fluoride salt-based MSR like the LFTR or MSFR is apt to be the isotopically pure ^{7}Li that its fuel and blanket salt streams must be made of[359]. Although one of ORNL's contractors produced a half tonne of pure ^{7}Li during the early 1960's to test its "molten salt reactor experiment" (MSRE), the USA no longer possesses the ability to make it[360] . However, it is likely that suitably motivated entrepreneurs could produce it for under $300/kg (Ault 2012) which means that all of the ^{7}Li within a MSFR would cost about as much as one day's worth of its energy product.

Similarly, the most expensive single component of a fast chloride salt, breeding capable MSR other than its startup fissile would be the isotopically pure ^{37}Cl that its salt stream(s) should be made up with. No one now makes it in bulk because there's no market, but, again, it should relatively easy/cheap to produce because the same centrifuges currently enriching uranium, could probably enrich chlorine (gaseous HCl) much more easily/quickly/cheaply than they can uranium[361]. It would also be easy to recycle that chlorine because the same process that represents the "best" way to treat/solidify a MCFR or MOLTEX reactor's waste streams - iron/aluminum phosphate glass vitrification – quantitatively separates their chlorine in an easily captured/recyclable form (HCl – see Siemer 2012).

7.2.1.4 Other Materials

Most thorium breeder reactor concepts would require large amounts of fluorine (e.g., the MSFR's fuel and blanket salts would contain about 33 tonnes of it). Although there's plenty of cheap and readily available "fluorine ore" (fluorite), a good source of already-separated fluorine would be that in the roughly 1.2 million tonnes of "depleted" uranium (DU) hexafluoride stored in/around the world's uranium enrichment facilities. Like the Hanford Site's reprocessing waste, UF_6 is a corrosive liquid that's currently being stored in steel casks, some of which are

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[359] Lithium's other natural isotope, ^{6}Li, has a very high neutron absorption coefficient (cross section) which simultaneously "kills" the reactor's reactivity while its transmutation generates troublesome tritium. Tritium is both exceptionally labile (can penetrate many metals) and is, in principle at least, biologically impactful. Chlorine-35 exhibits a substantial scattering cross section for fast neutrons which would significantly reduce a MCFR's breeding capability. Its transmutation would also generate politically incorrect ^{36}Cl (which is also, in principle, potentially biologically impactful) along with some ^{36}S that might be corrosive.

[360] ORNL's "COLEX" lithium isotopic separation process involved electrolysis of aqueous salt solutions with mercury electrodes, which in the "first nuclear era's " regulatory environment, resulted in serious ground water and soil pollution. Today that separation would likely be done with either atomic vapor laser isotope separation (AVLIS), a method by which sharply tuned lasers are used to separate isotopes via the selective ionization of metallic vapors, or liquid-liquid extraction with crown ethers.

[361] The ease of a centrifugal separation is determined by the square root of mass ratios: It'd be easier to separate chlorine's isotopes because [(1+37)/(1+35)]^0.5 >> [(6*19+238)/(6*19+235)]^0.5

several decades old and beginning to leak. It could be converted to safer-to-store and potentially useful solid UO_2 plus useful/recyclable HF via “steam reforming” with added hydrogen gas.

7.2.1.5 Startup fissile

Since building a GW_e's worth of any sort of breeder reactor other than the aforementioned tube-in-shell concept would require 4 to 15 tonnes of startup of fissile (^{233}U, ^{235}U, and/or ^{239}Pu), getting enough of it together to start enough of them to power my scenario's clean/green future constitutes its toughest technical issue.

Before describing a way to address it, I should point out that the current generation (GEN III) of non-breeder reactors also requires about that much fissile/GWe to start up – the difference being that they must be continuously batch-fed additional fissile derived from additional natural uranium throughout their entire lifetimes.

Appendix V is a simple program like those we were empowered to write back when our personal computer's operating system included a straightforward, customer-friendly, BASIC programming language[362]. I've assumed the scenario generally adopted by the world's nuclear engineering (NE) R&D experts for any sort of fast reactor; that is, they would be started up with fissile “pyroprocessed” from spent LWR reactor fuel (e.g., GNEP) plus that in the world's “excess” weapons grade ^{239}Pu and ^{325}U[363] . Since doing that is both technically feasible and serves two fine-sounding purposes[364], there's a pretty good chance that it might be employed. APPENDIX V's example program assumes that Mankind continues to do nothing for another five years (a pretty safe assumption) while the necessary R&D is being done and ~400 GW_e's worth of LWRs continue to operate . Those LWRs operate for another 15 years while new breeder reactors are added at a rate equal to total fissile pyroprocessed from spent LWR reactor

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[362] Downloading DOSBOX & QBASIC or GW BASIC (all are free – GOOGLE them) & figuring out how they work (it's not too tough) empowers you to write your own little programs like this one.

[363] The world currently has about 200,000 tonnes of spent fuel in retrievable storage. Assuming that such fuel contains an average of 1.2 wt% Pu, 70% of which is fissile (^{239}Pu+^{241}Pu) that total comes to 1680 tonnes. The USA also purportedly still possesses ~600 tonnes of cold war-generated, weapons grade HEU, (POGO 2014). In addition, the USA's production reactors generated roughly 100 tonnes of bomb-grade plutonium (>90% ^{239}Pu), much of which is currently being stored in vaults at DOE's Savannah River National Laboratory. This adds up to a grand total of 2380 tonnes of startup fissile if our leaders were to decide to beat their swords into ploughshares.

[364] i.e., it would consume both weapons grade fissile and reactor grade plutonium thereby rendering today's stockpile of spent fuel “waste” easier/simpler/cheaper to dispose of.

fuel[365] plus that in the world's "excess" weapons grade ^{239}Pu and ^{235}U divided by the number of tonnes of startup fissile required per reactor divided by15 (the number of years) . After twenty years additional new breeders are added with fissile (^{235}U) from annually mined natural NU (another variable) plus that generated by the already-built breeders. When the total time INPUTed (NUM which for 2100AD ='s 81) is reached, the program stops looping and prints out how many reactors exist and how much uranium had to be mined/processed to get them all started.

Let's assume that we want to build 30 TWe's worth of sustainable nuclear power plants by 2100 AD. If we start building them beginning with 1900 tonnes of spent fuel RGPU + excess weapons grade fissile and each start up requires 5 tonnes of fissile, we'll have about 807 total GW_e of nuclear power (400 LWRs and 407 breeders) at the end of twenty years. From then on, the amount of freshly mined NU required to start 30,000 reactors by 2100 AD depends upon their CR – if they are isobreeding (CR=1.00), nearly 23,000,000 tonnes of fresh NU must be mined/processed. If they generate 20% more fissile than they consume (CR =1.2, the figure attributed to the Russian's BN-350), only 7,000,000 tonnes of NU would be required. The former figure is about 25% greater than the uranium industry's 2014 Redbook's best guess of total "*proven plus undiscovered resources*".

Such calculations reveal that it is indeed possible to become 100% sustainably nuclear powered by 2100 AD but only if we start soon and quit burning our "seed corn" (^{235}U and ^{239}Pu) in inefficient burner/converter-type nuclear reactors[366].

Again, the exception would be LeBlanc's tube-in-shell reactor concept because it should require far less startup fissile – likely under 2 tonnes ^{235}U - to get a GW_e's worth of isobreeding reactors up and running (depends upon reactor size/shape). If that turns out to be the case, then building my scenario's 30,000 full sized breeders would take far less time and NU; i.e., it could probably be completed by 2060AD utilizing the same amount of "new NU" as would just continuing to run today's ~400 equally powerful LWR's until then (see APPENDIX VI).

Consequently, it's a *good* thing that the USA's approach to radioactive waste management remains dysfunctional. The reason for this is that much of the fissile inventory required to

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365 APPENDICES I & II go through some examples of how spent LWR fuel could be converted to fuels compatible with breeding capable MSRs.

366 For example, during INL/Argonne's IFR project's last few years, its designers/modelers were told to deliberately reconfigure it to maximize "waste" burn up; i.e., waste as much precious startup fissile as possible. That's why Argonne's workers decided to switch the name of what they were working on from IFR to SFR ("sodium fast reactor"). Personally, I find it difficult to be cynical enough about what routinely happens within DOE's nuclear complex.

initiate a sustainable nuclear renaissance is now considered "waste", the management of which has received a great deal of "study" but resulted in actions/programs that didn't work out as planned, hoped, or promised. For example, SRL's MOX boondoggling means that its 34 tonnes of "excess", almost pure "bomb-grade" ^{239}Pu still exists in a useable condition and almost everyone who had worked on that project is richer than he/she would have been if no such work had been provided (Walmart, Uber, & Lyft can's employ all of the USA's unemployed nuclear engineers, scientists, and trouble-makers)..

Another example of how DOE's approach to nuclear project management might turn out to be a good thing is that the Navy's "spent" naval reactor HEU remains in a form capable of serving as a sustainable reactor's start up fissile.

Simultaneously reestablishing the USA's "leadership in nuclear power", cleaning up its atmosphere, restoring/maintaining the fertility of its farmland, and creating millions of worthwhile jobs (not just service-type gigs) and high-tech business opportunities for its citizens would be worth doing whether the reactors enabling it would cost $860 billion or ten times that much. For comparison, Stanford University's Pied Piper of the "green new deal" movement estimates that his 100% wind, water, and solar powered alternative (WWS) would cost us about $13.4 trillion paid for with big cuts in military spending, an unrealistically high carbon tax, more highly taxed "wealthiest Americans", plus lots of "resilience"[367] – not the bond drives which would give average US citizens a personal stake in the outcome of any such campaign.

Of course, since we're pretending that the world's human population will be 11.2 billion by2100 AD , the cost of the ~30 thousand full-sized reactors required to comfortably power everyone would be proportionately higher, ~30 (or 60)   trillion of today's dollars. To put that number into perspective, it's ~12% of what the "power walls" capable of backing up a similarly capable solar panel and/or windmill-based energy supply system for one day would cost.

7.4 Radwaste's rediculously overblown « management » costs

" *…eventually the antinuclear groups found the soft underbelly of the industry. It was something that had remained in the engineering background for decades. It was not nearly as exciting as striving for plutonium breeder reactor configurations or ceramic cores for jet engines, but it was there, and it was a distant bother. It was a nag, it was the long term disposal of all the radioactive byproducts of nuclear fission.*" (Mahaffey 2009 p 304)

Since the US has always been one of the world's most litigious countries (Rubin 2010), its reflexive anti nukes quickly realized that rendering waste management unnecessarily difficult

[367] aka "conservation" aka "doing without".

would serve their purpose. That plus the fact that DOE could be depended upon to waste lots of money "studying" waste management without accomplishing anything constructive, turned reprocessing waste management into one of the biggest hurdles that anyone championing a nuclear renaissance must surmount .

There have been two catastrophic nuclear power plant accidents and one that was perceived as a catastrophe at that time – Fukushima in 2011, Chernobyl in 1986-, and Three-Mile Island in 1979. Significant amounts of radioactive isotopes were released in the former two cases. Concern was particularly great in Europe in the case of Chernobyl because it was anticipated that a radiation cloud could blow across the continent.

But in the case of Fukushima, at most one person died from radiation. In the case of Chernobyl, confirmed deaths from radiation were under 50 and almost entirely due to how little Russia's leaders value their country's soldiers' lives. Three Mile Island posed zero to human physical health. Wind power has caused more deaths per kilowatt-hour of electricity produced than nuclear power.

The "should costs" of my scenario's waste management would be small because the relatively little waste it would generate would be simple to treat and then dispose of. Unlike today's fuel cycle, its reactors would "burn" almost all of the especially politically troublesome[368] long-lived transuranic radionuclides and thereby consist of only relatively short-lived fission products (FP). The mass of such waste generated by 22 TW_e's worth of MSR-type power each year would be about 18,000 tonnes. When everything required to isolate that FP is combined with them and that mixture vitrified, the resulting glass would weigh from 15 to 40 tonnes/GW_eyear and occupy 5-13 m^3 of space/GW_eyear depending upon the type of reactor (Siemer* 2013 & Siemer* 2014). These figures correspond to a total annual waste form volume ranging from 0.00015 to 0.00038 of one percent of that of the ash currently being generated and dumped every year by the owners of the world's coal-fired power plants[369] . Burning coal dumps mercury into the atmosphere and its ash is mildly radioactive and contains a host of other toxic trace metals (e.g., cadmium) all of

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[368] "politically" because all of the TRU isotopes are easily immobilized by the waste form materials (concretes, glasses, or ceramics) that would protect both us and "the environment" if buried in any of the USA's host of technically suitable geological repository sites. DOE is apparently spending several million tax dollars for yet another "study" of this issue (see NWTRB.gov). It's a waste of both money and intellectual resources to do such things because the problem is political, not technical.

[369] Like mining wastes, coal ash often ends up dumped behind huge earthen dams that are becoming increasingly vulnerable to global warming-enhanced flooding. The resulting almost inevitable disasters routinely kill many people and pollute huge swaths of land downstream of such impoundments. http://theconversation.com/coal-ash-spill-highlights-key-role-of-environmental-regulations-in-disasters-1034 http://www.pollutionissues.com/Co-Ea/Disasters-Environmental-Mining-Accidents.html

which possess infinite half-lives. This means that coal represents a much greater (and proven) threat to both the environment and the people in it than does the waste generated by my scenario's 20-30 thousand nuclear power plants.

7.4.1 Radioactive Waste Treatment

Disposal of the current nuclear fuel cycle's spent fuel remains a persistent challenge. With respect to a nuclear renaissance's reprocessing waste issues, what matters the most is "acceptability".

Both DOE and the rest of the world have considered glass to be the "best" waste form material (the stuff that's to be buried or "stored" somewhere) for both "low" and high" level reprocessing waste for over 4 decades. What's more important is that glass is both good enough and simple/cheap-enough to make if it's done right as the Russians (they've made both borosilicate & phosphate-type glasses), British, and French have amply demonstrated.

That's the rub, DOE's nuclear project managers can't seem to do anything right & have always managed to come up with a way to screw up almost everything they've set out to do, especially with respect to reprocessing-type waste management.

Its Environmental Management (EM) managers have been promising to vitrify Hanford's waste since 1988 & and to date haven't succeeded in doing much of anything other than spending 60-80 billion tax dollars trying to come up with a workable way to reclassify (separate) most of it so they can then make both "high" and "low"-type glasses instead of just one glass. That's insane of course, but to date US taxpayers have been willing to put up with it because the US is a "representative" democracy meaning that its citizen/taxpayers don't make the decisions.

The sole exception that I'm aware of was DOE's one and only "Vitrification and Privatization Success" (Picket et al 1995 -GOOGLE it). In that instance, a contractor (Duratek) promised to and then actually did convert 670,000 gallons of the Savannah River Site's liquid "mixed" (both radioactive and chemically toxic) radwaste plus some" hot" dirt and sludges to ~2180 tonnes (~780m^3) of borosilicate glass "gems" (irregular marbles) for $13.9 million (that's ~$6300/tonne or about 3 times what real-world glass usually costs). Those gems would be an almost perfect "aggregate" for DOE-site waste tank grouting.

That project succeeded because Duratek's, not DOE'S, vitrification experts had managed it & no one was therefore being encouraged to drag their feet.

That "success' made considerably more glass than that same melter could have produced from INL's "sodium bearing waste" which is the reason that Duratek prepared a bid to vitrify that waste too for $75 million a few years later. However, instead of doing that, circa 2006 DOE/INL's dazzled-by-BS waste management wizards promised to "steam reform" the stuff & send the resulting dust/sand-like "carbonate product" off to an imaginary out-of-state repository by 31dec2012 because it "*would be more cost effective*".

DOE & its pet contractors did of course miss that deadline and to date (February 2023) have wasted over a billion more tax dollars trying to get INL's "reformer" to run reliably enough to begin "treating' that waste.

That's why people don't trust anything DOE's nuclear experts have to say about nuclear power's waste issues. It's also why its most-favored solution to every other issue that it's been entrusted with addressing would cost too much and take too long.

While countries, including the United States, have opened disposal sites for low-level nuclear waste, progress on disposing either untreated spent fuel or whatever might be made of the "high-level" wastes that could be generated by recycling its useful components has been elusive. Finland is currently within a few years of potentially becoming the first country to successfully dispose of its power reactors' spent fuel and several other countries are making tangible progress too. But those nations' advances have been slow and the U.S. has effectively ceased to make any progress.

Vitrification has been deemed the "Best Demonstrated Available Technology" (BDAT) for immobilizing "high level" radwaste for over four decades. One of the reasons for this is that vitrification is intrinsically both simple and cheap which is why real-world glasses often aren't recycled. Because the temperatures r equired to make glasses are dangerously high (1000-1300°C), all vitrification is done more or less "remotely" within thick-walled and thereby heavily "shielded" radiation-wise, melters. Consequently, there's not much reason to assume that the cost of "remotely" making a radioactive glass should be vastly more than that, let's say $10,000 per tonne.

Given that figure and a 15% mass-wise waste loading what should it cost to vitrify the ~18,000 tonnes of radionuclides generated/a to produce 22.4 terawatts worth of breeder reactor power?

Tonnes of glass per year = 18000/0.15 =120,000 tonnes

Glass cost/a = $10,000/t*120,000 t/a=$1.2 billion/a

Vitrification cost per kWh = $1.2 billion/(22.4E+12 J/s*3600 s/hr*24 hr/day*365 days/a/3.6E+6 J/kWh) = $6.1E-6/kWh (trivial!!)

with addressing would cost too much and take too long.

7.4.2 Radioactive Waste disposal

Disposal of such glass shouldn't be prohibitively expensive either because one of the USGS's senior most hydrologists described a cheap way to safely accomplish it 40 years ago (Winograd 1981), Here's his paper's abstract:

"*Portions of the Great Basin are undergoing crustal extension and have unsaturated zones as much as 600 meters thick. These areas contain multiple natural barriers capable of isolating* *solidified toxic wastes from the biosphere for tens of thousands to perhaps hundreds of thousands of years. An example of the potential utilization of such arid zone environments for toxic waste isolation is the burial of transuranic radioactive wastes at relatively shallow depths (15 to 100 meters) in Sedan Crater, Yucca Flat, Nevada. The volume of this man-made crater is several times (i.e., ~ 5 million m^3) that of the projected volume of such wastes to the year 2000. Disposal in Sedan Crater could be accomplished at a savings on the order of 0.5 billion, in comparison with current schemes for burial of such wastes in mined repositories at depths of 600 to 900 meters, and with an apparently equal likelihood of waste isolation from the biosphere*."

That single, already radiologically contaminated/excavated, huge pit situated in the USA's most worthless "Federal land" (desert) could contain 20–50 years-worth of the future's HLW "waste forms".

The scientific basis of Dr. Winograd's concept was subsequently thoroughly investigated by the SANDIA scientists, who then dubbed it "Greater Confinement Disposal" and subsequently implemented it within the Nevada (bomb) Test Site's (NTS's) nearby "area 5" (APPENDIX X goes further into that story).

A properly-sited GCD-type repository is key to solving the USA's interminable defense-type radwaste boondoggling because it would eliminate the single greatest action-paralyzer/cost-driver in its radwaste management paradigm – the ridiculously high volumetric costs self-servingly assumed for such waste's burial plots which, in turn, serves to rationalize its decision makers' insistence upon trying to separate such waste's "highest" stuff (e.g., TRU, ^{137}Cs & ^{90}Sr) from everything else. Such huge scale, fully "remoted"[370] attempts at entropy-reversal are if implementing dangerous, unnecessary, and prohibitively expensive.

Dr. Winograd's initial estimate ($0.5 billion) seriously underestimated the cost of DOE's hypothetical high-level radwaste graveyard[371]. It is also likely that he didn't suspect that DOE would end up charging US taxpayers roughly $1 million for each tonne (about 0.4 m^3) of "high level" glass that its contractors might eventually make[372]. The sole exception I've seen so far is

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[370] Almost all activities involving genuinely "hot" radioactive materials are performed "remotely", i.e, from a safe distance with shielding imposed between the machine & its operators.

[371] The USA's regulatory environment renders "privatized" radioactive waste disposal ridiculously &prohibitively expensive as well – see APPENDIX XXVII

[372] Again, in the DOE Complex, most of "vitrification's" cost is due to the separation activities (aka, "pretreatment") preceding it o minimize the volume of the "high" fraction destined for its especially volumetrically-challenged imaginary repositories. By August 2013, the Savannah River Site's glass melter had produced 3728 stainless steel canisters containing about 1.72 tonnes of glass each. That facility started up in 1996 and has received about $0.55

its afore mentioned “Vitrification and Privatization Success” (Picket et al 1995) which made ~2180 tonnes (~780m^3) of radwaste-type borosilicate glass $13.9 million or ~$6300/tonne). Tougher-to-produce (higher melting) real-world bottle/window glass currently costs under $3000/tonne which renders it too cheap to be worth recycling in much of the USA.

“32N164W”, Chapter 16   of Gwyneth Craven’s “Power to Save the World” describes another competent, low-cost waste disposal scenario thoroughly investigated by scientists eminently competent to do so. GOOGLE EARTH reveals that it refers to a spot situated near the center of the Pacific Ocean far from the edges of any continental plate where the water is about twenty thousand feet deep and the basaltic bedrock underlying it covered with a several hundred-meter-deep layer of soft pelagic mud/ooze[373].   It’s simultaneously about the most stable, most isolated, and least valuable piece of the “earth’s” surface.   Her chapter does a fine job of explaining why the World’s top geoscientists concluded that it represents a truly excellent radwaste disposal site: big torpedo-shaped, steel-encased glass (or concrete) radioactive waste forms dumped off a ship there would bury/spear themselves deeply within that mud thereby isolating their contents from the biosphere for millions (billions?) of years.

If such ships were to be powered with little THORCON or Terrestrial Energy IMSRs instead of diesel engines, transporting such radwaste forms to that disposal site wouldn’t even “pollute the environment”. The diesel fuel currently consumed by big ships is a sulfurous, tar-like, “bunker oil” - not the relatively clean stuff sold by the first-world’s terrestrial service stations. It’s literally the “bottom” of the barrel” both quality and impurity-wise which is why it’s suitable only for an application that pollutes a “commons” (the oceans) rather than anyone’s sacred “private property”.

Incidentally, the world is already experiencing a steadily worsening “spent solar panel waste crisis”. (To learn about this, see Tomioka 2016).

It is unlikely that Goeller & Weinberg’s cornucopian world could be implemented by either the world’s currently poorest people themselves or the institutions that have traditionally provided most of their aid. Avoiding a deadly “hothouse earth” will require the simultaneous redirection of humanity’s actions from selfish, for-profit exploitation to genuine stewardship and rapid transition to a genuinely sustainable economic system (Steffen 2018). It won’t be cheap or easy

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billion 2013 dollars per year since then. That works out to a glass cost of $1.46 million/tonne. Real world bulk glasses cost under $2000/tonne. http://srremediation.com/dwpf_40_canisters.html https://www.emcbc.doe.gov/SEB/SRSPostFY18Ops/Documents/Site%20Tours/2-SRS%20Industry%20Day%20-%20Overview%20-%20Spears%20-%20161027.pdf

[373] https://www.ngdc.noaa.gov/mgg/sedthick/data/version3/fig_2_new_press.png

because rendering the world's energy systems GHG-free, ensuring that its land, water and other resources are used sustainably, adapting to climate change and cleaning up an already polluted world will require changes that many influential people and the vested interests they own/control will resist.

The western world's national policies are largely shaped by the neoconservative belief that a market economy is the life force of civilization, and that consumption is its purpose, thereby creating the nation's wealth, and material prosperity (Ayn Rand has become some of their leaderships' most-admired intellectual). That paradigm holds that producers will act for the common good guided by "sovereign" consumers without interference from government. By their thinking, if we just exhort individual consumers to purchase "green" products and services, we will eventually arrive at a clean/green/prosperous/fair form of capitalism.

While there is some (not much) truth to that notion, it's inconsistent with the realities of corporate power and humanity's natural selfishness[374]. Corporations seek to maximize gains for their managers and shareholders while minimizing environmental and other nonmarket obligations. That's why there are far more lawyers and lobbyists than elected "public servants" in Washington DC. In a technological civilization containing millions of enthusiastic, intelligent, and eminently trainable young people, "saving the world" is a political, not technical, problem and success will require the same extremely rare combination of technical smarts, unflinching commitment and hard-headed management skills exhibited by General Groves and Admiral Rickover over a half-century ago – not leaders exhibiting the "symptoms" of most of the people that have managed most of the USA's recent nuclear initiatives (Abdulla 2017, Ford 2017).

The following are the DOE nuclear project management "symptoms" identified by the National Academy's all time "best seller", " *Barriers-to-science-technical-management-of-the-department-of-energy Environmental Remediation Program*" (NAP 1996) over two decades ago.

1. Planning driven by existing organizational structures rather than problems to be solved.
2. Commitments that are made without adequately considering technical feasibility, cost, and schedule.
3. An inability to look at more than one alternative at a time.
4. Priorities that are driven by narrow interpretations of regulations rather than the regulations' purpose of protecting public health and the environment.
5. The production of documents as an end in itself, rather than as a means to achieve a goal.

[374] In practice, those drivers translate to an economic system based upon '*let the buyer beware*" which makes it difficult for buyers to determine what they're getting for their money (the technical details of the things we purchase is often considered "proprietary" information)

6. A lack of organizational coordination.
7. A “not-invented-here” syndrome at individual sites.

An earlier report by the also “outside” Galvin Commission (Galvin 1995), revealed a “*counterproductive federal system of operation*” for DOE’s national labs, saying, “*the current system of governance of these laboratories is broken and should be replaced with a bold alternative*”. The problems it identified included, *“increased overhead cost, poor morale, and gross inefficiencies as a result of overly prescriptive Congressional management and excessive oversight by the Department,”* and *“inordinate internal focus at every level of these laboratories on compliance issues and questions of management processes, which takes a major toll on research performance.”*

Those outsider-generated reports had about as much inhibitory effect upon DOE’s subsequent behavior as does a spritz from a child’s squirt gun upon a charging hippopotamus. Similar efforts by insider troublemakers (APPENDICES VII & VIII) didn’t cause its decision makers to “embrace change” either.

The consequence is that DOE still hasn’t done the research necessary for anyone to decide what a Rickover/Groves/Musk-like program manager should build for us.

7.5 How should we pay for it?

By acting as the planet’s balance sheet, nature’s capital provides critical services by supporting water cycles and soil formation while protecting communities from major storms, floods, fires, and desertification. By absorbing CO_2, it limits the pace of climate change. Biodiversity, a core component of natural capital, supports activities as wide-ranging as pharmaceutical innovation, ecotourism, and crop pollination. These are just a few of the “co-benefits” that make Nature so valuable. Yet the complexity of natural capital makes its benefits hard to quantify, leading many to overlook its preservation as an investment opportunity.

McKinsey & Company’s report quantifies some of the costs and benefits of conserving Nature and identifies how doing so would protect the climate, create worthwhile jobs, and improve human health. It focuses upon both the importance of conservation and its value by presenting a compelling case for investments in protecting it. To head off its further erosion, scientists and policy makers must call for the permanent conservation of at least 30% of the planet’s surface by 2030. The report’s analysis of six alternative conservation scenarios suggests that doubling the areas of both land and water that are still in a more or less natural state by 2030 could have a measurable impact and constitute a compelling case for investment.

James Conca’s Forbe’s opinion piece (Conca 2020) quantifies the benefits of conserving natural capital and suggests policy changes that could render implementation of what we must do to make it sufficiently attractive to investors. However, it's wrong to assume that privatized, market-based, capitalistic decision-making ill automatically solve our problems.

In a capitalistic society, how do we assign sufficient monetary value to doing big things like preserving Nature or inventing a save-the-world MSR concept to make them happen? To succeed we must shift our paradigms because humans are natural born capitalists (simultaneously competitive and self-serving) which means that in a capitalistic society, unless governmental policies meant to preserve our common environment sufficiently incentivize individual investors, we'll collectively continue to destroy it.

The "obvious" source of the money required for the USA to first develop and then implement a clean, green, nuclear-powered future is its tremendously bloated defense budget. President Trump's last budget request asked for ~$740 B/a including several tens of billions of dollars for nuclear weapons. It represented the first step of a $1.7 trillion plan to start a new nuclear arms race including brand-new $100 billion nuclear-armed missiles. He'd also proposed reassuming nuclear bomb testing.

The majority of such spending is nominally discretionary meaning that it could and should be used to address the energy-related technical issues apt to affect national security recognized by many of the military's senior-most officers (CNA 2014). If a proposal to have them manage such a new mission were to be presented to those officers, it's likely that they would be both willing and able to so-serve their nation.

Other obvious funding sources include:

- Revise the USA's tax structure to more like it was back when America was genuinely "great" (late 1930's to circa 1970); i.e., heavily tax inherited wealth and raise the uppermost marginal income tax rate to at least 90%. Doing so would level the playing field for succeeding generations of its citizens and raise some (not most) of the money required for nation rebuilding. During 1944–45, "*the most progressive tax years in U.S. history,*" the rate
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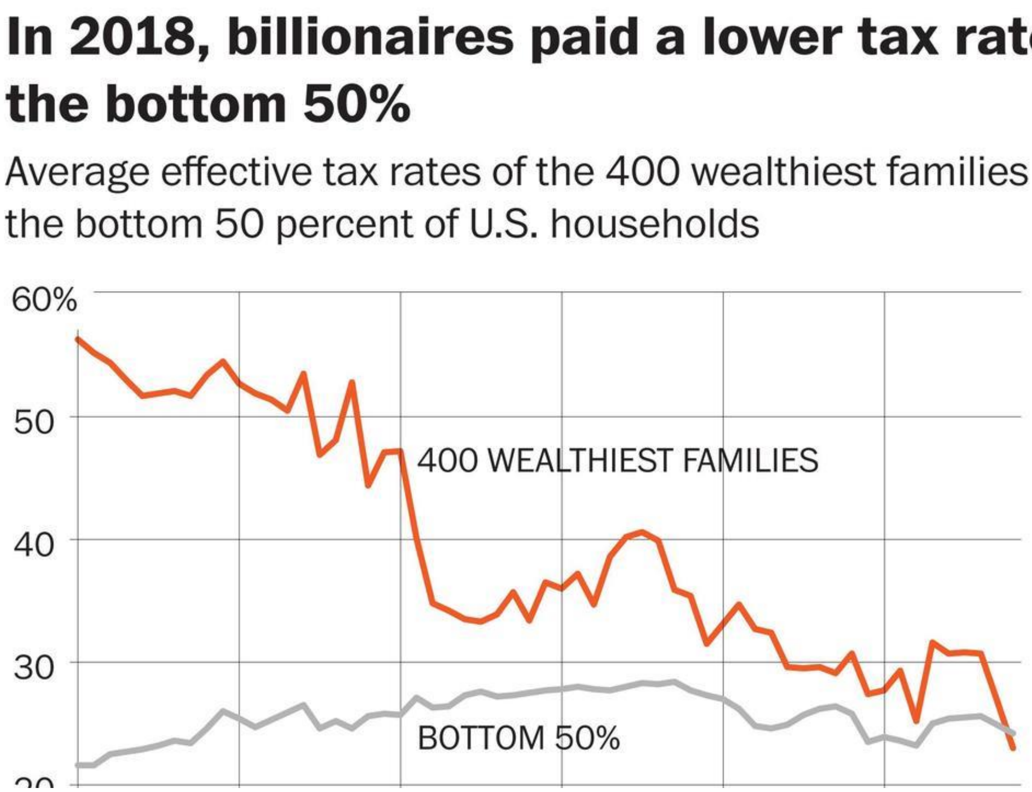

Figure 77 US tax rate trends(https://www.brainerddispatch.com)

applied to any income above $200,000 ($2.9 million 2020 dollars) was 94%. WWII's tax law revisions increased the number of "*those paying some income taxes*" from 7% of the U.S. population (1940) to 64% by 1944. Since then the "privatization" of governmental responsibilities combined with tax cuts for rich people and corporations and budget cuts for everyone else have led to widening economic inequality, decaying public services and a dysfunctional, hyper polarized, society. In particular, the USA's "middle class" has been devastated by rising unemployment and an inability to pay for rents, medical care, mortgages, food, and their increasingly unreliable electricity. The events of the past year (2020-2021) have proven that we need to shift to taxing excessive wealth not just our country's workers' earnings. The United States' billionaires added another $1 trillion to their collective wealth since the start of the pandemic with two individual fortunes now exceeding $180 billion. Ten of them made enough money during the COVID 19 pandemic to cover the cost of vaccinating everyone else in the world with enough to left over to finance development of a sustainable nuclear fuel cycle ***if*** their government's policies and bureaucrats permitted anyone to do that. We need to reform our tax system because it's another fundamental government function that's been ravaged by our leaderships disregard for facts and institutions.

- Issue "Nuclear Green New Deal bonds": War bonds (sometimes referred to as Victory bonds) are debt securities issued by a government in times of war to finance military operations without raising taxes to an unpopular level. They are also a means to control inflation by removing money from circulation in a stimulated wartime economy. They could and should be marketed directly to the public accompanied by appeals to patriotism and conscience. The last time the United States issued "war" bonds was during WWII when full employment collided with rationing and they represented a ay to remove money from circulation and thereby reduce inflation. Issued by the U.S. Government, they were first called defense bonds, which name was switched when the Japanese attacked Pearl Harbor. Bond rallies were held throughout the country with celebrities to enhance advertising effectiveness. Free movie days were held in theaters nationwide with bond purchases serving admission and all proceeds deposited into the U.S. Treasury. In those days, a median US yearly income was only about $2,000 despite which ~85 million Americans — over half its population — purchased the bonds paying about two thirds of that biggest of all (yet) war's cost.
- "Carbon taxes" most[375] of which should be rebated evenly (everyone gets the same) directly to individual citizens, not spent by dominant politicians upon their pet programs.

Hansen's proposal is the right way to do it.

He's made it clear that President Trump's complete dismissal of climate science is stupid but also criticized the Obama administration's Clean Power Plan for being too focused on regulation and likely ineffective.

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375 Sweden's carbon tax is another of the reasons that it is doing so much better than are most other countries at fighting global warming. Its relatively big tax (now US $126) didn't hurt its economy either; according to the Swedish Tax Foundation: "*Since the implementation of the carbon tax 30 years ago, Sweden has been able to reduce carbon emissions while maintaining solid GDP growth. In fact, GDP per capita increased in real terms by more than 50 percent between 1990 and 2019*." The Canadian government has just introduced a strengthened climate plan including billions in energy upgrades, subsidies for electric vehicles, and grid modernization. The biggest and most controversial item is a dramatic increase in the carbon tax, ratcheting up every year until it is C$170 (US$132.72) per tonne of carbon by 2030, at which point it would likely increase the cost of gasoline by 25%. The funds collected are then rebated back to the taxpayers. Most people will get more money back than they pay for their country's "price on pollution."

Hansen suggested a \$55/ ton $_{CO2}$ tax, which could generate a dividend of approximately \$1,000 per legal resident and a maximum of \$3,000 for a family with two or more children if they didn't generate any "new" $_{CO2}$ themselves.

According to his logic:

"*This [carbon tax] actually stimulates the economy. If it's a tax taken by the government, it makes the government bigger and it depresses the economy. That's why I object to the Democrats as much as to the Republicans. The only way the public will allow a carbon fee is if you give the money to them — people don't want to see the price of gasoline at the pump going up*."

Hansen insists that there really is no other realistic solution to mitigate future climate change risks. If fossil fuels continue to be available as the cheapest source of energy, they will continue to be burned. The economic reality here in the U.S. is that consumers have always balked at paying higher fuel and utility prices.

For example, a \$100/ tonne CO_2 tax would cost the owner of a 30 mpg gasoline-powered car~2.9 cents/mile. If he drove a 50 mpg car or drove less, his rebate would more than pay him/her for making that change. The USA currently consumes about 20 million, 42-gallon barrels of petroleum per day, ~86% of which is burned, meaning that a \$100/tonne tax rate would raise about \$284 billion per annum. Several percent of that money should be spent on a crash R&D program to quickly determine how best to go about implementing this book's renaissance. The rest should be rebated equally to individuals via the federal government's taxation system.

The USA's Manhattan project cost about \$2 billion 1940-dollars (~\$36 billion 2019 dollars). In just over three years, its workers turned an abstruse scientific observation[376] into the technical infrastructure that succeeded in abruptly ending WWII and thereby likely saving a half million US lives and five times that many Japanese lives. The USA's WWII bond drives raised over ninety times that much money, \$186 billion 1940 dollars (that's ~\$3.2 trillion 2019 dollars)[377].

A recent review of thirty-three previous studies of the return on investment (ROI) of infrastructure-type investments suggests that smart infrastructure development programs like

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[376] Over 1938's Christmas vacation, physicist Lise Meitner and chemist Otto Frisch made a discovery that revolutionized nuclear physics and soon led to the "atomic bomb"; i.e., that when ^{235}U absorbs a neutron, it usually (about 80% of the time) splits into two smaller atoms (fission products) and 2 or 3 "new" neutrons.

[377] This cost assumes the US federal government's official inflation rate figure. For the sorts of technical things required to fight wars or build nuclear power plants, inflation has been greater than> 3.2/0.186.

those that China's been doing exhibit a 10-20% rate of return in terms of increased economic activity (Bivens 2017). That suggests that the federal government's borrowing money from its citizens to first develop and then implement a "nuclear green new deal" represents a great investment. I suspect that I'm not the only US citizen who would be delighted to have an opportunity to invest in something like that rather than in the mysterious "financial products" that my financial advisor invests my savings in now.

Another way to painlessly fund this book's scenario would be to convince the rich/influential people in today's fossil fuel energy businesses that their companies' futures lie in selling energy implemented via a sustainable nuclear fuel cycle.   It's not incompatible with what most of them are doing now because cheap nuclear power would render synfuels much more practical than they are now.

Chapter 8. The nuclear establishment's self-inflicted wounds

Today's widespread distrust of science combined with the political left's weaponization of the precautionary principle to fight nuclear power are largely due to the behavior of the US Department of Energy and its predecessors. The first such agency, the Atomic Energy Commission (AEC), was created just after World War II to oversee all the USA's non-military nuclear programs. Rooted in its military beginnings, it was hyper secretive and obsessed with "teamwork". It dismissed public fears as hysterical and used every available legal and bureaucratic maneuver to brush off anyone who questioned its decisions which policy eventually converted even modest skeptics to embittered enemies. Its most influential chairperson, Lewis Strauss was a Wall Street financier who helped private industry assume control over what had been the Federal government's nuclear power program. That engendered mistrust because the AEC's businessmen-membership oversaw both the promotion and regulation of nuclear energy for their businesses benefit (Weart 2012).

Public trust is a prerequisite for nuclear power to play its part in mitigating climate change. Too often, the debate about how to move the world onto a more sustainable energy path is framed in the false dichotomy of "either we invest in solar and wind power, or in nuclear energy." Because privatization of the USA's energy system has prevented the adoption of a sustainable nuclear fuel cycle, at this point in time reaching net zero carbon emissions soon enough to head off environmental collapse will require investments in all of them.

Since governments can fund themselves with taxes and/or selling bonds to its citizens, doing reactors builds that way would get the USA's also very much privatized banking industry's sharks out of its citizens wading pool. If that approach were employed, then no one working for that government would benefit from holding up that project by doing the sorts of things (e.g., "studying" Environmental Impact Statements (EISs), siting, decommissioning, waste management plans and blueprints for several years) which combined with build-loan costs >10 times the US government's prime lending rate has rendered building any sort of reactor prohibitively expensive.

There's no good reason to assume that the power generated by one of GE Hitachi's simplified new 300 MW BWRs (see https://aris.iaea.org/PDF/BWRX-300_2020.pdf)should cost its purchasers more than ~five US cents/kWh. If GE Hitachi can no longer efficiently build its own reactors here in the USA, I suspect that a Chinese or Korean subcontractor could do it for them.

Both that industry and its supporters were contemptuous of public fears and responded to public concerns with glowing promises of '*energy too cheap to meter*'[378]. When the AEC's first chairman, David Lilianthal (a "new dealer" who had previously headed the TVA), told the industry's illuminati at the American Nuclear Society's 1963 meeting that, "*unless the nuclear community became more open to criticism, they might let loose a 'wave of disillusion' against all of science and technology*", that audience booed him. To which Lilianthal replied that "*the louder the industry tried to shout down its critics, the more the public would wonder*."

In his last book seventeen years later, "Atomic Energy: A New Start", Lilienthal restated his conviction that there that while there is no turning back from nuclear energy, it should be implemented with something other than today's still-predominant light water reactor technology.

The environmental movement was also developing during the late 50s and early 60s due largely out of concerns about nuclear weapons and radioactive fallout. One of its leaders, Barry Commoner, "*I learned about the environment from the Atomic Energy Commission in 1953*." Rachel Carson wrote that while in her early years, she had believed that Nature was "*beyond the tampering reach of man*" radioactive fallout killed that faith. In her iconic book, Silent Spring, she repeatedly emphasized the dangers of industrial chemicals by likening them to radiation. In that book's chapter on cancer, she paralleled the fate of a Swedish farmer who died after spraying his fields with pesticides with the deaths of the Japanese fisherman whose vessel had been immediately downwind of the USA's unexpectedly large Castle Bravo thermonuclear explosion.

"*For each man, a poison drifting out of the sky carried a death sentence*".

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[378] The AEC's boss's (Straus) prediction about what the cost situation would be by 1969 never made much sense because the USA's electrical utilities always meter their product and back then coal was still dirt cheap. For instance, 13 million BTU/short ton lignite sold for $1.86/ton in 1969 which translates to a fuel cost for that era's ~30% efficient power plants of $0.00163/kWh. Any further reduction in their fuel costs would have been totally irrelevant.

For one, it was still-“hot” radionuclide-poisoned ash; for the other, chemical dust.

Tens of thousands of the Western World’s young people subsequently participated in huge anti-nuclear/anti-war rallies. Many of the participants translated the pervasive anxieties arising from the fear of nuclear war into a full-scale critique of contemporary society. That led to a loss of confidence in science, scientists, experts, and “government” currently manifesting itself as opposition to genetically modified food, industrial chemicals, vaccination, “socialism”, and, of course, nuclear power.

Goeller and Weinberg’s utopian future can’t come to pass if those individuals most able to bear the cost of the necessary sweeping changes — those who’ve benefited the most from current economic and political systems — don’t help to pay for it. Since interfering with current business practices and taxing excessive wealth are anathema to most of the Western world’s “conservative” political leaders, it’s likely that Eastern, not Western, countries will be the “outsiders” helping the world’s disadvantaged people to implement this or any other scheme capable of achieving its goals. One reason for this is that most of the West’s decision makers believe that nuclear power’s technical innovation should be left to the private sector, not government. While that might make sense for IT (hardware, software, and cell phone app development), it is unlikely to work because reactor development is especially “risky” requiring a far greater investment of money, time, special materials, experimental work, and technical experts capable of addressing a host of mechanical, physical, chemical, and, especially, legal issues – it can’t be done by a few clever “hackers” in a rented garage. Its ultimate goals – achieving genuine sustainability, preventing further environmental damage, and providing a better life for everyone including the poor several decades off in the future – are also inconsistent with those of most of today’s politicians and venture capitalists. Getting government “out of the way” sounds nice but is not enough by itself because every major energy breakthrough in recent history has received public support that moved an idea to proof-of-concept to demonstration after which the private sector’s movers and shakers then heavily invested and thereby became richer (Siddiqui 2018).

Similar paradigm shifting must happen if the USA wishes to devise a nuclear solution to this book’s energy conundrums. Its development will require a substantial number of “risky” (high failure probability) experiments and lots of expensive equipment that may never make money for anyone. I feel that the real problem here in the West is that no one– certainly not our lawmakers - seems to be responsible for seeing to it that we make ourselves ‘sustainable’.

This means that developing a suitable reactor along with the wherewithal required to render its output sustainable should be a joint R&D effort directed by someone like Admiral Rickover[379]

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[379] In his dual role as AEC member and government employee/project manager, Admiral Rickover “privatized” the development of his submarine reactor in that, he could sign off on his own proposals and funding requests. There aren’t many non-uniformed people that I’d trust with that much power now, but it certainly is an efficient way of doing things. His employer, the U.S. Department of Defense (DOD) is the world's largest with a budget larger than

and funded by the government, not private citizens. In the USA, initial patent filing dates protect IP and providing both that and other such paperwork is often so expensive and time-consuming that little or no progress is made on the necessary experimentation. This suggests that an inventor's interests should be protected by an umbrella entity that only a government can provide. In the absence of such protections, solo inventors can literally kill themselves trying to hold onto most of their IP while giving enough of it to venture capitalists to keep up the fight. It is an extremely disagreeable and in this particular field, usually unsuccessful system that should be replaced with one in which everything "technical" learned is immediately "open sourced" and everyone contributing to the project's successful completion - inventor(s) and the people enabling their work – rewarded the way that George Westinghouse did the inventor of the AC motor; i.e., receive a fraction of the "value" generated by the invention. This would incentivize everyone to do whatever they can to make the effort succeed ASAP - not try to stretch the project out to provide themselves with more paychecks. It would also mean that a country's citizens, not its venture capitalists, would "own" Mother Nature's IP.

Of course, the other reason is that many of the West's topmost decision makers have apparently been sold on the notion that the future should/could be adequately powered by an "all of the above" mix of politically correct non-nuclear, renewable technologies (see Jacobson 2009, Jacobson 2017 - for opposing views see Bryce 2013, Beckers 2016, Clack 2017, Maloney 2018, and Brook 2018), and, have therefore supported/subsidized efforts consistent with that paradigm. The USA's green movement was born in defiance of the New Deal Order in the 60s and 70s. In gathering political, cultural, and economic power, it pulled from the traditional American view of monopoly: unfair conspiracies. This has been true even for public power. The anti-bigness bent amongst green progressives has continued up until this day. Tennessee Congressman Steve Cohen has put the Tennessee Valley Authority in his crosshairs because as a monopoly it does not allow enough "clean" solar power onto that region's grid. Even though most of America's competitive electricity markets have dirtier energy portfolios than the TVA and are encountering greater reliability and affordability problems, Cohen's bill "would remove TVA's exemption from outside competition and its inability to compete for customers outside its footprint.
Even if decision makers like him aren't overtly hostile to anything "nuclear", they pay only lip service to developing a sustainable nuclear power system. This is understandable because 1) most of nuclear power's champions haven't presented a particularly compelling case for massive

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many countries and a huge influence on both local and global politics. With its gigantic energy and resource footprint, anything it decide to do will have a ripple effect. Its leaders have recognized for a long time now that climate change is serious business and have made many forward-thinking policy statements related to adaptation within its own facilities. Secondly, unlike Congress the USA's military has retained credibility because it is rigorously apolitical, mission oriented, thoroughly and consistently organized, and routinely succeeds in accomplishing things that other branches of our government can't seem to get done. When the military comes around on anything, people listen which means that it can serve as an example for other large institutions, cities, or even states when it comes to addressing this book's technical issues.

expansion[380] and, 2) most US politicians were originally lawyers and/or businessmen, not engineers or scientists, and therefore don't think quantitatively about non immediate or technical issues – especially anything that's controversial or "safe" to ignore until they've achieved their own personal goals. Of course, the people that work for them in the USA's privatized national laboratory system[381] (e.g., INL, ORNL, Hanford…) pretty much must do whatever its politicians want because becoming a "poor team player" in that work culture is tantamount to career suicide.

The most accurate measure of any country's commitment to accomplishing anything is how much money it is willing to spend trying. In the world's richest Western nation (USA ~ $21 trillion GDP) we hear things like, "*The US Department of Energy (DOE) has selected projects to develop a pebble bed reactor and a molten chloride fast reactor to receive multi-year cost-share funding worth up to a total of $80 million*." (DOE 2018), and, that "*Secretary of Energy Rick Perry Announces $60 Million for U.S. Industry Awards in Support of Advanced Nuclear Technology Development*", which support is to be split between 13 projects in 10 different states (Perry 2018). Although much of this work will be performed in the government's laboratories by its contractors' employees (it's illegal to do genuinely "hot" research anywhere else in the US), its leadership won't assume responsibility for guiding it or insist upon appropriate goals. Finally, although these projects have accomplished a good deal of computerized modeling, simulation, and "road mapping" (see Appendix IX and DOE's http://gain.inl.gov website), DOE's nuclear scientists/engineers can't effectively address the future's energy issues until they become empowered to do the same sorts of "risky" work performed at its National Reactor Testing Station (NRTS, now INL), during the 1950s & 60s. Unfortunately, although its people helped design, built, operate, and then safely decommission ~50 different reactors, the USA never got around to building a test reactor capable of evaluating today's more promising MSR concepts and is still apparently not planning to do so (see Petti 2017) .

Here's a 10Jul18 example of DOE's commitment to developing a sustainable nuclear cycle.

"*U.S. Department of Energy Provides Nearly $20 Million for Domestic Advanced Nuclear Technology Projects*" https://www.energy.gov/ne/articles/us-department-energy-provides-nearly-20-million-domestic-advanced-nuclear-technology

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[380] For the most part, its spokespersons haven't been championing anything that could "save the world" because doing so would require them to challenge their industry's current business models. The most compelling selling point that they could/should present is that their new reactors would be generating "renewable" power that's also reliable.

[381] Since the Manhattan Project, the management of DOE's sites has been done by private M&O contractors. DOE spends ~90 percent of its budget on those contracts which makes it our government's largest non-Defense contracting agency. Although each site nominally operates under DOE's oversite, they work independently because their M&O contactors are, in effect, continually competing for DOE's next big contract. This plus the revolving-door shuffling of top-level managers back and forth between state & federal governments, contractors, industry, and "independent" advisory groups generates a tremendous amount of duplication/overhead/covering-up and thereby constitutes a root cause of the USA's notoriously inefficient nuclear project management.

Here's a breakdown of those awards.

$ million	Funded Activity
7.00	Calendar Year 2018 Activities for Phase 2 of NuScale Small Modular Reactor project (a mini PWR)
0.498	Regulatory Support for Advanced Light Water Reactor Deployment: Advanced Boiling Water Reactor Source Term Reduction –
6.314	Advancing and Commercializing Hybrid Laser Arc Welding (HLAW) for Nuclear Vessel Fabrication
2.101	Fluorination of Lithium Fluoride-Beryllium Fluoride (FLiBe) Molten Salt Processing – Flibe Energy
1.120	Experimental Verification of Post-Accident Integrated Pressurized Water Reactor (iPWR) Aerosol Behavior, Phase 3
1.925	Reactor Plant Cost Reduction to Compete with Natural Gas Fired Electrical Generation (Hitachi small modular BWR)
0.400	Conceptual Engineering for a Small Modular Reactor Power Plant Based on Lead-Bismuth Fast Reactor (LBFR) Technology

Finally, "DOE has selected two companies to receive GAIN technology development vouchers in this second review cycle. The companies selected are Yellowstone Energy (Knoxville, TN) in the amount of $160,000, and ThorCon US (Stevenson, WA) in the amount of $400,000. Further detail and description of these awards can be found under the GAIN website." (Same reference)

Note that of DOE's $19.9 million commitment to "advanced" reactor development, only $ 2.5 million is to study anything having to do with a potentially sustainable nuclear fuel cycle. These are Flibe Energy's spent LWR fuel fluorination "demonstration" plus another round of Lead-Bismuth Fast Reactor's (LBFR) conceptual engineering.

"The President's Budget provides a total of $32.5 billion, $30.2 billion in discretionary funding and $2.3 billion in new mandatory funding in FY 2017 to support the Department of Energy in the areas of nuclear security, clean energy, environmental cleanup, climate change response, science and innovation". https://www.energy.gov/fy-2017-department-energy-budget-request-fact-sheet

$2.5 million represents 0.0077% of DOE's budget and will be mostly spent supporting contractor personnel working on "safe" (not "risky") projects at its national laboratories.

Two years later (December 2020) the US Department of Energy (DOE) announced that it is backing five projects to develop the USA's private industry's advanced nuclear reactor concepts https://www.energy.gov/ne/articles/energy-department-s-advanced-reactor-demonstration-program-awards-30-million-initial

It's Advanced Reactor Demonstration Program (ARDP), the DOE's Office of Nuclear Energy's US ~$30 million dollars' worth of initial funding is expected to grow to US$600 million over the next seven years.

The goal of these grants is to promote the development of reactors for deployment in 10 to 14 years that are not only more efficient and more economical to operate but are also inherently safer to run via the use of more robust fuels and cooling systems that can passively keep the reactor from melting down when there's no power available.

"All of these projects will put the US on an accelerated timeline to domestically and globally deploy advanced nuclear reactors that will enhance safety and be affordable to construct and operate," says US Secretary of Energy Dan Brouillette. "Taking leadership in advanced technology is so important to the country's future because nuclear energy plays such a key role in our clean energy strategy."

The five reactor concepts getting that support include the Hermes Reduced-Scale Test Reactor by Kairos Power in Alameda, California. Intended to lead to the building of the commercial-scale Kairos Power Fluoride Salt-Cooled High Temperature Reactor (KP-FHR), this advanced test reactor is based on Tri-structural ISOtropic (TRISO) particle fuel and is cooled by a low-pressure fluoride salt coolant.

TRISO fuel consists of tiny particles composed of uranium, carbon, and oxygen formed into kernels and then encapsulated within three layers of carbon and one of silicon carbide to prevent the release of radioactive atoms. Its poppy seed-sized kernels are embedded within pyrolytic graphite in cylindrical pellets or billiard ball-sized spheres, which can withstand the extremely high temperatures within gas or salt-cooled reactors. ((see https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth)

The second project is the Westinghouse Electric Company's "eVinci" heat pipe-cooled 5-25 MWt micro reactor technology demonstrator. "*The purpose of the demonstration is to assess the risks of such a design and determine how to improve the manufacturing and efficiency of its heat pipe system*." Total award value over seven years: $9.3 million (DOE share is $7.4 million). That concept features a solid stainless steel (SS) core containing multiple channels each of which contain TRISO pellets embedded within a metal-like zirconium hydride moderator surrounded by evacuated (no air) SS heat pipes containing molten potassium - a volatile metal which like water possesses a substantial heat of vaporization. The reactor's heat energy is to be removed via vaporized potassium moving to an external heat exchanger where its condensation transfers heat to a gas turbine-powered electricity generator or to something else requiring such energy. Brookhaven National Lab. (BNL) has published an excellent description of this concept (Hernandez et al 2018, also 1501599 (osti.gov)).

Upon reading its report, the feature that jumped out at me is that this concept is terribly inefficient with respect to fuel (uranium resource) utilization. Assuming 19.8% enriched fuel, 40% heat-to-electricity efficiency, a power output of 25 MW thermal, and a fuel residence time of 11.34 years, its discharge burnup would be only 18.05 (not 22.54) MWd/kgU and would require the mining/refining/enrichment etc. of over 1900 tonnes of natural uranium per GWe year's worth of electricity - far more than do today's LWRs (see itsTable 3).

In my opinion doing demonstrations like this wastes time, money, and human energy that should be devoted to coming up with something capable of powering the whole world indefinitely , not a few tiny "niches" for a few years. We already know how heat pipes work and "burning" natural uranium's fissile that inefficiently is like burning your seed corn.

Third is the BWXT Advanced Nuclear Reactor (BANR) by BWXT Advanced Technologies in Lynchburg, Virginia. It plans to develop a commercially viable transportable micro reactor focused upon using TRISO fuel particles to achieve higher uranium loading and a core using a silicon carbide (SiC) matrix. Total award value over seven years: $106.6 million (DOE's share is $85.3 million). To date no even semi detailed description of this concept has been revealed though unless the project demonstrates that it's possible to run the system as a fast reactor (minimize moderation) to the point that it could become a breeder, it's likely to be just another high temperature helium-cooled "converter".

The fourth is the Holtec SMR-160 (MWe) Reactor from Holtec Government Services in Camden, New Jersey. Like NUSCALE's concept, it is a small, modular, light water moderated/cooled utilizing commercially available French-made LWR fuel assemblies. Holtec is receiving funding for early-stage design, engineering, and licensing activities to accelerate the development of its SMR. Total award value over seven years: $147.5 million (DOE's share is $116 million)

Finally, there's the "Molten Chloride Reactor Experiment "by Southern Company Services (and Bill Gate's *Terrapower* startup), Inc. in Birmingham, Alabama. In this 1,200 MW critical fast-spectrum salt reactor concept, the fuel is mixed in with the molten salt coolant. The project will design, construct, and operate the Molten Chloride Reactor Experiment (MCRE) – the world's first critical fast-spectrum salt reactor. Total award value over seven years: $113 million (DOE's share is to be $90.4 million)[382],

"There are three kinds of men. The one that learns by reading. The few who learn by observation. The rest of them have to pee on the electric fence for themselves" Will Rogers .

In contrast to the USA's "pretend" commitment to nuclear energy research and development, its DOE/NNSA's nuclear arm plans (2020) to spend ~$12.5 billion/year to maintain its stockpile of

[382] A later (November 2021) Southern Company press release characterized that collaboration as a seven-year, $179 million cost shared R&D project including itself, DOE's Office of Nuclear Energy through the ARDP, TerraPower, , CORE POWER, Orano Federal Services, the Electric Power Research Institute (EPRI), and 3M Company which is to be performed at Idaho National Laboratory (INL).

nuclear weapons. During that same year the Department of Defense (DOD) will spend ~$24.8 billion on its nuclear weapons deployment -related activities. Altogether the USA's total nuclear weapons related expenditures have been on the order of $20–40 billion/a for a long time (Rumbaugh and Cohn 2012). "Nuclear modernization" is a euphemism for a wide range of hypersecretive activities that many feel to be a new, especially dangerous, and fabulously expensive global nuclear arms race. In the United States, the 30-year cost of the plethora of programs under its "nuclear modernization" umbrella – including new nuclear-capable bombers, land-based nuclear missiles, "mini nukes" (bombs)[383], and nuclear submarines – has recently been estimated at $1.2 to $1.7 trillion. Observers familiar with the Defense Department's $640 toilet seats suspect that if that entire program were to be funded, its cost would be much higher even than that (Mecklin, 2019).

James Mahaffey recently characterized the nuclear establishment's cultural norms as follows:

"*Under fire nuclear engineering is to engineering as modern Islam is to religion. It's become more conservative and fundamentalist. Criticism from outside was so severe that internal criticism became more than the system could tolerate. The designs of nuclear reactors, plants, auxiliary mechanisms, and associated facilities, such as "waste" disposal systems or fuel handing strategies, all become more conservative*[384]*, with less engineering risk or innovation*." (Mahaffey 2009, p. XVI).

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[383] According to Frank von Hipple, each of the USA's new mini nukes would contain a miniaturized version of the Nagasaki bomb weighing about two percent as much. Its "primary" would consist of a hollow plutonium shell (pit) surrounded by a chemical explosive. When that explosive is triggered, the pit would implode to a spherical mass compressed to about twice plutonium's normal density. Near that point and before the plutonium can rebound to its normal density, a tiny neutron generator will spray it with a burst of neutrons initiating fission chain reactions that will fission about 20 grams of the plutonium immediately heating everything around it to about a million degrees Centigrade. At that point, fusion reactions occurring within the several grams of tritium and deuterium injected into that pit just before the implosion will generate an intense burst of fast neutrons that will fission about one-half kilogram of the plutonium, thereby "boosting" total energy release to about 10 kilotons (~4.2E+13 J or about one half that of the original bomb). An especially deranged ("stable"?) topmost decision maker might want to surround this assembly with a couple tonnes of depleted uranium within a cobalt steel shell and thereby enable him to do unto to his political enemies (kill 'em all and then "salt" their earth) that we read about in the first half of our holy bible.

[384] An American-type conservative embraces political beliefs characterized by respect for "business", private property, American traditions, republicanism, Judeo-Christian values, anti-communism, individualism, American exceptionalism, Social Darwinism, and defense of Western culture from the threats posed by big government, foreigners, socialism, authoritarianism, regulation, and moral relativism.

Franklin D. Roosevelt said it better: "*A conservative is a man with two perfectly good legs who, however, has never learned to walk forward*."

One of the ways that that culture manifests itself is that its adherents –including its still-being-educated (i.e., "trained") students – seem to be as interested in hearing about the sorts of things discussed in this book as are cows are in learning quantum mechanics. It manifests itself within DOE's nuclear complex as an over reliance upon authority, "procedures" (see APPENDICES VII, VIII, and XII), fine-sounding but irrelevant principles combined with excessive secrecy and a compulsion to shade the truth a bit when dealing with outsiders (*if hard pressed, tell the truth but never the whole truth if there's any way to avoid it* - see APPENDIX XII).

Government's role in this arena should be to fund long term, revolutionary projects, not sustaining and incrementally improving an already well-performing LWR technology - that should remain the domain of private industry. Government's job is to retire a *worthwhile* concept's risks so that private enterprise can then step in and capitalize upon its effort. Unfortunately, instead of restricting its scope to areas where academia and industry lack the funding, people, or facilities required for innovation, DOE's nuclear engineering office (hereafter designated "NE") is engaged across the USA's entire nuclear enterprise, spreading its focus and expenditures over myriad, disparate, & mostly not cutting-edge, activities. Evidence of its lack of focus is the blizzard of road mapping and strategy documents prepared by its employees. The thirty anonymous experts interviewed by Ford et al. (Ford 2017) characterized NE's activities as follows:

1. "Y*es, we have enough roadmaps to publish an atlas. And yet, no vision*."

2. NE's real goal is to maintain its funding stream, "*flying under the radar to the greatest extent it can in order to avoid political controversy, and it generally succeeds at that.*"

3. NE's project funding is an "*old boys' club,"* where investigators are funded, "*if NE had funded them in the past*."

4. NE favors funding "*known quantities*" in order to "*prevent surprises*." Evidence of good performance or innovative research rarely comes into the equation[385].

5. NE is most definitely not interested in "*taking risks*:" *it neither rewards nor encourages radical deviations from its programming norm.*"

Those outside experts lamented the fact that the USA's nuclear R&D enterprise is led by an organization that avoids taking risks and making hard decisions, frowns upon ambitious, long-

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[385] Again, within DOE's NE division, a project's products are reports ("paper") and, occasionally, a "decision" – nothing concrete.

term projects, funds them at starvation levels, and is primarily concerned with the next congressional appropriations cycle.

More than two-thirds of them opined that NE's national laboratories ought to be mainly a facilitator, or enabler, of research. They should conduct high-risk and potentially high-reward research and maintain the facilities that buttress industrial innovation, as opposed to micro-managing its own and other organizations' activities.

8.1. Refusal to either choose or set rational goals

As of September , the USA apparently still isn't serious about either "electrification" or GHG elimination.

For example, Indian Point Energy Center (I.P.E.C.) was a nuclear power station built on ~50 acres of an old amusement park near Buchanan, New York, just south of Peekskill. It sits on the east bank of the Hudson River, about 36 miles (58 km) north of Midtown Manhattan. That facility permanently ceased power operations as of April 30, 2021. Before its closure, its two operating reactors generated about 2,000 MWe including about 1/4 of Manhattan's electricity. The locals loved it for its good jobs, taxes and no smoke or gas-plant CO_2 emissions. However, to Entergy, the power company that had operated it, Indian Point had become a burden. The opposition of a host of important antinukes including RFK Jr., Governor Cuomo, & the Hudson Riverkeepers along with electricity market rules favoring other sources (in practice primarily natural gas) turned it into a money-losing proposition worth more to shutter than to operate. Cleaning up the site would take decades and cost untold billions of dollars. Entergy found a nifty solution to its financial problem by selling it to Holtec International, a relatively small company based in Camden, N.J. That transfer, finalized Spring 2021, dissolves Entergy's responsibility for the plant and turns the job of closing and decontaminating Indian Point over to an outfit that had never before decommissioned a nuclear facility. Despite its lack of experience in such challenging work, Holtec appears confident that it can decommission Indian Point decades earlier than planned thereby shaving $millions off estimated cleanup costs which would allow it to pocket the remaining money that Entergy had collected from its customers and set aside to raze ("decommission") that power plant.

One consequence of its closing is that New York city's electricity is now about 40% "dirtier" than it was a year ago.

The same thing has happened here where I'm living now: Iowa's already-paid-for, one and only 601 million watt, CF 0.95, nuclear power plant was shut down a year ago because Iowa's energy business policies had rendered its operation unprofitable to its owners' stockholders[386]. Iowa's "conservative" Governor's hand-picked public utility regulators have since given that power plant's owner's permission to "replace " it with a 200 million watt, CF ~0.2, solar farm[387]. Averaged over one year that solar farm would generate just 7% [0.2*200/(601*0.95)} as much "green" power as did the nuclear power plant - and often none at all, especially during winters.

To add insult to injury, Iowa's proposed new "renewable energy" farm's power will cost Iowa's ratepayers about five times more than did their state's nuclear reactor's dependable energy [388].

This means that the politicians running USA's most "conservative states are behaving almost as dishonestly as are those running its most "liberal" states ("almost" because they don't claim to be doing anything other than satisfying their "base's" immediate desires).

There's been a great deal of confusion about what a nuclear renaissance should entail and even more about what its implementation issues would be. Although almost everyone working for the institution responsible for implementing it (DOE), knows that we live in a world that will soon need far more "new" clean energy than Dr. Jacobson et al.'s 100% wind, water, and solar power scheme could provide to 11 billion "EU rich" people, its decision makers refuse to admit that that's the real reason for doing NE R&D. Consequently, they've encouraged (forced) the people that work for them to devote their efforts to developing reactors/fuel cycles suited for tiny niche markets or addressing political issues, i.e., "less proliferative", "smaller", "modular", "safer", "zero risk", "waste burning", "simpler", etc.[389], not something able to "save the world". It is unreasonable to expect the individuals working for any such top-down driven ("stove-piped")

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[386] The three owner/operators/s of that plant are NextEra Energy Resources, Central Iowa Power Cooperative (CIPCO), and Corn Belt Power Cooperative.

[387] NextEra plan for 200 MW solar, 75 MW storage at shuttered nuclear plant approved by Iowa regulators | Utility Dive

[388] This statement is based upon a comparison of the figure that Iowa's utility regulators agreed to and what Lazard's (GOOGLE "Lazard") independent analysts concluded, see [Guest Op-Ed: Solar, the Most Expensive Power | Grid Brief](#) .

[389] For instance, during most the last two decades, it has been verboten to use the word "breeder" in reports or presentations having to do with the reactor concepts that INL's worker bees were studying. That's like telling NASA's engineers that they can't talk about "rockets".

system to devote much attention to developing anything capable of providing ~100% of their grandchildren's energy[390] or saving anyone else's' "environment" .

Let's look at some more examples.

8.1.4 The "lead nuclear engineering lab's" radwaste boondoggling

The AEC/ERDA/DOE's National Reactor Testing Station (NRTS) in Idaho had its own little fuel reprocessing facility to recover the highly-enriched uranium utilized for such testing for reuse (~50 different reactors – but no MSRs – were pilot-planted there from circa 1950 to the early 1970's). ~90% of the liquid reprocessing waste thusly generated was converted to a relatively stable/safe mix of dry dust and sand-like granules ("calcine") which was and still is, stored within stainless steel tanks within half-buried, reinforced concrete vaults ("binsets"). When the USA's decision makers decided to end its nuclear fuel reprocessing, US DOE's nuclear reactor R&D pretty much ground to a halt too meaning that a "new mission" had to be found for its Idaho Site[391]. Therefore, it became DOE's "lead laboratory in radioactive waste management" and renamed "Idaho National Environmental and Engineering Laboratory" (INEEL). Because the other DOE laboratories that had run reprocessing facilities (Savannah River and Hanford) had already decided how their wastes were to be treated, INEEL's new mission really just boiled down to devising "*uniquely cost-effective ways*" of dealing with its own. Top priority would be its remaining ~1 million gallons of still-liquid "sodium bearing waste" (SBW) because it's less stable and more mobile that its already calcined radwaste and

[390] The USA's academics cannot do that job because of its workers' dependence upon DOE research funding. Over 50% of US university professors do not have tenure-track contracts. They either teach the classes that more important professors are too busy to bother with or support both themselves & the university by attracting "outside" – mostly from existing business interests - research funding. Even nominally tenured professors in some universities must do the same thing or they'll be "retired" regardless of what their title or rank happens to be. Of course, this means that everyone in that academic arena must hew to whatever line that DOE's NE funding gurus have drawn.

[391] Its "old mission" had been to recover the remaining highly enriched uranium in spent naval PWR fuel. INEL's "Chem Plant" had been almost totally refurbished to do so by the time that I "came on board" in 1978 – well over a billion ~1970-type dollars had been spent to build a new fuel dissolution system, fuel storage facility, and New Waste Calcination Facility (NWCF). Unfortunately, its dissolvers were apparently designed to dissolve conventional zirconium (or "Zircalloy") clad fuel assemblies – not the Navy's "special" zirconium/uranium fuel assemblies alloyed (coated?) with a secret element that no one could mention. Anyway, it didn't work very well and after a few years, the Navy finally decided to quit pounding its money down DOE's latest rathole. After all, uranium recycling is/was irrelevant to naval operations – the Navy possesses cost-plus fuel contracts, and any recovered uranium was not going to be recycled to its own reactors anyway - it's both too radioactive due to in-bred ^{232}U and less "powerful" due to ^{236}U buildup (about 20% of ^{235}U nuclei "hit" with thermalized neutrons within a reactor become ^{236}U, not a random mix of fission products and fresh neutrons).

therefore represented (and still does) a greater[392] threat to the good folks of Idaho. Table 15 lists the composition of the liquid in one of INL's three ~300,000 gallon SBW tanks. The contents of other two are similar differing primarily how much sludge ("undissolved solids") is present. DOE/INL's still-current(?) steam-reforming waste treatment scheme would likely leave most of that sludge in those tanks because it plans to pump them down only until "suction is lost" and the bottoms of those access pipes end well above the tank-bottoms where the sludge is.   Those sludges contain about as much ^{137}Cs & Pu as does the liquid above them.

Consequently, if a future INL contractor does finally succeed in "reforming" its SBW inventory and sending it somewhere else, Idaho's local stakeholders will still have lots of "hot" sludge-wastes in its tanks to wring their hands about.

Since INEEL's calciner was still working at that time (1995), it would have been reasonable to simply add some sugar[393] to that SBW, calcine it, and store the resulting mix of washing machine detergent-like granules and dust (calcine) in its already-built-and-paid for stainless steel/reinforced concrete "bin set number 7" until someone decides for sure what's to be done with INL's calcines. That option had been invented and then successfully pilot plant tested

Table 15: WM-189 sodium bearing waste

component	g/l	molarity
Al	19.5	7.22E-01
H+	2.9	2.90E+00
Ca	2.95	7.38E-02
Na	47.8	2.08E+00
K	8.59	2.20E-01
Fe	1.51	2.70E-02
NO3	417	6.73E+00
SO4	17.5	1.82E-01

[392] "Greater" in the same sense that someone's peeing in the Pacific Ocean during a swim increases Miami's flooding risk – technically true but irrelevant magnitude-wise. Most of DOE's decisions/actions are justified with adjectives (e.g., "small", "high", etc.) and adverbs, not relevant information in proper context. DOE NE experts apparently remain more interested in maximizing adjectives (e.g., "smallness") than in either facts or addressing technical issues.

[393] Sugar contains reduced carbon forms that first serves as a chemical reductant for nitrate (or nitrite) and then provides the acidic carbon dioxide required to convert the resulting freshly formed alkali metal oxide intermediates to a high-melting mixture of aluminate and carbonate salts. This simultaneously prevents " agglomeration" and greatly reduces the amount of gaseous/toxic NOx generated (most of the nitrogen ends up as harmless N_2 instead). Japanese, British and French reprocessing facilities sugar-calcine the wastes fed to their glass melters with close-coupled rotary kilns.

Lead	0.234	1.13E-03
Cd	0.449	4.01E-03
Hg	1.18	5.76E-03
137Cs	8.32E-04	6.07E-06
90Sr	3.53E-04	3.92E-06
239Pu	8.04E-06	3.36E-08
235U	0.0384	0.000163

many times previously clear back to 1957. However, the folks who had previously managed the Idaho site's reprocessing facility became the leaders of its new mission, which meant that it would be approached in the same fashion, i.e., its already calcined wastes would be retrieved from their binsets, dissolved in nitric acid so that most of their especially "high" radionuclides could be isolated and then embedded within hot isostatically pressed (HIPed) ceramic waste forms. In other words, the "preferred alternative" would be to build an all-new facility to "reprocess" calcine instead of spent reactor fuel and then convert its so isolated highest stuff (^{137}Cs, TRU, ^{90}Sr…) to super durable, stainless steel encased, theoretically dense (maximally compact) ceramic monoliths. The rationale for INEEL's much admired road mapping exercise was that DOE considered the physical *volume* of its much-anticipated reprocessing waste forms to be their most problematic/expensive-to-realize characteristic. The rationale for that, in turn, was that there would not be enough "space" within DOE's already much-studied "pretend" repository (Yucca Mountain) to accommodate INEEL's reprocessing radwastes if their volume weren't maximally minimized first.

Of course, that didn't make sense because INEEL's ~4500 m^3 of calcine could certainly fit within the ~370,000 m^3 of space (~five miles of 25 ft.-diameter tunnels) that had already been created by the YM site's tunnel boring machine[394]. However, DOE's decision makers really liked that scenario because its complications meant that lots of research would have to be done to work out implementation details which translated to more job security for its field office personnel and their favorite contractors' technical experts and managers. They were also eager to put off "final" decision-making (what their job is supposed to be) until that research had been

394 It was also inconsistent with the statute defining DOE's hypothetical HLW repository's "capacity"; i.e., stuff containing radionuclides equivalent to that within 70,000 metric tons of spent ~33GWd/t power reactor fuel, not 70,000 or any other number of "cubic meters". An independent evaluation of INL's accumulation of calcines, spent fuel, etc. performed several years earlier had concluded that its HLW totaled up to an equivalent of about 320 tonnes of spent power reactor fuel (Rechard 1995). To make its brainstorm appear more rational to its stakeholders, DOE decided to claim that each cubic meter of INL's calcined radwaste is equivalent to 0.5 (not 320/4500) m^3 of spent fuel and that the price that it'd be charging US taxpayers to stash INL's somehow- to-be-treated "high" stuff within its already bored-out YM repository would be over \$800,000/m^3.

scheduled, performed, properly reviewed, revised, and documented[395]. Idaho's most important outside stake holders also liked it because it meant that another couple decades worth of federal funding would be spent on "their" lab's terribly important "*first of a kind*" project.

Well, since SBW is/was already a nitric acid/nitrate salt solution containing small amounts of a few specially "high" components (transuranic elements (TRU), ^{90}Sr, ^{137}Cs, and ^{99}Tc) it *seemed* to make sense to not calcine it as promised (Batt 1995) but instead reserve it to test the as-yet undeveloped separation technologies that were to be applied to its redissolved calcines (this is a typical example of what a DOE "road mapping" exercise accomplishes). Consequently, its remaining liquid reprocessing waste never was calcined. By the time that INEEL's "outside" stakeholders finally realized that its "preferred" separations-based waste management scheme didn't make sense, its "waste side" contractor had already permanently shut down its calciner[396] and the deadline to complete "treatment" of its SBW was now only about 11 years off (i.e., to be completed by 31Dec2012 – the official deadline for completing its calcines wastes' treatment/disposal was then and is still 31Dec2035). This temporarily sparked a renewal of the waste vitrification (glassmaking) research that had been limping along during most of the previous 3-4 decades (EIS 2002)[397]. However, that option also vanished when in 2002, DOE's brand new "EM-1" Jessie Roberson) declared that vitrification would be "too expensive" for INEEL but still OK for both Savannah River and Hanford – she'd apparently already been traumatized by the latter's "vit plant" boondoggling. Consequently, INEEL's decision makers had to look for something else that would be uniquely cost effective. Ignoring several "outsiders"[398] and one insider's advice (mine – Siemer 2005), they settled upon "steam reformation" because it invoked a ("proprietary" and therefore perfectly OK for everyone to

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[395] Everyone working for DOE in one way or another (civil service, contractor/subcontractor, and the occasional academic it funds) - is rewarded for doing/saying anything consistent with its management's current thinking (see APPENDIX XX IV). Consequently, during those times when its leadership apparently is not interested in actually solving problems (e.g., while INEL/INEEL was DOE's lead lab in radioactive waste management), coming up with a fresh excuse for more "study" is career enhancing.

[396] The rationale ginned up for shutting down INEEL's calciner (NWCF) was that because it was a waste "incinerator" it would have to be rendered MACT compatible (i.e., modified so that it would not emit a cloud of NO_x) which, in turn, would "*cost taxpayers too much*" (~$50 million). What wasn't mentioned were that; 1) calcination isn't incineration because such waste isn't flammable, 2) sugar calcination would have greatly reduced NO_x emissions, and 3) calcination could have been completed well before the EPA's MACT compliance deadline (June 19, 2001, see EPA 1998).

[397] There really wasn't a need for "research" by then – SBW is simple to vitrify because it's largely comprised of stuff compatible with almost any sort of silicate or phosphate-based glass.

[398] " DOE-ID should not pursue further steam-reforming initiatives for treatment of SBW to produce waste forms for direct disposal in a federal HLW repository or in WIPP " (Gentilucci et al. 2001)

keep secret but nevertheless successfully patented[399], fluidized bed-based “steam reforming” technology[400] rather similar to the calcination that INEEL’s managers and engineers were already comfortable with. Other plusses were that the subcontractor in question claimed that its process could make a host of different products suitable for any sort of repository anywhere, and that one of them would only cost about $45 million[401] to completely treat INEEL’s SBW.

APPENDIX XIV describes that steam reforming process and explains how it came to be DOE’s “preferred alternative”. I had some up-close-and-personal experience with one of the “demonstrations" of that subcontractor's bogus liquid "sodium bearing” liquid reprocessing waste treatment technology that INEEL's (now INL's) 's decision makers had apparently already swallowed hook, line, & sinker.

I'd volunteered to set up a little on-site analytical lab so that the subcontractor & INL fluidized bed experts running that test could know what was being produced by their "steam reformer" in near-real time without the usual 1–2-week sampling/transport/lab turnaround delay.

That darned thing never could be made to work for more than a few hours without getting plugged up with some sort of solid stuff ("agglomerated"). When it was running, most of its product consisted of a fine, partially water soluble, mixed carbonate/silicate rock dust mixed with carbon black.

However, the official reports generated after those exercises always characterized the test(s) as "successful[402]" which means that when the ~5 years that DOE had allowed itself for

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[399] The USA’s patent office doesn’t have any Einsteins working for it.

[400] Steam doesn’t “reform” anything other than some of the solid carbon (instead of dissolved sugar) serving as the reductant in the preferred subcontractor’s (THOR’s) proprietary approach to calcination (i.e., $C+H_2O \rightarrow CO+CO_2+CH_4+H_2$ etc.). Unfortunately, much of that reductant (generally coal) is simply blown up and out of its especially hot (>>600°C) reactor along with the other “fines” collectively constituting the bulk of its product. In principle, but not in practice (too problematic), it is possible to convert SBW’s ash-forming elements (mostly sodium, potassium & aluminum) to a more durable (not as water soluble) nepheline-like, alkali aluminosilicate mineral assemblage by adding some clay too (Siemer 2005). See APPENDIX IV

[401] That’s the figure quoted to me by the STUDSVIK expert that eventually became THORTT’s chief technical expert when I first explained INEEL’s SBW treatment problem to him circa October 1997 & then asked him to remind my bosses that fluidized bed sugar calcination had also worked for the subcontractor he was still then working for (VECTRA) the goal of which work was to render Hanford’s tanked radwastes easier/quicker to then immediately vitrify (VECTRA GSI Report #. WHC-VIT-03).

[402] Success was inevitable but variously defined to best suit particular experimental outcomes. Usually, it just meant that a defined volume of liquid waste simulant had eventually become “denitrated”.

deliberation/foot dragging finally ran out, that technology officially became what that Site's brand-new cleanup contractor was supposed to implement.

That was 16 years and over a billion dollars ago. This story is already getting too long, but suffice it to say that circa 2006, DOE finally decided that steam reforming's easiest-to-make (and least durable - water soluble) "carbonate product" would be good enough for INL radwastes destined to be sent to its not-so-high-level waste repository (WIPP) and that every attempt to get even that relatively simple process to run for more than a few hours have since failed (it's now January 2022, almost ten years after the last of INL's "treated" SBW was to have been hauled off to WIPP). INL's ~3400 m^3 of still-liquid SBW remains in the same tanks it was in when I retired (2006) & DOE still won't admit that it should admit failure and hire an outfit (Duratek?) to bring in a little glass melter & vitrify it.

When reminded about this,   INL's "Management and Operating" (M&O) or "lab" contractor is always a bit defensive - it's always the previous contractor's fault.

It's this sort of boondoggling that makes it tough to convince outside folks that the experts entrusted with developing a sustainable US "nuclear renaissance" would competently manage its perforce much "hotter" (fresh - not decades old) radwastes.

In the DOE Complex, "troublemakers" like I'd turned into are ignored because there is no reason not to: programmatic waste, fraud, abuse, and failure had become the norm for its nuclear projects (meaning that no "fair" bureaucrat would hold its/my/new managers responsible for failure) and the only thing that really counted with respect to an individual worker bee's career development was becoming a well-organized, compliant, good team player with a good gift of gab[403]. Also, every test of the system I've made/performed both while & after I quit working[404] indicated that the outside stakeholders that really do count (politicians) as far as DOE is

[403] Another reason is that DOE's program managers don't take responsibility for any sort of technical goof and are rarely punished for failure - contractors get/accept the blame. The same applies to the managers of the institutions nominally responsible for overseeing its activities. In the DOE Complex, no one seems to be responsible for anything other than complying with rules, procedures, and deadlines that can't be renegotiated. If program oversight doesn't mean accountability, it doesn't mean anything. DOE's management philosophy is totally counter to Admiral Rickover's: "*You may delegate it, but it is still with you... If responsibility is rightfully yours, no evasion, or ignorance or passing the blame can shift the burden to someone else. Unless you can point your finger at the man who is responsible when something goes wrong, then you have never had anyone really responsible*."

[404] None of the politicians & officials to whom I've sent letters has responded with anything but generic form letters (e.g., APPENDICES VII & VIII).

concerned, demonstrated that they aren't much interested in anything beyond maintaining/protecting local spending & employment figures[405].

The worst news is that circa 2005 INEEL was reacronymed "INL" and its leadership given a new and much more important mission to "manage" – it became DOE's "lead nuclear engineering laboratory" and has remained so ever since.

To date, its NE R&D projects have failed to accomplish that mission for the same reason that its previous signature waste management mission (SBW "treatment") failed – the DOE's managers neither motivate nor empower its scientists and engineers to do whatever's necessary to address its nominal technical missions.

I'm not alone in possessing that opinion. "*A Retrospective Analysis of Funding and Focus in US Advanced Fission Innovation*" jointly funded by the John D. and Catherine T. MacArthur Foundation and six other agencies independent of the US DOE (Abdulla 2017) concluded that, "*Using extensive data[406] acquired through the Freedom of Information Act, we reconstruct the budget history of the Department of Energy's program to develop advanced, non-light water nuclear reactors. Our analysis shows that—despite spending $2 billion since the late 1990s—no advanced design is ready for deployment. Even if the program had been well designed, it still would have been insufficient to demonstrate even one non-light water technology. It has violated much of the wisdom about the effective execution of innovative programs: annual funding varies fourfold, priorities are ephemeral, incumbent technologies and fuels are prized over innovation, and infrastructure spending consumes half the budget. Absent substantial changes, the possibility of US-designed advanced reactors playing a role in decarbonization by mid-century is low*.

Another paper published that same year , "*Expert Assessments of the State of U.S. Advanced Fission Innovation*" (Ford 2017) concluded that *".... results from structured interviews conducted with 30 nuclear energy veterans to elicit their impressions of the state of U.S. fission innovation. Most experts assessed NE as having been largely unsuccessful in enabling the*

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[405] The fact that DOE's locally important stakeholders routinely agree to ridiculously distant project completion dates supports this probably "controversial" contention. If in 1995, Idaho's Governor Batt had given DOE, let's say, five years to complete the calcination of INEEL's reprocessing wastes with its then still-functional calciner, that's what would have happened. Allowing DOE & its favorite contractors seventeen years to accomplish something that could have been done within two years, effectively issued them a license to steal akin to that left to the USA's "health care providers" by the federal government's refusal to assume 100% of Medicare's costs and "shop" for drugs.

[406] Abdulla et al had to sort through a 400,000-page FOIA DOE data-dump to extract the numbers supporting their conclusions (Abdulla 2017 – read it, it's "open access".)

development of advanced designs. The interview results highlight the importance of leadership and programmatic discipline, and how their absence leads to poor performance in driving change. Responses point to the likely demise of nuclear power and nuclear science in the U.S. without significant improvements in leadership, focus and political support."

Amen.

8.1.1. NGNP and the "hydrogen economy"

During circa 2000-2013, DOE's vision for the future invoked a "hydrogen economy" in which most of the things currently powered with petroleum would be powered with hydrogen instead. Hydrogen's chief virtues are that 1) it is a "clean" replacement for the natural gas currently powering much of our economy, 2) it's much cheaper to store large amounts of energy in the form of hydrogen than it is in/with lithium-ion batteries, and 3) it's much cheaper to push a GW's worth of power through a pipe than a wire. For transport applications, hydrogen never made much sense because it is a volumetrically challenged energy *carrier* (not fuel) – at normal atmospheric pressure, burning it generates 0.034 of one percent as much heat energy as does burning the same volume of petroleum. While hydrogen fuel cells are 2-3 times more energy efficient than are hydrogen-burning heat engines, it's still very difficult to imagine how regular sized cars and trucks could be powered with it due to its uniquely low mass and boiling point - tanks strong enough to carry the equivalent of 10 gallons of gasoline would be impractically big/heavy[407]. Second, if we really wished to make more hydrogen, the goal should be to generate the necessary electricity sustainably and cheaply, not to dream up yet another especially "advanced" unsustainable reactor/fuel cycle requiring lots of unobtanium to increase the efficiency of hydrogen production - this world needs sustainable hydrogen, not "efficiency".

[407] Nevertheless, Europe's largest bus manufacturer, Solaris Bus & Coach (Poland-situated but owned by Spanish investors) has demonstrated a full-sized metrobus powered by two 125 kw electric motors fed with a lithium-ion battery pack kept charged with a 70 kW hydrogen fuel cell fed with compressed hydrogen gas.

A recent such example was DOE NE's "Next Generation Nuclear Power" (NGNP) boondoggle intermittently funded from 2005 to the present (Park et al 2009). Its champions invoke building high pressure, helium cooled, graphite moderated, solid-fueled, "very high temperature reactors" (VHTRs) to generate hydrogen *somewhat* more efficiently via high temperature chemical reactions rather than water electrolysis[408]. Of course, accomplishing this would require that the Lead Lab's new HTGR (High Temperature Gas-cooled Reactor) operate at very much higher temperatures (~1000°C) than had any of the previously built TRISO-fueled, graphite moderated, gas-cooled reactors (HTGRs). That translates to having to spend lots of time and money developing "special materials" (unobtanium) before any sort of actual reactor has to be built. HTGRs represent an old, much investigated, and consistently commercially unsuccessful reactor concept[409]. It turned out that the special materials required for DOE's especially "hot" VHTR

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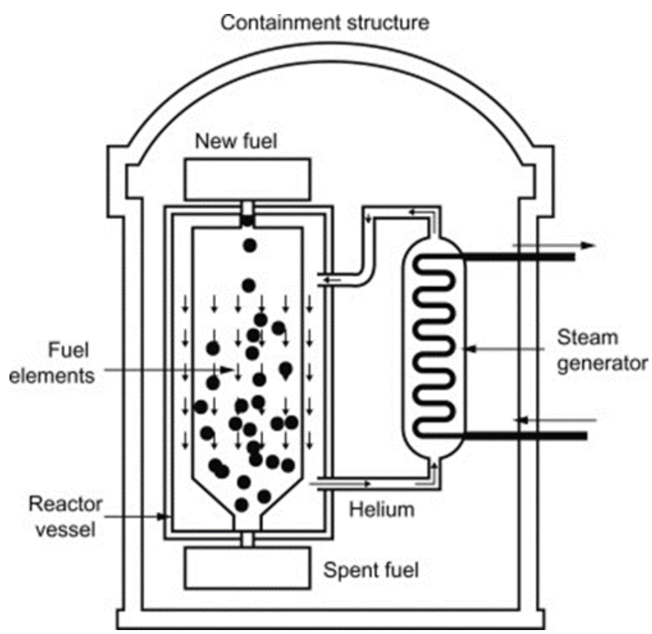
[408] The energy "efficiency" of water electrolysis isn't all that terribly important if you've got plenty of cheap energy. That's why I feel that the "lead lab's" infatuation with super high temp HTGRs was just another of its wastes of time, its worker bee's brain power, & our tax dollars. As far as the electolyzer's cost is concerned, it seems likely that the future's electrolyzers will be a lot cheaper today's because High-frequency sound waves make electrolyzers produce 14x more hydrogen newatlas.com) which means that they could be much smaller.td build cost is electr bb

[409] PowerPoint Presentation (inl.gov) describes US HTGR development efforts. The last "serious" attempt to get a practical HTGR up and running ran from 1993 to 2010 in South Africa. It would have been the first nominally "Generation IV" unit to enter the construction phase (but never did). Its proposed "pebble bed modular reactor" (PBMR) was based on a technology last demonstrated during the 1970s and 1980s in Germany (Figure 78). Like any HTGR it was to be graphite-moderated, and gas (helium) cooled with a closed-cycle gas turbine utilizing in this case a Brayton thermodynamic cycle. Its output was to be 400 MWt and output (net) 160 MWe. Its fuel would comprise thousands of ~6 cm diameter spherical graphite "pebbles", each filled with thousands of tiny silicon carbide and pyrolytic carbon coated UO_2 particle, tristructural isotropic (TRISO) fuel kernels which were supposed to retain all fission products in any accident scenario. However, a good deal of the FP in the earlier German, nominally ~ 950° C, VHTR's TRISO fuel kernels had leaked out of greatly overheated pebbles which hadn't flowed through their reactor as reliably as assumed. South Africa's PBMR's fuel pebbles were to have a life expectancy of three years and circulate through the core about six times before replacement. On the other hand, DOE's NGNP VHTR designers assumed that their new/improved NGNP's TRISO kernels would be embedded within big "prismatic" graphite logs fixed within its core as were Ft St Vrain's, not circulated. Currently, INL's road mappers are looking at several other possible applications for their TRISO brainchildren.

would be prohibitively expensive (or outright impossible) to make and, since any such fuel would be especially difficult to "reprocess", it would also be almost impossible to render a power supply system utilizing that sort of reactor sustainable. Consequently, DOE's best and brightest nuclear engineers

Figure 78 Gas Cooled Pebble Bed Reactor



spent another decade "studying" a concept that the USA's civilian nuclear power industry hasn't been interested in since it replaced Ft St Vrain's reactor with gas turbines and doesn't represent a solution to anyone's long-term energy conundrum (APPENDIX XXIV).

The NGNP program's other issues were largely due to NE's lack of programmatic discipline. It tends to micromanage its grants to an intrusive extent; rarely follows through on any advanced, non-light water reactor project; does not fund them at a level or duration necessary for project success; and is so attuned to political sensitivities that just-started programs are often abandoned in favor of others suddenly deemed more politically palatable. Some factors beyond NE's control such as the inflexible cost-sharing arrangements dictated by Congress, or the Office of Management and Budget (OMB) also render it difficult for industry to collaborate with DOE.

Of the approximately 400 papers and posters presented at a recent IAEA international conference having to do with "*Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development* (FR17)" (IAEA 2018), four presentations were made by people representing the USA – one was about DOE's latest road mapping efforts, two about its long-defunct LMFBR program, and one by an antinuke anxious to remind everyone that anything nuclear might be dangerous.

Another reason for the USA's embarrassingly (to me anyway) poor showing at such gatherings is that its current regulations criminalize many of the activities required for international cooperation.

Bill Gates recently summed up the situation as follows, "*Unfortunately, America is no longer the global leader on nuclear energy that it was 50 years ago. To regain this position, it will need to commit new funding, update regulations, and show investors that it's serious*" (Gates 2018).

The USA's decision and law makers should pay attention to Mr. Gates because he may very well be the person that their & my descendants will credit with having "saved the world". Microsoft's acting CEO has just issued a letter, " *My annual letter: Progress made and optimism for the opportunity ahead addressed to its "shareholders, colleagues, customers and partners*," that explains why Gate's company now has a market cap of over $2 trillion and cites examples of the technological transformation of business and society fed by its products.

His company is focused on four interconnected pillars."
• Support inclusive economic opportunity
• Protect fundamental rights
• Commit to a sustainable future
• Earn trust

That letter My annual letter: Progress made and optimism for the opportunity ahead (linkedin.com) details what Microsoft has already accomplished in each of these areas. I encourage you to read it because it's a stirring manifesto and demonstration that purpose and profit can travel hand in hand here in the West as well as it has recently in China.

Ground rules comprise the difference between our government's current project managers and people like Bill Gates, Hyman Rickover, or General Groves. Since to the people managing the federal government's laboratories deem any sort of project failure or even "unusual occurrence" to be unacceptable, they tend to be hyper conservative which characteristic virtually rules out genuine innovation. Since Bill can run his own shop within the limits imposed by the USA's regulations, his people can design out margins, perform "risky" tests, occasionally fail, learn from failures, modify accordingly, and immediately move on. That's how things were done at the AEC's National Reactor Testing during the 1950s and 1960s.

The real issue has to do with scaling.

If we're going to nuclearize civilization's anticipated energy demand by 2100 AD, we must build about 22TW's worth of reactors.*

Today's burner/converter-based nuclear fuel cycle consumes about 200 tonnes natural U/GWe-year which translates to needing 4.4 million tonnes of freshly mined U/year to generate 22TW. Most of the SMRs currently being proposed are no more fuel efficient than are today's LWRs.

According to the NEA's latest REDBOOK , "*identified uranium resources total 5.5 million metric tons, and an additional 10.5 million metric tons remain undiscovered*" .

That should tell anyone capable of mastering third grade math that operating 22TW's worth of reactors would burn all the world's "affordable" U within 1.25 years and all of its" identified plus *guessed-at* U resources" within 3.7 years.

That's why any reactor concept capable of "saving the world" must be able to generate at least as much new fissile as it consumes (breed).

That's why Mr. Gates isn't dicking around with reactor concepts that are merely "safer" (than what?), more "advanced", "smaller", and/or "modular" – he's too smart for that.

DOE NE's cultural characteristics along with several embarrassing (to me anyway) multi-billion-dollar boondoggles have led many "smart" outsiders to be leery of anything having to do with nuclear power.

In a finite world, money and time wasted doing unnecessary things is money and time that can't be spent doing necessary things. Let's take a closer look at some of those wasted expenditures.

8.1.2 DOE's Savannah River Site's MOX boondoggling

After doing considerable roadmapping during in the early 2000's, DOE concluded that the best way to "manage"[410] the US federal government's ~34 tonnes of surplus weapons/bomb-grade plutonium would be to fabricate MOX (mixed oxides of plutonium and uranium)-type fuel for the USA's civilian power plants[411]. This isn't a novel idea or even a particularly difficult thing to do because the French, Russians, and Japanese have been making MOX of the poorer quality (lesser ^{239}Pu fraction) and far more radioactive, (more ^{240}Pu and ^{241}Pu) "reactor grade plutonium" recovered by their civilian reactor fuel reprocessing facilities. Such fuel's assumed US customers (electrical utilities) didn't want it because its use would likely cost them more in

[410] In DOE-speak, "waste management" might mean anything from the "no action alternative" (doing nothing which in cases like INL's already calcined wastes or SRS's "excess" bomb grade Pu, is likely the best option) to promising to transmute whatever it is to diamonds and ship them to the other side of the moon. It shouldn't surprise anyone that the latter such exercises' inevitable "mission creep" tends to be in reverse. In the DOE contracting business, the biggest liar usually wins, which means that its managers do lots of goal post shifting (contract modifications) to cover their mistakes.

[411] Which decision apparently ignored an outsider's conclusion that such a facility would cost about $50 billion (Bolgren 2007).

terms of increased training and regulatory overhead than it'd be worth[412]. Construction started in 2007 but DOE's program management "symptoms" (NAP 1996) combined with the political pull of South Carolina's politicians quickly turned that project into another super profitable (for those politicans' constituents) nuclear boondoggle. In 2007, DOE's experts promised that its MOX plant would cost $4.8 billion and be completed by 2016 (CATO 2018). As of two years ago, assuming flat $350 million per year continuous funding, they then estimated that it would cost $17.2 billion and take until 2048 to complete (this sounds a lot like DOE's predictions/promises having to do with its Hanford and INL sites' waste treatment projects)[413]. In 2014, the DOE finally admitted that excess plutonium could be managed (wasted) far more cheaply via "dilute and dispose" but that notion was opposed by South Carolina's redoubtable Senator Lindsey Graham because it might kill what had become a very fat and dependable golden goose to his constituents. Consequently, from 2014 to 2016, Congress repeatedly gave DOE the same message: "*keep building the MOX plant.*" In 2017, Congress authorized energy secretary Perry to stop construction if he could show that another approach would cost under half that much. In May of 2018, DOE promised that if it were allowed to stop, the building's shell could be converted to an even fatter "*manufacturing plant for nuclear weapons*"- type goose. As of May 2018, DOE was spending ~$1.2 million per day studying its options (Judy 2018)[414].

That batch of bomb grade plutonium isn't "waste" because it had originally cost US taxpayers several billion dollars to make and could serve as the start-up fuel for from four to twenty (depending upon their designs) full-sized breeder reactors[415]. This means that we should

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[412] In today's world, the raw uranium going into a commercial light water moderated reactor's fuel assemblies represents only about 25% of their cost which, in turn, represents only 20-25% of the reactor's total operational cost, most of which is the "overhead" generated by the 400-700 people running/maintaining/overseeing it. Again, with such fuel, about 80% of the raw uranium mined is discarded during enrichment and never ends up in a fuel assembly. Such "depleted" uranium is currently considered waste although some is utilized to make military-type tank armor and ammunition.

[413] At $17.2 billion, such fuel would cost well over twice as much as today's "mined uranium" ^{235}U-based fuel assemblies.

[414] Update 1May2020. The national academy of science/engineering/medicine has just released its report about this DOE treatment/disposal brainstorm https://www.nationalacademies.org/...ant-final-report-public-release%20-%20232K . According to the NAS's experts it's "doable" of course but will certainly require another decade or two's worth of their studies/palavering to work out all of the details. The goal of this exercise is apparently to please Mr. Trump's Russian friends by shooting ourselves in the foot.

[415] Rumor has it that the SRS site's repurposed MO_x fuel manufacturing facility is to convert some of DOE's "waste" weapons-grade plutonium to fresh "pits" for the USA's nuclear weaponry. Due to its multiplicity of allotropes, metallic plutonium tends to "age" (change both its structure and size) meaning that its bombs' pits occasionally need maintenance and/or replacement. Since a fresh pit requires only about 3 kg of plutonium, there's enough of it to make us about 11,000 brand new warheads. Dr. Stangelove would really love that.

continue to store it until it has been determined for sure which breeder concept represents the best way to implement a nuclear renaissance.

8.1.3 DOE Hanford's reprocessing waste treatment project's boondoggling

Some time ago another QUORA's reader asked me, "*Why do we continue to develop more nuclear energy and products when we cannot safely get rid of the radioactive waste*?"

Like many of QUORA's questions it is somewhat misleading because the US is already implementing a perfectly reasonable way of dealing with that sort of "waste"; i.e., the physically intact "spent" raw fuel assemblies generated by its civilian power reactors. It's reasonable because, 1) "dry cask storage" (see https://en.wikipedia.org/wiki/Spent_nuclear_fuel)is both safer and cheaper than is reprocessing those assemblies and then dealing with the several radioactive waste streams so generated; and, 2) the MOX-type LWR fuel made from recycled plutonium isn't burned efficiently enough by today's reactors to significantly extend their fuel supply.

If the world's decision makers were to decide to address mankind's environmental and economic challenges with an appropriately scaled (big enough) "nuclear renaissance", they/we would have to commit to switching to a breeder-based nuclear fuel cycle and repeatedly reprocessing/recycling 100% of their fuel. Today's myriad of self-defeating rules, laws, and assumptions render such rosy scenarios impossible because they prevent the USA's technical people from dealing with its existing reprocessing wastes in a rational fashion which, again of course, is exactly what its anti-nukes like to see. The USA's approach to radwaste management has been trans-scientific, not scientific during most of the last half century and there's no sign that that will change any time soon. Unfortunately, DOE's radwaste muddling provides the "safe", long-lasting, jobs supporting lots of its technical people along with their management, contractors, and a hoard of "outside" advisors, helpers, officials[416] & critics which means that very few of them challenge the paradigm that's driven Hanford's radwaste boondoggling since 1988.

[416] I'm no longer as impressed with the NAS as I was before seeing how some of its generic-science "experts" (e.g., most of the NWTRB's membership) perform when called upon to advise DOE about radwaste management. It's too "conservative" - its members refuse to draw definite conclusions when they're both obvious and necessary &, instead, invariably ask for "more information" and then when they finally catch on to the fact that DOE will ignore anything it doesn't want to hear, decide to "spend more time with their family" (resign) . Several decades worth of that sort of governmental boondoggling/waffling is what got Donald Trump elected.

The root cause of DOE Hanford's Waste Treatment Plant's (WTP) interminable cost overruns, delays, etc. (Figure 79)[417] , is that politically correct but technically unrealistic assumptions morphed into "promises" nearly impossible to keep. Its unwavering paradigm - that Hanford's tank wastes should be separated into "high" and "low" fractions so that the former can be dumped somewhere else and that both will be converted to borosilicate-type glasses – doesn't make sense for the following reasons:

- The ~55 million gallons of salt-wastes in Hanford's tanks is extremely dilute radionuclide-wise and also old enough to generate relatively little heat which means that it is "high level" solely due to its origin/history/associations[418], not its properties (see APPENDIX IX)
- The probability that another US state would ever choose to host a repository for the "highest" stuff that DOE's contractors may eventually recover from Hanford's (Washington's) waste tanks is low.
- Hanford's tanked reprocessing waste is situated well above the water table in one of the USA's driest deserts (it's already within a perfectly adequate but not "perfect" repository site – Hanford was one of three disposal sites originally proposed for the USA's HLW).
- That site is already heavily contaminated – DOE's hypothesized destination for Hanford's "highest" stuff (Yucca Mountain) remains pristine ~four decades after DOE's contractors began to spend ~25 years and ~15 billion tax dollars "studying" it[419].
- The huge-scale radioisotope separations (aka "pretreatment") required to isolate that waste's especially "high" fractions are intrinsically difficult – mixing such stuff is easy/cheap: separating it (entropy reversal) is tough/expensive.

[417] Figure 85 was excerpted from slide set presented by a Washington state official a decade ago describing the history of that project's first 21 years. At that time, Hanford's worker bees were working to its fourth official plan – they are now trying to implement its eighth official plan. Hanford's 2019 "Lifecycle report" estimated that completion will require $323 to $677 billion. Taxpayers have been spending about $2.5 billion annually since its inception.

[418] The reason that the bulk of DOE's HLW consists of non-radioactive sodium, potassium, aluminum, iron, etc., salts is that the AEC's approach to fuel reprocessing stressed "productivity", not the minimization of ash-forming additives.

[419] Their studies quickly revealed that if the goal is permanently bury anything that's genuinely "nasty", YM was/is vastly inferior to WIPP's half mile deep, 300-million-year-old rock salt formation. YM's rock stratum is too complicated (tough to model), too "leaky" (porous), and too strongly oxidizing which means that some of such waste's especially problematic transuranic radioisotopes would be especially leachable. However, since the goal was apparently to spend lots of money on "studies", it was indeed "successful" Yucca Mountain: A Case-Study in Political Treatment of Nuclear Waste (stanford.edu) .

- Pretreatment requires additional chemicals which would inevitably create more radwaste[420].
- DOE's one and only "Vitrification and Privatization Success" (Pickett 1995) didn't involve "pretreatment" – everything in those radwaste tanks was simply mixed with powdered sand & borax along with some contaminated dirt and then vitrified (melted) to make about 2000 tonnes of borosilicate-type glass "gems" (irregular obsidian-like pebbles).

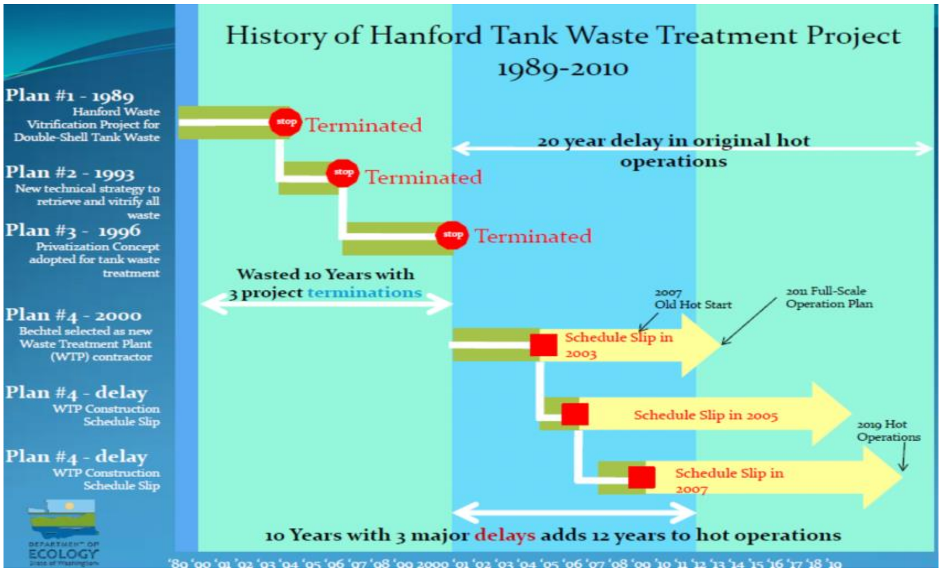

Figure 79 The first 21 years of Hanford's Tank Waste Management Project (Suzanne Dahl 2010

Hanford's tank wastes contain large amounts of non-radioactive materials (e.g., sulfate and halides) incompatible with the type of glass (borosilicate) that its decision makers have fixated upon.

• More suitable glasses for such waste have been extensively researched in the USA (Day 2005) and extensively employed elsewhere (Glagolenko 2005).

• Such glasses would be more chemically compatible with cementitious "grouts" (pumpable slurries that set up to form concretes) than is borosilicate glass.

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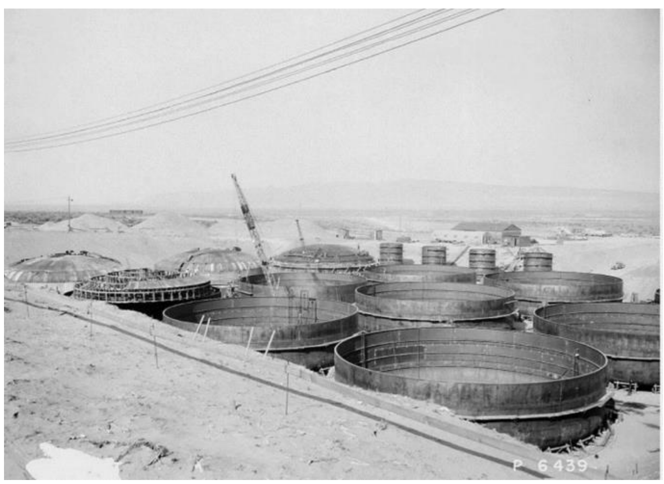
[420] Glass durability is largely determined/limited by the proportion of alkali metals in them meaning that adding additional sodium or potassium to affect a separation (e.g., washing sludges with a sodium hydroxide solution to remove trivalent chromium and/or aluminum - see NUREG 2000) increases the total amount of glass or whatever must be made.

Consequently, a more reasonable management scenario invokes mixing, not separating, Hanford's tanked radwastes followed by vitrification of that mixture to create millions of iron phosphate glass "marbles" which would serves as the aggregate of a cementitious grout which would be disposed of by pumping it back into the same tanks

Here's why that proposal makes sense:

- Hanford's tanks themselves (Figure 80) are neither evil nor apt to be going anywhere.
- They have already been paid for – the ~106,000 huge "transportable" (to where?) stainless steel canisters that DOE's plans call for have not.
- Phosphate glasses can contain/immobilize considerably more sulfate, chromium, aluminum, etc. than can borosilicate-type glasses which fact is important because it translates to making considerably less glass – roughly 330,000 tonnes vs >500,000 tonnes of borosilicate glasses
- Phosphate based glasses are especially well suited to immobilizing the actinides (e.g., plutonium &other TRU) in such wastes

Figure 80 Hanford's waste tanks during construction (typically 1 million gallons each)



- Hanford's much larger (typically 1 million gallon), steel-lined, reinforced concrete, underground "canisters" (tanks , see Figure 80) are apt to more durable over the eons than its planned plastic-lined "not-high" waste disposal pits would be.
- This scheme would also remediate the tanks themselves because filling them with grout (concrete) would simultaneously immobilize any residual waste within them, seal, and then render them both crush and corrosion resistant.
- It would obviate Hanford's planned huge "interim" high level waste form packaging, storage, and (hypothesized) retrieval, repackaging, offsite transportation, and disposal costs.

- It would be safer because it's a great deal simpler which means that the treatment facility's operators wouldn't have to do nearly as much to properly treat/isolate that waste
- Consequently, it would also be much, much, cheaper to do[421].

Because that glass would be more compact than the raw waste going into it. implementing this scheme with Hanford's vitrified/grouted tank wastes would utilize under 30% of the space within its tanks[422]. Since the Hanford site currently possesses many other sorts of radwastes ("crib" dirt, sludges, etc.) for which no permanent solution has been implemented, most of them could and probably should be converted to more of the same durable "aggregate" and grouted into those tanks too. After that's been accomplished, it would then be reasonable to fill any remaining tank headspace with a cementitious grout serving double duty as a waste encapsulant for low-level "orphan" radwastes[423] imported from elsewhere.

When this proposal was presented to Hanford's decision makers and their "independent" advisors seven years ago (NWTRB 2013), I pointed out that Hanford could probably levy substantial fees for providing such valuable services for other states and National Laboratories. I also mentioned that Congress may eventually decide to quit funding their boondoggle (~$59 billion had been spent by that time) which would downsize everyone employed by it.

Hanford's decision makers ignored me because they had already made too many silly assumptions, pronouncements, and promises rationalized by what the US federal government's radioactive waste management experts had told them ~30 years earlier, and (more important), no sufficiently influential "outsider" was either forcing or apparently even wanting them to shift their paradigm. That's why its "vitrification" project still hasn't accomplished anything much other than reliably provide ~$2.5 billion/year worth of taxpayer-funded "work" for the horde of technical, legal, and bean counting experts struggling with that boondoggle's technical issues[424].

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[421] The glass made by DOE's one & only "Vitrification and Privatization Success" (GOOGLE it) cost about seven thousand dollars per tonne. Extrapolating that up to 330,000 tonnes comes to ~$2.8 billion to vitrify everything or about 4% of what Hanford's radwaste wizards have already spent "studying" how to go about keeping the promises its/their managers have made.

[422] The reason for this is that such waste's major components, both mass and volume wise, are thermally labile species (nitrate, nitrite, organics, and water) which would not end up in any glass.

[423] "Orphan" wastes don't have a designated real or imaginary "home" (repository) yet.

[424] I suspect but don't know that its desperate decision makers may be fixated upon the fact that my suggestion would bury a TRU-type waste form material (>100nCi/g long-lived TRU) in their desert instead of someone else's 'desert. My best guess of the TRU content of my scenario's glass is ~440 nCi/g. It's a totally phony "concern" because phosphate absolutely immobilizes TRU migration in dirt meaning that if the whole damned thing somehow flooded eventually dissolving that glass, the TRU within it still wouldn't move offsite.

Another Hanford cleanup issue recently getting special attention (Cary 2020) has to do with a battle between contractors about which is to get the $10 billion that DOE wants to spend addressing the consequences of >4 decade-old ^{137}Cs & ^{90}Sr spills around one of its several hundred buildings. Of course, that's just another of its phony "safety' issues because…

- Neither of those isotopes or any Pu that might have been co-spilled are mobile in Hanford's vadose-zone (desert) soils.
- Their half-lives are relatively short, and…
- Nobody's going to be either "subsistence farming" or eating dirt anywhere on that Site for several hundred years.

Brace yourself taxpayers!

That project's leadership along with many of its local stakeholders are apparently getting even more ambitious: recently (1Feb2019), the Hanford site's local newspaper reported that, "*The increase in costs for the tank waste treatment and disposition increases from an estimate of $53.5 billion in 2016 to a range of $221.4 billion to $518.1 billion in the report released Friday*" (Cary 2019).

The US electorate's docile acceptance of such self-serving nonsense from the people and institutions that nominally work for them is what's turned most of their governments' reprocessing waste management exercises into festering boondoggles - Hanford's just happens to be the biggest/worst example.

Two years ago it seemed that "*Change may finally be at hand*": On 18Mar2019, the Trump administration responded to Hanford's request for still more money by cutting its budget by $416 million (from $2.5 to 2.1 billion) https://www.seattletimes.com/seattle-news/trump-administration-proposes-big-cut-in-hanford-spending/

Mr. Trump was carrying on the POTUS tradition of "managing his beast" (government) by starving it. That's the easiest thing for a frustrated politician to do with boondoggles like Hanford's, but unlikely to accomplish much other than throw working-class people out of work.

Update 4February2022: Dr. Charles Rhodes just sent this out to Dr. Pavlak's group yesterday.

" "*A new report from the Energy Department estimates the remaining cost of completing the cleanup of the Hanford nuclear reservation in Washington to be about $300 billion to $640 billion, down from a 2019 estimate of $323 billion to $677 billion. The agency expects to gain some savings from improvements in waste glass formulation, as well as lower projected operational costs at the Hanford Waste Treatment Plant*".

What in God's name are they doing? They could replace the entire US LWR fleet for that sum."

To which I responded:

"*Hanford's guys are boondoggling 'cause that's what's both expected of them and encouraged here in USA.*

Not to worry - we've still got lot of printing presses to pay 'em for it

Doesn't Canada have printing presses?"

Ha, ha

It's just too darn bad that Hanford's decision makers didn't decide to phosphate glass-vitrify the crap in its tank farm a long time ago. If that had happened, that job would be done by now & this country's antinukes wouldn't still be able to claim that implementing a closed fuel cycle (i.e., genuinely sustainable and thereby requiring the generation of "new" reprocessing waste) would raise insuperable waste management cost issues. Oh well – it's still not too late to get started which decision would give Hanford's vitrification experts something useful to do.

Finally, the primary problem is that the USA's people are supposed to be "worrying" about TRU migration from Hanford's burial ground tanks into the river and from there into everyone's baby formula.

The simplest, safest, and cheapest technically correct way to address Hanford's technical issues would be to grout its underground tanks and the dirt surrounding them with a cementitious grout containing finely ground-up phosphate rock "sand". Southeast Idaho's got a mountain range made of that sort of rock and a big nearby phosphate fertilizer plant and now-idled cement plant that could supply that sand to Hanford's waste wizards.

In other words, glass (vitrification) isn't genuinely necessary - it makes sense only from the standpoint of DOE's nuclear program managers actually wanting to keep their promises (ha ha)

8.2 Fukushima's "nuclear disaster"

In 2011, an eminently predictable earthquake and subsequent tsunami off the east coast of Japan did about $300 billion worth of property damage and killed about 9,000 people. Nevertheless, about the only thing that we heard about is the Fukushima Daiichi nuclear power plant's "nuclear disaster" which killed no one[425] and damaged only that facility's equipment and buildings. Several days after its reactors had been safely shut down, the cooling water in three of them and

[425] Two people did drown there when the tsunami initially flooded it.

some adjoining fuel assembly storage tanks eventually boiled away[426] after which that fuel's zircalloy cladding became hot enough to melt, react with steam, and thereby generate hydrogen gas. That hydrogen accumulated at the tops of several hermetically sealed[427] fuel storage buildings () and subsequently exploded. Those chemical – not nuclear – explosions didn't injure anyone but them along with the fact that some of the fuel itself subsequently melted down prompted Japan's authorities to grossly over-react[428] thereby causing panic, confusion, ~1600 additional deaths, and even more property and other economic losses.

As is also the case in most Western countries, any sort of "nuclear" incident causes Japan's authorities to act like frightened chickens. Due to the consequences of that behavior, many Japanese people have completely lost faith in TEPCO, their government, and the clean power source responsible for much of their nation's economic success. Fukushima's people are suffering not just from the earthquake and tsunami, but also from "radiophobia" which generates stress and suppresses human immune systems.

One reason why that power plant's fate constitutes a genuine disaster is that Japan's economy will continue to suffer economic fallout estimated to eventually reach one trillion USD. That money will go to pay for cleanup, additional imported fossil fuels that they will continue to have to pay for, loss of economic productivity, insurance claims, lawsuits and addressing the stress-related health issues (including suicides) engendered by fear mongering and government's mandated dislocations.

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[426] The removal of fission product decay heat is a key feature of any reactor's primary cooling system. When the reactor's chain reaction stops for any reason (it is no longer "critical"), fission product decay continues to generate a substantial amount of heat. Just after shutdown, decay heat amounts to about 6.5% of the reactor's prior power output but drops to about 1.5% of that figure within an hour. After a day, it's fallen to 0.4%, and after a week it's only ~ 0.2% of the reactor's at-shutdown heat output. Nevertheless, cumulatively that's enough heat to melt a LWR's fuel assemblies unless it is safely dissipated. Fukushima's subsequently melted-down reactors were generating about 1.5% of their rated heat output when the tsunami disabled their cooling systems. Had there been several Olympic-sized swimming pools worth of fresh water stored upon the hill behind them they all would have survived intact.

[427] They were sealed to "protect" outsiders from infinitesimal gaseous radioisotope leakage and thereby created genuinely dangerous/destructive situations.

[428] "Overreacted" because many of the official decrees that severely impacted peoples' lives and livelihoods were unnecessary – see this chapter's next sections. What really needed to happen rad-wise was for those authorities to assure that the locals consumed a total of roughly one gram (less for infants) of sodium or potassium iodide during the first month after the tsunami (Verger 2001). Some of their actions suggest that decision makers believed that radioactive atoms are like pathogenic microorganisms, i.e., a trace of contamination might multiply within its victim rendering him/her a potential "carrier" of something deadly (COVID-131?) that other people might catch.

Japan will not meet its greenhouse gas emission reduction targets and will become more polluted because it'll burn more coal and other fossil fuels to generate electricity. Because coal concentrates natural radionuclides, it's likely that the average Japanese person will be exposed to slightly more radioactivity than when all of its nuclear plants were still running.

Japan will move to renewables more quickly than planned and, because its feed in tariff[429] for them is high, that will raise its citizen's electricity bills for several decades thereby lowering their living standards.

The Japanese used to call such behavior "seppuku" (aka "hara-kiri").

World-wide, "Fukushima" has been an even bigger disaster because it's caused many of the world's otherwise rational decision makers to swear off nuclear power. If the inevitable strife ensuing when a "no-nuke" future's oil/gas becomes too expensive sets off a "WW III", Fukushima might prove to be the "incident" that sparked the end of civilization[430].

The root causes of Fukushima's dismal fate are the same human factors responsible for most of the other "issues" that have prompted widespread distrust of nuclear power.

In Fukushima's case, human nature first manifested itself in reactor siting. GOOGLE EARTH reveals that the Fukushima Daiichi industrial complex occupies a roughly one square mile parcel of coastland ranging in altitude from 10 to about 40 meters above sea level. Its reactors and their attendant spent fuel storage buildings occupy roughly 10% of that area and are all situated along the coastline where the ground is currently only about 10 meters above sea level – ancillary buildings etc., are situated on the "hill" that's behind them. Since the tsunami that wrecked everything was "only" about 13 meters high, one of the ways that that disaster could have been averted would have been to simply site its reactors upon that parcel's higher areas rather than immediately next to the ocean. Another would have been to build a higher sea wall

Even worse, documents filed with Japanese authorities in 1967, reveal that when TEPCO (the electrical utility owning that facility) was planning its new nuclear power plant, it decided to

[429] FITs typically include three key provisions: 1) guaranteed grid access. 2)   long-term contracts, & 3)   cost-based purchase prices. Under them, eligible renewable electricity generators, including homeowners, business owners, farmers, and private investors, are paid a cost-based price for the renewable electricity they supply to the grid. This enables diverse technologies (wind, solar, biogas, etc.) to be developed and provides investors a "reasonable" return. This principle was explained in Germany's 2000 Renewable Energy Sources Act.

[430] There is a point beyond which power and pride cannot back down regardless of cost. As people akin to some of today's topmost leaders become more and more invested in a situation, they themselves lose the freedom to choose alternatives and therefore continue to march their subjects off into Hell. That's how both of the 20th century's world wars started.

deliberately lower that site's natural, 35-meter high "seawall" (cliff) to just ten meters which, of course rendered the power plant subsequently built upon it vulnerable to the 13-meter tsunami that struck it in March 2011. A former TEPCO executive who had been part of that decision making team explained that it was based upon two considerations. One, that reducing that site's natural cliff wall's height by ~25 meters would render delivering equipment to it much easier (equipment which was mostly delivered by sea – a full sized LWR's, saturated steam, Rankine-type, turbo generators weigh about 500 tonnes); and, two, that it would be somewhat easier/cheaper to access the seawater cooling its reactors from 10 meters above sea level rather than 35. In 1991 the USA's Nuclear Regulatory Commission warned Japan's decision makers of a risk to that site's losing its emergency power system (its big/heavy backup diesel-powered pumps were situated in basements where they could be readily flooded) and Japan's own "Nuclear and Industrial Safety Agency" (NISA) subsequently reminded them of that again in 2004. Also in 2004, two more of Japan's governmental oversight committees issued warnings that tsunamis over twice the height assumed by TEPCO's planners circa 1967 (5.7 meters) were possible. In response to the Indian Ocean tsunami, during 2006 and 2008 two TEPCO-employee (in house) studies investigated the effects of tsunami-waves higher than their facility's design-basis barrier height upon its performance. The 2006 simulation's concluded that a 13.5 meter wave would cause a complete loss of all power, render it impossible to inject water into reactor No.5, and that the costs of protecting the plant from them would be about 25 million US dollars (under 0.01% of what Japan's ministry of trade, and industry ministry subsequently declared (in 2016) that dealing with the disaster would ultimately cost). The 2008 study assumed a more moderate 10-meter-high tsunami. In both cases TEPCO failed to act because its decision makers deemed such studies to be training exercises for junior-level technical employees and neither they nor their industry's apparently "captured" regulators expected such large tsunamis.

The similarly designed/sited Fukushima Daini nuclear power plant seven miles south of it was also successfully shut down but suffered almost no damage largely because one of the "outside" power lines to it had survived the tsunami.

In any case, most of that nation's nuclear capacity has been offline since the 2011 and only nine of its reactors are currently in service.

In Japan, the nuclear accident is generally considered to be just one of the Tōhoku earthquake's consequences. However, in much of the world, Fukushima was taken as an occasion for an anti-nuclear mobilization push which made it along with Three Mile Island in 1979 and Chernobyl in 1986, the third world-wide nuclear power catastrophe.

In Germany anti-nuclear activists successfully labeled the Tōhoku disaster as the "Fukushima disaster," conflating the devastation caused by Mother Nature's earthquake and tsunami (~20,000 deaths) with the consequences of the nuclear accident (no radiation-related deaths). The latter dominated the headlines while the fates of the tsunami victims and displaced persons were largely ignored. Millions of people still erroneously believe that those who fell victim to the earthquake and tsunami were victims of a nuclear disaster.

Amardeo Sarma, Anna Veronika Wendland, Ten Years of Fukushima Disinformation, Skeptical Enquirer , Volume 45, No. 4, July/August 2021 https://skepticalinquirer.org/2021/06/ten-years-of-fukushima-disinformation/)

That fiasco generated plenty of opportunities for fear mongers to scare people about Fukushima's "deadly radiation". The goal sought and often attained by such mongering is to scare normal people with big technical-sounding numbers and acronyms. For example, a recent Dailykos posting's really big scary number is that "*some of the tuna caught near Japan had up to 1000 Bq*[431]*/kg of deadly* ^{137}*Cs in them*".

Let's look at that FUD quantitatively assuming a victim who's both rich and dumb enough to eat nothing but Japanese tuna, i.e., those fish most exposed to the Fukushima reactors' "terribly radioactive" drainage. Let's also assume that that person weighs 70 kg and needs about 2000 kCal per day to keep body & soul together.

Since 3.5 oz. of tuna has about 200 kCal, he'd/she'd have to eat about 362 kilograms of it every year.

That's a tuna consumption rate of 1.15E-5 kg/sec which at 1000 Bq/kg equates to 0.0115 Bq of ^{137}Cs consumed per second.

According to the radiation decay equation (see APPENDIX XI), that corresponds to consuming 1.58E+7 [0.0115*3600*24*3600/ln2] ^{137}Cs atoms/sec.

Over a year, that'd be an accumulation of 4.98E+14 ^{137}Cs atoms if 100% of 'em "stuck". However they wouldn't stick because Cs has a biological half-life of ~70 days (less if one consumes lots of beer or anything else containing lots of potassium (homework, why is that true?) which means that ~0.27% (0.5^(365/70) of the ^{137}Cs atoms consumed would actually contribute to his/her rad dose – which translates to an average of 1.34E+13 "evil" radioactive atoms decaying away within our hypothetical maximally exposed victim.

The radiation decay equation equates that many ^{137}Cs atoms to a decay rate of 97,900 disintegrations per second (Bq) throughout the year.

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[431] Bq (one of the smaller measures of radioactivity in common use) = 1 decay "event" per second = 1 d/s = 1 dps. One "Curie", another common unit, = 3.7E+10 Bq (thirty-seven billion times bigger). Someone who really wants to scare/impress you might express radioactivity in terms of pico or fempto curies. The potassium within an average-sized banana would subject anyone eating it to ~ 600,000 fempto curies worth of beta-type radiation for a time determined by potassium's "residence time" within you. A can of beer is about one fourth that deadly.

Since each ^{137}Cs decay generates about 1.1 Mev & 1 ev = 1.6E-19 J, that's a whole-body dose of 0.0544 J/year which in a 70 kg body translates a yearly dose of 0.0077 J/kg (Sievert) [97000*1.1E+6*1.6E-19/70]. Table 16's figures should put that number into perspective, i.e., that diet wouldn't be as "deadly" as would his/her moving to Denver CO.

doserate		Situation
mSv/year	nSv/h	
1	100	ICRP recommended maximum for external irradiation of the human body, excluding medical and occupational exposures[1]
1.3	150	Residential houses in Chernobyl circa 2009[2] (it'd be under that now)
2.4	270	Worldwide global average human natural background exposure[1]
~8	900	Average natural background radiation in Finland[1]
8	900	Current field next to Chernobyl's "New Safe Confinement" sarcophagus[1]
11.8	1350	Natural background in Denver CO[3]
20	2000	Upper radiation worker & mandated Fukushima region excavation limit
~24	~2700	Natural background at typical airline cruise altitudes[1]
46	~5200	Next to the Chernobyl plant before the new sarcophagus was installed[1]
130	15000	Ambient field in Ramsar's "hottest" human dwelling [1]
~1000	114000	Upper most hormesis/beneficial radiation exposure level[4]
2940	346000	Inside the deadly "Claw of Chernobyl" circa 2009[2] (it'd be a lot lower now)
?	?	Inside Mr. Trump's skull
[1] Wrixon AD, Barraclough I, and Clark MJ, 2004, Radiation People and the Environment, IAEA in Austria, February 2004, IAEA/PI/A.75 / 04-00391 https://www.iaea.org/sites/default/files/radiation0204.pdf		
[2] http://www.chernobylgallery.com/chernobyl-disaster/radiation-levels/		
[3] https://isis-online.org/risk/tab7		
[4] Cuttler JM, Feinendegen LE, and Socol Y, 2018, Evidence of a Dose-Rate Threshold for Life Span Reduction of Dogs Exposed Lifelong to γ-Radiation, Dec; 16(4): doi: 10.1177/1559325818820211 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6311660/ (fig. .1).		
[5] Mortazavi SMJ and H. Mozdarani H, Is it time to shed some light on the black box of health policies regarding the inhabitants of the high background radiation areas of Ramsar? Iran. J. Radiat. Res., 2012; 10(3-4): 111-116		

Table 16 Some natural background & other especially relevant radiation levels

The average US Citizen gets about 0.0062 Sievert's worth of radiation per year – more if he/she lives in especially dangerous (high altitude) places like Denver Colorado or does things like jet-setting or mountain climbing.

Consequently, our maximally exposed, extremely rich hypothetical victim (that much tuna would cost ~10x an average Japanese citizen's disposable income) would be getting about the same dose from his food fetish that average US citizens normally receive from the part of the world that they live in.

The "technical" rationale underlying he USA's radwaste boondoggling and Japan's response to TEPCO's travails is that the institution responsible for setting radiation dose recommendations, the National Council on Radiation Protection (NCRP) utilizes a too-simplistic linear dose effect model assumption to predict the effects of vanishing small radiation exposures upon living creatures. That model's acronym is LNT which means linear-no-threshold. Its principle was introduced in the late 1950s and remains the basis for dose limits recommended because it's simple to understand, politically correct and conservative ("safe"). Back in the 1950s a "target theory" dominated the evaluation of radiation data. It was assumed that the biological impact/result was due to a "hit" – and the number of hits does indeed increase linearly with dose. A few years later it was also accepted that the initial step for carcinogenesis (cancer's initiation) is damage to a cell's DNA. Again, the initial number of DNA-damages does increase linearly with dose. Thusly as long as our experts and authorities continue to ignore the defense and repair mechanisms possessed by any/all of the Earth's real-world biological systems, it's not unreasonable (conservative) to assume the LNT-model. It's especially useful to anyone seeking to frighten people or rationalize additional personnel-related overhead expenditures ("we need more 'health physicists') and/or more super-profitable, grossly inefficient, radwaste boondoggling.

Despite extensive research attempting to find any such effects no harmful effects from chronic exposure to low-level radiation (<500 millisieverts/year) have ever been confirmed. Moreover, nuclear energy has ultimately saved an estimated 2 million lives via replacing generators originally fired by fossil fuels.

The fact is that there are dose thresholds below which the cell repair mechanisms protecting us from the free radical damage caused by the fact that we eat food and breathe a reactive gas (oxygen) also protect us from the free radicals generated by low dose rate ionizing radiation (certainly anything under about ten times above normal background). That's why the nuclear industry's workers live longer than do those of most other professions, and there have been no massive die offs after the initial effects of Hiroshima's bombing, the USA's atmospheric bomb testing, or even big screw-ups like Fukushima's have dissipated.

For example, inhabitants of the southwest Indian state of Kerala have lived for thousands of years with background radiation levels considerably higher than the 20 mSv/yr limit that triggered the evacuation of Fukushima[432]. People living in sections of Kerala experience an average of 70 mSv/yr, with some areas as high as 500 mSv/yr and locally grown food averages about five times as radioactive as is that consumed in the United States. Despite its unusually high background levels, Kerala's cancer incidence is the same as that of greater India, about one-half that of Japan's and under a third that of Australia's. Kerala's high background is largely due to the presence of monazite sands containing approximately 9% thorium and 0.3% uranium (a

[432] 20 mSv/year is the statutory limit permitted for most of the world's professional radiation workers.

rather rich “ore” for either of them). Its citizens’ average life expectancy was reported to be 72 years whereas the national average was only 54 (Kerala 2015). As the linked article says, “*Cancer experts know a great deal about the drivers of these huge differences, and radiation isn’t on the list*.”

A similar situation obtains in Ramsar, a city in northern Iran, whose citizens have received an annual background radiation dose of up to 260 mSv/y for many generations – that’s 13 times higher than that which triggered the Japanese government’s expropriation of ~100,000 of the Fukushima Prefecture’s citizens’ homes, farms, and businesses. Here’s part of the ABSTRACT of a paper describing how Ramsar’s elevated background radiation impacts its people’s health (Ghiassi-nejad 2002)

“Cytogenetic studies show no significant differences between people in the high background compared to people in normal background areas. An in vitro challenge dose of 1.5 Gy of gamma rays was administered to the lymphocytes, which showed significantly reduced frequency for chromosome aberrations of people living in high background compared to those in normal background areas in and near Ramsar. Specifically, inhabitants of high background radiation areas had about 56% the average number of induced chromosomal abnormalities of normal background radiation area inhabitants following this exposure. This suggests that adaptive response might be induced by chronic exposure to natural background radiation as opposed to acute exposure to higher (tens of mGy) levels of radiation in the laboratory. There were no differences in laboratory tests of the immune systems, and no noted differences in hematological alterations between these two groups of people.”

Note too that that study’s authors observed the same effect that several other such studies had noted (Jaworowski and Waligorski 2003, Calebrese 2000, Cuttler 2017, Cuttler 2018), i.e., that modestly elevated radiation levels seem to strengthen mammalian immune systems akin to the way that physical exercise does their other bodily systems.

The key to understanding current radiation protection regulations is the linear no-threshold (LNT) model, which assumes that radiation harm increases linearly with exposure and that zero harm exists only at zero exposure which, in turn, constitutes the rationale behind ALARA. That model grossly overestimates low radiation level risk, which means that resources expended to meet LNT-based standards yield don’t benefit anyone not being employed to meet those standards. Decision-makers have repeatedly deferred decisions to replace the LNT model and have instead called for more research.

To conclude, LNT does not realistically model radiation harm. An organism's dose response curve is highly non-linear and critically dependent on dose rate. Cell based laboratory experiments, extensive animal testing, and many human studies have detected no statistically reliable harm unless dose rates were well above that experienced by people living in the world's highest natural background regions. At the very low dose rates experienced by the people "downwind" of both TMI and Fukushima, LNT is off by orders of magnitude.

Consequently, the USA's National Council on Radiation Protection (NCRP) should be disbanded. It instigated the USA's LNT-based radiation safety policy back in 1960 and has repeatedly promised to review that decision but never actually does so (Jaworowski and Waligorski 2003). Calling for "more research" is simply a bureaucratic delaying tactic to avoid addressing issues – which in this case is a tactic blocking both the nuclear energy option and treatment of some common maladies– blind faith in an overly simplistic, unreasonable, and repeatedly proven wrong theoretical model.

We do not need more or new research because we know now as we did 60 years ago what the effects of radiation are.

There is no justification for the precautionary principle or ALARA because there are no significant uncertainties in that scientific information.

Protection policy should be to keep radiation exposures below the dose and dose-rate thresholds for onset of detrimental effects). No precautionary evacuations are warranted when the radiation level is below the dose-rate threshold for onset of detrimental effects.

"*Poison is in everything, and no thing is without poison. The dosage*

makes it either a poison or a remedy."

Paracelsus

The USA's hyperconservative approach to establishing radiation guidelines impacts its "civilians" too. For instance, an abandoned elemental phosphorus plant situated ten miles west of Pocatello ID is shadowed by a roughly 30 million tonne mountain of phosphate rock slag that the EPA has deemed too radioactive to utilize for any constructive purpose. Prior to that decision that slag had been widely used for road and parking lot construction, construction fill, railroad ballast, home foundations, driveways, and even for built-up-type roofing materials. The "alarm level" imposed upon the people owning, living in, or trying to sell such property (20 mrem/hr or 0.00175 Sievert/a) represents just ~25% of the radiation dose that an average American citizen gets from everything else he/she does (Gesell 2013).

This is just another apparently almost universal manifestation of human nature, i.e., that especially "important" people want to remain important. It is the reason that when agencies established to address certain obvious safety issues have accomplished that mission, their leadership tends to keep ratcheting up criteria to keep their jobs/agencies/programs relevant. For instance when I and my fellow analytical research chemists during the 1970s and 1980s, made it possible to detect hazardous substances (in my case, toxic metals via graphite furnace atomic absorption spectrometry) at progressively lower concentrations in foods, water, or the "environment", the statutory limits for such things tended to drift in the same direction, "*to provide an extra margin of safety*" and, of course, to keep the regulators, inspectors, analysts, researchers, and publishers busy). This tendency often goes well beyond reasonable levels and thereby generates a great deal of anxiety, and, in the case of radionuclides especially, waste, fraud, and taxpayer-abuse[433].

Today's medical community might just be getting desperate enough about the COVID-19 thingy to be willing to revive a currently verboten (too politically incorrect) old-fashioned cure for killer-type pneumonias (Feinendegen 2010, Calebrese & Dhawan 2013). Because the major cause of death in COVID-19 is severe pneumonia leading to respiratory failure and low dose radiation (<100 cGy) had been used for several decades prior to the Korean War for its anti-inflammatory effect, it's apt to reduce COVID-19 mortality too.

A small fraction of those infected with the COVID-19 virus do not recover which is likely due a shared inherited immune system quirk. When that virus invades their lungs, their immune systems overreact initiating a cytokine storm that kills their alveoli air sac cells. Those sacs then fill with fluids that block the transfer of oxygen to their blood.

That disorder could be remediated in nearly all COVID-19 patients exhibiting acute respiratory distress by a prompt lung X-ray treatment (0.5 Gy) to induce the anti-inflammatory M2. Phenotype. Inflammation would start to subside within hours and most (~90% ?) patients could leave hospital within one week. After his/her immune system has cured that disease, that person would be immune to that virus.

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[433] The same sort of bureaucratic overreach has also nominally rendered a good deal of the USA's drinking water "unsafe" because a substantial fraction of its groundwater contains enough arsenic to exceed the EPA's "new" 10 ppb (part per billion) limit – prior to 2001 that limit had been 50 ppb. Affected regions include Southwestern states like Nevada, to the upper Midwest and New England, where a belt of arsenic-infused bedrock taints aquifers in stretches from the coast of Maine to a point midway through Massachusetts. The studies serving to rationalize that hugely impacting (too expensive) ruling were performed in Bangladesh where well water arsenic levels are typically higher than 50 ppb, and more importantly, such water is used to irrigate a single crop (rice) constituting both its citizen's and their domesticated animals' staple food under conditions uniquely well suited for its uptake (rice paddies). The people genuinely affected by that problem are too poor to quit raising rice (it's their most productive food crop)– the USA's citizens are not so poor and have far more varied diets.

This treatment could be delivered by the dedicated fluoroscopy X-ray devices available in virtually every first world hospital. (Jerry Cuttler personal communication).

Several necessarily rather rushed studies performed during 2020 have already verified Drs. Cuttler's and Calabreses' suspicions (Skinner 2020, Sharma et al 2020, Flemming et al 2020, Hess et al 2020,) Moyses et al 2020, Sanmamed et al 2020. Kapoor et al 2021).

"*It's never too late to drop your beliefs and let your wounds heal instead of wounding others as well*"—Adam Scythe

Mr. Scythe's statement aptly fits the potential offered by low-dose, low-cost, radiation therapy (LDRT) for treating the inflammatory over-response responsible for both COVID-19 and its newer, even deadlier, variants' deaths[434].The USA's medical professionals' deep rooted and unfounded fear of low radiation doses needs be challenged before thousands more of our lives are lost. That treatment could be delivered, bedside using our hospital's already-licensed X-ray device(s), "off-label", as was done during the 1940s.

Before antibiotics were discovered/developed, patients with severe ear infections were treated with one low dose of X-rays or radium gamma radiation. This article is an historical assessment of the role of radiotherapy [Historical use of x-rays: Treatment of inner ear infections and prevention of deafness - EJ Calabrese, G Dhawan, 2014 (sagepub.com)](). It tweaked the patient's immune system.

Guelph Ontario's veterinary college treats animals with low dose X-rays but like it is in the USA, doing so is considered too controversial for humans. Doctors everywhere are paid to provides services of their own choosing to human, not to cure them.

Jerry

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[434] https://link.springer.com/article/10.1007/s00204-021-03124-x

Abstract

Purpose: This article provides an historical assessment of the role of radiotherapy in the treatment of inner ear infections. Materials and methods: The research utilized a literature-based evaluation of the use of x-rays during the first half of the 20th century on the treatment of otitis media (OM), mastoiditis, and cervical adenitis and their impact on the occurrence of deafness. Results: X-Rays were consistently found to be effective as a treatment modality at relatively low doses, in the range of 10–20% of the skin erythema dose (600 roentgen), rapidly reducing inflammation, and accelerating the healing process. The mechanistic basis of the clinical successes, while addressed by contemporary researchers, is evaluated in the present article in light of current molecular biology advances, which indicate that clinically effective low doses of ionizing radiation act via the creation of an anti-inflammatory phenotype in highly inflamed tissue. Conclusions: X-Ray treatment of OM, mastoiditis, and cervical adenitis was widely accepted in the first half of the 20th century by clinicians as an effective treatment when administered within an appropriate dosage range. [Historical use of x-rays: Treatment of inner ear infections and prevention of deafness - EJ Calabrese, G Dhawan, 2014 (sagepub.com)]

If you happen to come down with that disease, make sure that your medical service provider becomes aware of this information – threaten to not pay him/her & the hospital they work for if they're not willing to make a comprehensive effort to save your life.

Another contributor to a discussion group that I follow recently pointed out that the COVID-19 crisis has exacerbated intergenerational economic conflicts & is also causing some of the world's businesspersons to kill other animals that might harbor that virus. My response was as follows.

Maybe old farts like us should just die and get it over with. Although I've paid enough into both of the systems that I'm collecting pensions from (the Federal govt's INL contractors & Social Security) to not feel too guilty about getting those checks, it is a bit unfair to the younger US citizens that have to pay me to sit around on my ass. If protecting me and my comormidities from the threats posed by cute little minks, housekitties, etc. that might be harboring new/improved versions of COVID-19 means that they will all be wiped out, maybe I oughta just get out of the way. However, if I do happen to end up in a hospital barely able to breathe, I'll be doing my darndest to try convince my "health care provider" that it'd be safe (for them) to zap my lungs with a half Grey's worth of hard x rays).

As President Trump said about his own much-hyped drug-type fixes (Lysol?), "*what have we got to lose?*"

8.4 **ALARA** (As Low Reasonably Achievable)

Without evidence of any good reason to do so, US regulators have continually reduced its workers' radiation exposure allowances (Figure 81 The history of dose limits). This fostered acceptance of the ALARA (As Low As Reasonably Achievable) safety concept which has rendered the costs of almost anything having to do with implementing additional nuclear power uncompetitive. It basically says that there is no safe threshold because ALARA's "reasonably" descriptor is not quantitatively defined. As long as the costs of nuclear plant construction/operation remained in the same ballpark as those of other power sources, its reinterpretations of "safe" were automatically considered "reasonable".

This might seem sensible, until you realize that **by definition it eliminates any chance for nuclear power to be cheaper than its competition.** Nuclear can't innovate its way out of that predicament because under ALARA, any technology, any operational improvement, or anything else that reduces costs, gives the regulators more room and more excuse to push for more stringent safety requirements, until costs once again rise to render nuclear power a bit more expensive than something else. Actually, it's worse than that: it essentially says that if nuclear becomes cheap, then the regulators *have not done their job*.

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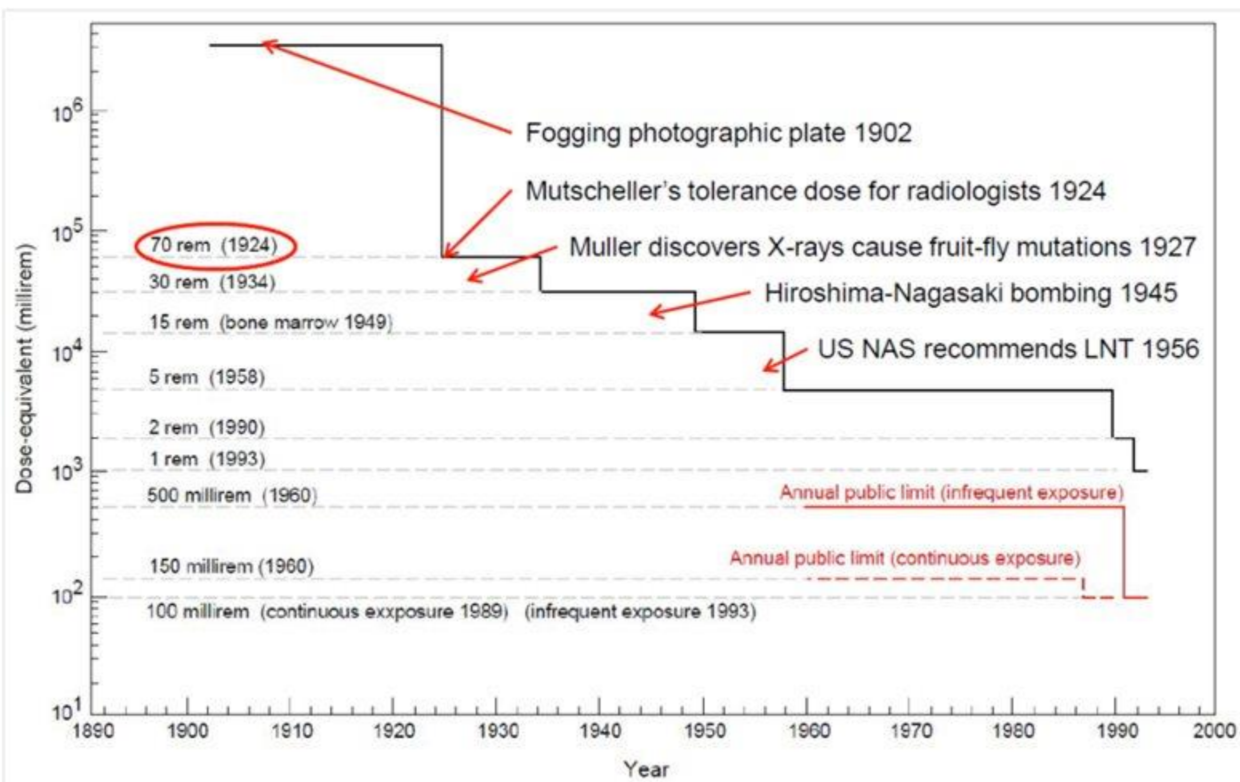

Figure 81 The history of dose limits

ALARA is another of the fine-sounding principles that have served to cripple the nuclear industry and hamstring the people working for/at the USA's nuclear-missioned national laboratories[435]. In practice, the "reasonably" part of that acronym is ignored meaning that there is no limit below which additional expenditures/efforts/training to further reduce personnel radiation exposures aren't "worth it". ALARA's deliberately "fuzzy" but ever-tightening standard makes it almost impossible for nuclear power to be cheaper than its competition.

Here's some examples taken from Ted Rockwell's especially sapient essay, "What's Wrong with Being Cautious". http://radiationeffects.org/wp-content/uploads/2015/05/Rockwell-NN-1997_Whats-wrong-with-being-cautious.pdf .

What kinds of inefficiencies did this mindset cause?

One was a prohibition against multiplexing, which resulted in designers leading thousands of individual sensor wires to a space called the facility's "cable spreading" room. Multiplexing would have cut that number by several orders of magnitude while simultaneously providing greater safety by providing the reactor's operators with multiple, redundant information paths.

Consequently, a power plant that would have required 670,000 yards of signal cable in 1973 required almost double that number (1,267,000 yards of it) by 1978 when it should have dropped precipitously given that era's explosive digital technology growth rate.

Another example was 1972's official acceptance of the Double-Ended-Guillotine- primary loop pipe Break scenario as a credible failure mode. It assumes that a section of piping instantaneously disappears. Steel cannot fail in this manner. As usual Ted Rockwell put it best, "We can't simulate instantaneous double-ended breaks because things don't break that way." Designing to handle this impossibility-imposed requirements on pipe whip restraints, spray shields, sizing of Emergency Core Cooling Systems, emergency diesel start up times, etc., so severe that it pushed reactor designers into specifying developmentally unrobust technologies. A far more realistic scenario would assume "Leak Before Break" in which the designer must account for a slow-moving crack penetrating the pipe before a section of it disappears.

Here's another example from Rockwell's essay:

One of the Idaho National Engineering Laboratory forklifts moved a small spent fuel cask from its deionized (pure) water storage pool to one of its hot cells. The cask had not been properly

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[435] Since the people managing DOE's laboratories don't have to produce anything but "reports" and, occasionally, a decision, there's no real-world pressure upon them to do anything quickly and efficiently. To the contrary, foot dragging keeps their missions alive which, in turn, keeps the study-money coming in. Since "unusual occurrences" of any sort – especially anything involving radionuclides - upset DOE's "award fee" deciders, its contractors discourage their employees from doing anything apt to be considered "risky".

drained, and some pool water dribbled onto the blacktop highway along that way. Even though several of its workers had recently taken a midnight swim in one such storage pool and were none the worse for it, spent fuel storage pool water is officially defined to be a hazardous contaminant. It was therefore deemed necessary to dig up the forklift's entire path creating a trench two feet wide by a half mile long dubbed Toomer's Creek after the unfortunate worker who had failed to ensure that the fuel cask was fully drained & dried.

The Bannock Paving Company was hired to repave the entire road. It used the same slag aggregate generated by a local phosphate plant that it and other local contractors had used in many other paving projects in southeastern Idaho. After the job was complete, it was then pointed out that such slag contains relatively high concentrations of both natural uranium and its daughters and is therefore more radioactive than was the stuff that had been dug up, marked with the dreaded radiation symbol, and hauled away for long-term burial somewhere else on that site.

Such governmental behavior is insane – almost Trump like - but of course "makes work" for lots of people & serves a noble-sounding purpose .

ALARA's champions within the industry tacitly assumed that its workers and helpers would always possess cost-plus contracts and therefore never face serious competition regardless of how much additional overhead costs they assumed. Neither assumption is correct. Since the "safest" way to work with anything that's radioactive, is to not work with anything that's radioactive, the DOE nuclear site leaders replaced most of its" hot" laboratories/pilot plants along with the people who had worked in them (e.g., me) with computerized modeling/modelers thereby rendering themselves incapable of doing the experimentation required to develop anything that's genuinely new.

"*Nothing in life is to be feared, it is only to be understood. Now is the time to understand more so that we can fear less*" Marie Curie.

"*You miss 100% of the shots you don't take*" **— Wayne Gretzky**

"*The country needs and unless I mistake its temper, the country demands bold persistent experimentation. It is common sense to take a method and try it. If it fails admit it frankly and try another. But above all try something*". **Franklin D. Roosevelt**.

The main reason that many people fear radiation is a deeply rooted psychological fear of mysterious entities that can't be seen or touched (e.g., Blair-type witches and voodoo)[436]. Such

[436] During the last millennium, roughly a million certified "witches" were executed because they could not prove that they had not caused harm to someone or something. Since no one can prove that tiny amounts of radiation did not cause a particular leukemia—for that matter one cannot prove that they caused it either—those who wish to succumb to low-level radiophobia are free to do so and those who don't wish to do so, don't. On the other hand,

fears were originally engineered into our ancestors' more primitive brains on the African savannah millions of years ago to make them safer from predators at night. However, we're not quite so primitive now and should know better than that: we've all seen images of the mangled and burned bodies caused by car accidents, yet we continue to embrace automobiles because such risk is considered worth taking because we have trained both ourselves and our children to distinguish between rational expectations and gut feelings. We must become willing to do the same with nuclear power, especially with the sorts of new reactors required to save the world which would also feature improved safety, lower costs, and greater efficiencies.

Chapter 9. "*The Damned Human Race*" (Mark Twain)

Before I get on with writing this sad chapter, I'm going to admit that I'm old, world-weary, and tired of listening to mostly bad "news" mostly consisting of alternative facts and slanted/fixated opinions, not real and/or helpful information in proper perspective. However, as cynical as that's made me, I also realize that most people are "nice", behave more or less rationally, and some even go out of their way to unselfishly help the rest of us navigate around the barriers erected by the "important" people who've established our country's business models. "Good" examples include the thousands of folks who freely share their expertise via YouTube's DIY videos and the technical experts who've rendered WIKIPEDIA my go-to information source for lots of things.

"It's not what we don't know that gets us in trouble, but what we are sure we know."

Mark Twain

Almost anyone asked today about what should be done to make our economy green, will say that we need more "renewable" energy. Attempting to realize that goal has become the rationale behind state and federal policies granting massive subsidies to the purveyors of politically

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very few people fear the smoke emitted by burning the dirtier fossil fuels (coal, peat, heavy fuel oils, etc.) and all forms of biomass currently responsible for about 7 million "excess" deaths per year. Consequently, James Hansen has estimated that nuclear power has thereby already saved about 2 million human lives (Silva 2013, WHO 2018).

correct energy technologies and an excuse for penalizing others. It's the reason that several US states and other countries have already spent billions on new energy infrastructure, burdened their citizens with sky-high energy costs, and have achieved only modest greenhouse gas reductions.

Solving the tough technical problems posed by the natural world's rules requires hard work and intellectual honesty – seeking Nature's opinion regardless of whether it agrees with yours, your peer group's, or your boss's personal beliefs. It's about finding reasonable solutions, not winning arguments, or pleasing the people funding your research. It's also sometimes hard and somewhat "risky" work. To many of the people who've chosen to become scientists & engineers, doing such work also happens to be a great deal of fun[437].

For success to happen, R&D workplace managers must foster a culture where everyone can:

- Feel safe to speak up
- Express alternative points of view
- Challenge the status-quo and/or their bosses
- Acknowledge mistakes without fearing punishment

Unfortunately, doing this would require their leaders to embrace vulnerability, which is easier said than done. It is tough for the most "important" people within any organization to let go of their need to be, and, equally important, to always have been[438], "right" about everything. Decisions should be grounded upon facts, not habits or the stature, position, or history of individuals either working on or managing a project.

System justification theory (SJT) explains why people within large groups often act/vote in ways that are directly contrary to their own self-interests (also see Shenkman 2008). It points out that system-justifying beliefs serve a psychologically palliative function to many people even when

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[437] "Happiness lies in the joy of achievement and the thrill of creative effort." Franklin D. Roosevelt.

With a few exceptions I do not miss the people that I worked with at INL but do miss my lab. I really do like being retired but liked having a well-equipped lab to play around in at work even more. By circa 2006 almost all of INL's real labs including mine had been trashed & everything in them (chemicals, glassware, atomic absorption spectrometers, emission and ion spectrometers, ion chromatographs, etc.) pushed into pits & backfilled with dirt because it was possible, if you're willing/eager to wait/count long enough to detect that they'd all had been "exposed" to radionuclides. That and boredom is what finally convinced me to "retire".

[438] This is one of the reasons why institutions rarely start over from scratch when projects like this book's radwaste boondoggling examples have repeatedly failed – doing so is a tacit admission that the institution's decision-making is flawed. To survive, most of its lower ranking people just keep pretending that their emperor's not-so-new clothes continue to be as beautiful as they were at first "sight".

that system is disadvantageous to them. It is responsible for the counter-intuitive behavior often seen in oppressed ("low-status") groups, wherein they buy into their oppressors' propaganda.[439]

According to SJT, humans have three competing psychological motives: ego motive, group motive, and system justification. Our ego says, "*I like me*." The group motive makes us say, "*I like us*" (and, conversely, "*I don't like them*"). However, the system justification motive causes us to believe that, "*I like things the way they are*." Sometimes these motivations reinforce and sometimes they compete, depending upon circumstances.

System justification embodies our desire to believe that the world is logical (makes good sense) - that things are the way that they are for a "*damn good reason*" (God? the Constitution?). It is the reason that many low-status people within a culture often defend the privileges and sometimes grossly inappropriate behavior of its high-status people (e.g., Mr. Trump and his minions). Further, it explains why if disadvantaged members of a group are not having their ego or group justification needs met, they will be less likely to demand societal/cultural changes. They rationalize[440] their position within it and internalize a belief that they deserve to be in their current position (*I'm just a chemist, who am I to question whatever the Chem Plant's engineering experts want to do?).* Of course, the advantaged members of such groups have an even more "conservative" view: "*things are right as they are*". Consequently, to them, everything is simple: just set up the rules and structures ("procedures") to be blind to individual characteristics, and the system will assure that everything will work out fine with everyone having a "fair and balanced" shot at achieving happiness and success. In such a culture, if anyone happens to fail, it is attributed to a flaw in their personalities or "not following procedures", not the system itself[441]. In many ways, conservatives consider the "system" to be the most important thing which is one of the reasons that the leaders of many of our political parties, corporations, and national laboratories behave the way they do.

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[439] Examples of such individuals would be the majority of Mr. Trump's "base".

[440] When I was a kid, my heroes were Isaac Asimov and Robert Heinlein. I wasn't surprised to recently learn that Heinlein had characterized us humans as rationalizing, not rational creatures. Mark Twain hadn't been that kind to us: "*... what a dull-witted slug the average human being is ...*". ("Life On the Mississippi", 1883). As these words are being written (July 1, 2020) the USA's political tribes' willingness to self-identify with cults & ignore both history and facts has collectively triumphed over common sense, science and even self-preservation. Having seen how things were done by a competently managed/incentivized bureaucracy during his experience as a WWII naval officer, Heinlein's writing thereafter expressed admiration for competence and emphasized the value of critical thinking which often posed provocative situations challenging conventional social mores.

[441] That's why it's so easy to brush off the complaints of such losers by simply calling them "disgruntled employees". I suspect that some of the Jews sent to Auschwitz eventually also become "disgruntled".

The examples that I have already given reflect several of human nature's less admirable characteristics including…

9.1 Greed

Doing the right things at Fukushima would have cost a bit more and thereby reduce profits. Doing the wrong things with Hanford's, INL's, and SRLs' reprocessing waste increased profits by making more "work". In cost-plus government contracting, no mole hill is too small to be considered a mountain if the people authorized to surmount it choose to pretend that it is and no one challenges them[442].

The first thing that everyone facing a "new" technical problem should do is to familiarize themselves with what has already been done to address similar problems. There are already perfectly reasonable solutions for most of the world's technical issues including those that this book discusses – what has been absent is the collective will to recognize that fact and address those problems. One of the reasons for this is that most of the people assigned to deal with them are either in the "research" (study) business (most of our scientists and engineers) or don't want to "rock the boat" (upset anyone) any more than they absolutely must (politicians and their government's project managers) or are satisfied with the status quo. These characteristics incentivize both "experts" and the people they report to(pay them), to ignore what should be obvious solutions and, instead, turn every "new" technical mole hill into a uniquely challenging mountain requiring a great deal of cutting-edge research before any significant changes must be made. That's one of the reasons why the US Department of Energy's "legacy" reprocessing waste treatment efforts at its Idaho and Hanford sites have morphed into the interminable multibillion dollar "study" boondoggles described in this book.

Organized (usually corporate-sponsored) greed seems to have become especially pernicious. Acquisitiveness is the chief driver for entrepreneurial activity and therefore should be, but often isn't, trammeled by rules/regulations serving the common good[443]. For instance, in the early

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[442] One of the things that any agency/company/government wishing to mountain-build must do is to choose regulators and advisors that won't interfere with its plans. In the DOE Complex, one such group is the INL's DOE-funded, Site Specific Citizens Advisory Board (SSCAB). It's not its membership's fault though because 1) DOE can block anyone (e.g., me) from serving on that board and 2) everyone so-considered must promise to go along with whatever its majority desires – all of its advice/conclusions must be "unanimous". Furthermore, DOE must only "consider" advice proffered by it and its other oversight/advisory groups – not act upon it.

[443] That's the reason that citizens of other Western countries with private health insurers don't get surprised/beggared by $10,000/hour medical "service" bills like US citizens do – their governments regulate both health insurers and institutional providers. Olga Khazanc (essay) The Atlantic April 11, 2019 https://www.theatlantic.com/health/archive/2019/04/do-europeans-get-big-medical-bills/586906/ It's also the

1970s, continued nuclear power development was still seen by most of the first world's decision makers as essential to serving the energy needs of an increasingly affluent and quickly growing population. However, uranium supplies were suddenly threatened by the imposition of a protectionist U.S. embargo that compelled its power utilities to use only U.S.-sourced uranium. That embargo was imposed even though some of those foreign mines had been developed with U.S. government encouragement. It depressed prices from external sources, threatening to force closure of some Canadian, Australian, and South African uranium mines. In response, the Canadian government led in the creation of a world uranium cartel supposedly so secret that any Canadian who talked about it could be jailed. Its existence was first brought to public attention when confidential documents were stolen from the files of an Australian company in 1976. It is another sad story too long to detail here (see Gray 1982) but the point is that an OPEC-like cartel quickly succeeded in pushing the price of uranium up seven-fold thereby destroying any confidence that the world's nuclear power utility owners may have had about the future price of their fuel.

These days, Canada's federal, provincial, & tribal governments are busily augmenting their coffers selling drilling/fracking leases to oil & gas companies[444]. Its supreme court has also just approved construction of a pipeline capacity expansion that will probably triple the CO_2 emissions resulting from Alberta's grossly environmentally impactful tar sands oil extraction activities (see APPENDIX XXVI).

Here in my new home state of Iowa, I've been gathering up info about the decision-making behind its Iowa Utilities Board's decision to OK the shutdown of its one & only and already-paid-for, nuclear power plant. Its root cause is that both "special" individuals & businesses are being subsidy-bribed to say/do dumb things like pretend that a nominally 600 MW "solar" farm can replace the power generated by a 600 MW nuclear plant. None of Iowa's source-utility spokespersons' talking points mention either that its energy ratepayers & taxpayers will inevitably have to pay for the "benefits" laid out in their sales pitches or that substituting unreliable power sources for a reliable one will also require building/paying for more gas or coal-burning "peaker plants". They also don't mention that Iowa gets about one quarter as

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reason that Florida's latest hurricane (Ian) destroyed so many of its cities within a few hours. Its real estate entrepreneurs were allowed to tear out mangroves and drain swamps to construct thousands of homes directly in the path of that or any other hurricane's storm surge.

[444] Another downside to fracking is that it's now being done in regions that threaten the stability of existing Canadian hydroelectric dams https://thenarwhal.ca/peace-canyon-dam-at-risk-of-failure-from-fracking-induced-earthquakes-documents-reveal/ .

much sunlight during the winter when its people need lots of heat than under the "average" conditions officially assumed in determining what its solar (or wind) farms' "capacities" are.

Here's a note that I wrote yesterday to the author of a local newspaper article about Iowa's most influential political king/queenmaker.

> Your article, "Who is the Iowan behind Summit's $4.5 billion carbon capture pipeline?" ([Who is the Iowan behind Summit's $4.5 billion carbon capture pipeline? (desmoinesregister.com)](desmoinesregister.com) about Iowa's biggest ag businessman, Bruce Rastetter, does a fine job of revealing the root causes of the "food insecurity" issues addressed in my little technical nerd's cookbook. Those same root causes are the reason that it's unlikely that the USA will ever regain leadership in nuclear energy or addressing global warming – in the USA, short term money/profit "Trumps" decency, common sense & science at every confrontation.
>
> Keep up the good work & don't forget that " *He who dares not offend cannot be honest*". (Thomas Paine)

After sending off that note, I submitted a comment to the Des Moines Register's opinion website about her article.

Alice's "wonderland" isn't as strange as the USA's energy landscape has become.

Twelve years ago, Kevin Rudd, a "liberal" Australian Prime Minister, spoke at the National Climate Summit in Canberra, famously declaring climate change to be "*the great moral challenge of our generation*".

He has since been replaced by a "conservative" exhibiting the same attitudes about business, environmental issues, foreigners, national exceptionalism, and science as does the USA's thankfully now ex-President Trump. Brazil's similarly "low information" voters have since done the same thing – their President's (Jair Bolsonaro's') policies encouraged ranchers to deliberately light 2019's >74,000 fires responsible for the greatest loss of Brazilian rainforest (over four million acres) during the last decade. When they got together for their annual summit in Biarritz, France that year, horrified G7 member nations ("foreigners") offered Mr. Bolsenaro a $22 million donation to the firefighting cause[445].. He refused their/that offer because, "*The Amazon is Brazil's, not yours*".

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[445] $22 million was not nearly enough to save Brazil's forests from further destruction even if its government had tried to do so. The state of California had spent nearly $1.8 billion fighting the 9,000 fires that had ravaged "only" 1.2 million acres of its forests during 2017 (California's wildfires have since gotten even worse).

That's a stark reminder of just how badly the world's rainforests - important buffers against global warming and home to thousands of the world's remaining wildlife species - are faring in today's hyper-polarized, too-crowded, demagogue-led, and privatized world.

The leaders of some of the world's most "advanced" countries seem to have become completely incapable of making decisions based upon physics & facts. A consequence is that lots of their citizens' descendants are apt to lead miserable lives and suffer premature deaths along with most of the Earth's other living creatures.

Cornering the market on anything from filling teeth to supplying government mandated "EpiPens" or "renewable" energy remains as much of a goal of free enterprisers now as it did back in the 1930's. Implementing a "Clean New Deal" represents a potentially much more important/lucrative business opportunity than is supplying EpiPens or insulin and thereby provides even more temptation for selfish behavior. This is another reason why a nuclear renaissance should not require fuel that could be so-controlled again. Natural uranium and thorium are so abundant that if they were to be efficiently "burned", no one could corner the nuclear fuel market.

Finally, civilian nuclear power has been subjected to "technological lock-in" for about 50 years because its first movers established a profitable business model utilizing converter/burner-type reactors that didn't emphasize efficiency or long-term sustainability. It worked for quite some time, but its weaknesses eventually rendered nuclear power much less attractive than it should/could be (see Cowan 1990)

9.3 Gullibility

Here are some of the logical fallacies clouding human decision making

- "appeal to authority" (believing/claiming that something must be true because it is apparently believed by someone currently considered to be an "expert")
- "appeal to fear" (it's no secret that in the USA's industries and governments, poor team players are apt to experience "solitary, poor, nasty, brutish, and short" careers[446])

[446] One of Admiral Rickover's especially sapient quotes , ""*If you're going to sin, sin against God, not the bureaucracy; God will forgive you, but the bureaucracy won't*" identifies the reasons for this behavior. Fear of job/career loss is an effective motivator for DOE's technical people, especially anyone still having a mortgage & dependents to support. So too is the fact that its troublemakers are "disfellowshipped" until their managers can come up with a plausible-sounding excuse for reorganizing them out of their jobs. Questioning anything brands you a suspicious character – probably unpatriotic & maybe even apt to become "disgruntled".

- “wishful thinking” (see my discussions of the consequences of USA’s reprocessing waste management decisions)
- “sunk cost” (decisions tainted by an accumulation of emotional investment – the more effort that’s already been devoted to rationalizing something, the harder it is to abandon (e.g. Hanford’s “vitrification” boondoggle); and finally…
- “appeal to ignorance”; e.g., “*extremely low level radiation dose rates must be evil because you can’t prove that they aren’t*” (it is statistically/scientifically impossible to prove such things).

The real reason that Donald Trump was elected is because the actions of his three Ivy League-educated and therefore “elite” predecessors (Clinton/Bush/Obama) - encouraging low-skill immigration, foreign trade deals, special interest driven tax reductions, off sourcing, and other upward wealth transfers had reduced the incomes of the bottom two thirds of America’s electorate. Trump’s ascendancy represents a rebellion against its elites most of whom still haven’t gotten that message. Many believe that the non-elite “deplorables”

Figure 82: Deplorable sans MAGA hat

(Hillary Clinton’s self-defeating but accurate characterization) who voted for Trump did so because he’d been running their country for most of their lives, i.e., that election’s result was a manifestation of class warfare[447] - an important distinction. In spite of his own "deplorable" characteristics (…*disagreeable, sociopathic, liar, hypocritical, paranoid, grandiose*[448]*, vindictive, toxic, small-minded, evil, selfish, arrogant, cruel, and, sometimes, even "funny*") and manifest incompetence at doing almost everything that any topmost executive must do, he was nearly reelected because his opposition's predecessors had supported policies that moved both "heavy" and "light" manufacture overseas thereby engendering massive US middle class job losses and dependency upon foreign (mostly Chinese, Korean, and Indian) suppliers for the medical wherewithal required to fight *our* pandemic. Those supplies flooded into the U.S. *after* countries that didn't deliberately pick fights with China had their orders filled. There is also the fact that "Bush Two" (President GW) had started two tremendously expensive, unsuccessful, and misdirected foreign wars after which Mr. Obama added two more militaristic boondoggles (Libya and Syria). For the most part, the USA is governed by an in-bred, special-interest-driven, winner-take-all political duopoly incapable of learning from either its own or anyone else's mistakes.

In the real world, this century's further contributions to the root causes of global warming (anthropogenic GHGs) will be dominated by India, China, and Indonesia—its first, second, and forth largest still-developing counties in terms of human population. Almost all of the fuels they'll need to do what want to do can be provided by their internal resources and those of Russia, Saudi Arabia, and Iran. What's noteworthy is that we here in the US now have bad to terrible relations with every one of those countries. Because Brix has become bigger than the G7[449],, the US, Europe and Japan are no longer the center of the universe which means that what we/they do is irrelevant unless we/they develop a lower cost, sustainable, reliable, and clean energy source before those "foreigners" do. The catch is that for several decades their political leadership has deemed informing the American public about such "technical" realities unacceptable.

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447 That's probably also the reason that Al Gore also didn't win - he looks, speaks, & acts too "elite" compared to Mr.Bush. Not contesting his competition's obvious "help" during Florida's hanging-chad vote recount was downright wussy too – a real man would have bombed the Supreme Court and Florida (but not Iraq - foreign wars cost big money & that country didn't have anything to do with 9-11.)

448 "*Maybe I should have been a doctor instead of running for President*" (www.washingtonpost.com › politics › 2020/03/06: report on President's Trump's tour of the CDC – its doctors had apparently been astounded at his immediate grasp of abstruse technical concepts. A few weeks later he demonstrated astounding creativity in that discipline as well when he pointed out to his team of COVID-19 experts that they should look into trying out LYSOL injections - something that none of them had even thought about yet!)

449 Bigger in terms of GDP PPP. "PPP" (Purchasing Power Parity) corrects a nation's GDP figure in terms of US dollars for the prices of its specific goods and services and therefore better reflects their real value.

As was President Trump's election, today's vaccination resistance is another reflection of US citizens' distrust of their government and the elites it's been serving. We've had three Ivy League presidents that drove down the incomes of those without a college education due to trade deals and low-skill immigration—both of which helped the top 20%. Clinton deregulated Wall Street, Bush ignored Wall Street, and Obama decided that nobody would go to jail for the massive banking industry fraud leading to the world's 2008 "great recession" (it's been estimated that about 10,000 people should have gone to jail). Bush oversaw Afghanistan and Iraq while Obama added Syria and Libya.

On the medical front, the cost of the USA's medical establishment is almost 20% of GNP versus about 10% in other western countries. The most important service provided by most of our physicians to their customers, is granting them permission to purchase whatever drug(s) he/she decides to prescribe. The most important service that they provide the system they work for is keeping its other employees , hospital owners, and stockholders happy. There have been about as many drug recalls as "new" drugs and every newcomer comes with a barrage of fine print listing possible side effects. The exception is the new COVID 19 vaccines that have been officially declared safe for various groups at various times. The US government's vaccine sales job probably boosted mistrust rather than reducing it, beginning with "trust us" and, to certain groups, ending with "we will force vaccines on you like it or not". The USA's CDC and NIH made a series of major mistakes—from messed up lab tests for covid to taking six to eight months to understand the nature of airborne disease transmission—something that the Chinese figured out within four weeks. Trump refused to implement an effective quarantine to stop Covid and Biden refused to implement an effective quarantine to stop Delta Covid—too much inconvenience to the traveling public.

We have gone from the trusted family doctor to "medical service providers" with whom we have no long-term relationships.

Because Trump's presidency represented citizen backlash at long-term incompetent governance; the question is not whether he is what "elites" like what I've become consider him and his enablers to be, it's whether the majority of the USA's electorate feel that his policies are apt to better their situation more than would those of his more elite-seeming opposition. Another consequence of many peoples' life experiences is that they no longer trust/respect anyone who seems to sound "elite" including those among themselves who've somehow managed to become experts in any posh-sounding "technical" discipline[450]. In a world that must quickly address the

[450] For example, while doing some more GOOGLING about how to better go about communicating with my colleagues; I stumbled upon the American Council on Science and Health's website. Its contributors have recently posted lots of mighty impressive opinion pieces about the COVID-19 crisis (Dr. Berezow's latest posting even inspired me to contribute $25 to help keep 'em coming). However, the problem is that his article was 891 words long and newspapers typically limit the length of their reader letters/comments to 150-250 words. It's really tough

technical issues that have inspired this book, that’s a really serious problem. Most of humanity’s looming residential heating problems could be resolved by using reject heat from thermal electricity generation either directly or as a source for heat pumps. That would require that the reactors be urban sited. In the USA the biggest problem with urban reactor siting is its public’s unwarranted fear of living near nuclear reactors which at least partially stems from a lack of trust in both their government’s experts and privatized service providers driven by a profit motive.

The USA’s business culture must change to address this book’s energy issues. Canadian, French and UK reactor fleets were built by public entities that put safety ahead of shareholders’ profit. In both Russia and China, the government is a big player in nuclear power enterprises. The US presently relies upon detailed regulations that handcuff everyone working in/for its nuclear industry and privatized national laboratories.

A downside of today’s Information Age - open internet, “free” social networking, and 24-hour news/entertainment TV shows - is that within a few minutes many people can convince themselves that they know as much about a technical issue as do genuine experts. They demand to be taken with equal seriousness (Figure 83) and any resistance is dismissed as undemocratic elitism. Paradoxically, today’s increasingly democratic dissemination of information, rather than producing an educated public, has instead created an army of ill-informed and angry citizens suspicious of intellectual achievement and willing to listen only to their favorite echo chambers.

« There is a cult of ignorance in the United States, and there always has been. The strain of anti-intellectualism has been a constant thread winding its way through our political and cultural life, nurtured by the false notion that democracy means that ‘my ignorance is just as good as your knowledge ».”

Isaac Asimov, NEWSWEEK, January 21, 1980

When a county’s ordinary citizens believe that no one knows more than anyone else, its democratic institutions are in danger of falling either to populism, technocracy or, worse, both. These trends threaten the survival of the USA’s democratic institutions and were exacerbated by the all-too-predictable consequences of Donald Trump's election.

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for someone like me to explain a technical issue in a rigorously accurate way that gets the message across while not seeming too elitist.

Figure 83 Two Americans, two opinions, two votes

The USA's "conservative"-dominated federal government's manifest incompetence at dealing with anything its business leadership deems controversial has inspired a number of liberal young & not so young politicians to espouse a "Green New Deal" calling for a transition away from a world primarily powered with fossil fuels to one powered by Dr. Jacobson et al.'s 100% wind, water, & solar (WWS) schemes. [451]

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[451] The "Green New Deal"'s best known "technical" Pied Piper started to hammer away at nuclear power well before he got his PhD, then gained fame as an eminently politically correct, big-name university (Stanford), renewable energy modeling expert who could save the world, and in 2013, along with actor Mark Ruffalo, businessman Marco Krapels, and activist Josh Fox, co-founded a non-profit organization, "The Solutions Project" that "*champions and invests in a climate justice movement that centers women and power-building organizations led by Black, Indigenous, Immigrant, and other people of color*." Its "Clean Energy Mastermind's" goal (Grist: The 50 People You'll Be Talking about in 2016 - Mark Jacobson - The Solutions Project) is *"combining science, business, and culture to educate the public about science based 100% clean-energy roadmaps for 100% of the worlds people*". From 2011-2015, his group developed individual WWS energy plans for each of the 50 United States and the entire world. He finally topped it all off by suing the National Academy of Science for $10 million because its deciders had dared to publish a paper (Clack et al, 2017) refuting the claims he had made in another previously reviewed/accepted/published by the same journal (Proceedings of the National Academy of Science). He along with some of his like-minded colleagues have managed to convince millions of people (many of whom are especially important actors, politicians, etc.), that the USA could replace 100% of its (and the entire world's too) power/energy sources with a suite of optimally-managed (by whom?) politically-correct renewable power sources - no nuclear, no gas, no coal, no oil and no reluctantly admitted impossibly gigantic/expensive batteries. Other than that, to me his most noteworthy achievement was finally deciding to withdraw his libel suit against the National Academy of Science. The last thing I've heard about that lawsuit is that he was then ordered by the court to pay the journal's publisher $425,000 in legal fees. Those fees are based on an anti-SLAPP statute, "designed to provide for early dismissal of meritless lawsuits filed against people for the exercise of First Amendment rights.". However, he remains the darling of the liberal left's Green New Deal movement because most of its true believers have still not

In most Western countries it is the "progressives" and socialists professing to care more deeply about the environment that seek to shut down nuclear plants, not the "conservatives" who typically choose to disbelieve in anthropogenic climate change. Consequently, progress on addressing climate change within the US has come to a virtual standstill because most of its liberal-leaning people cannot fathom how any rational human could doubt an overwhelming scientific consensus & neither of its political tribes is either willing or being forced to compromise.

"*Nuclear power is one of the chief long-term hopes for conservation…cheap energy in unlimited quantities is one of the chief factors in allowing a large rapidly growing population to preserve wildlands, open spaces, and lands of high scenic value…with energy we can afford the luxury of setting aside land from productive use*s." William Siri President of the Sierra Club 1966-1968.

The political left's anti-nuclear bias is illogical because Sweden and France represent two of nuclear energy's greatest tangible successes and both are regarded by most liberal-leaning people as the best kind of society. Through a combination of sensible policies and free-market incentives, starting circa ~1970 Sweden cut its per capita GHG emissions by a factor of three while doubling its per capita income and providing even more of its notoriously "pro-people" social benefits with nuclear power. A just-published Swedish book's subtitle contends that it, much as France had *almost*[452] done before, has already "*solved climate change*" by expanding its electrical supply with nuclear power during the 1980's & 1990's (Goldstein & Qvist 2019). Sweden's primary concern then was reliability, not global warming: its government's leadership deemed further hydropower development too environmentally impactful and the previous decade's OPEC-driven oil crises had rendered fossil fuel supplies too unpredictable. Consequently, Sweden built a dozen nuclear power plants on four different sites, eight of which continue to operate today. They currently supply ~40 percent of Sweden's electricity which is as much as do the hydropower plants that Mother Nature had liberally endowed both it and Norway with the potential to employ. Consequently, electricity in both countries is still cheap, clean, and reliable. Goldstein & Qvist's book contends that, "*Sweden became the most successful country in history at expanding low-carbon electricity generation and leading the way in addressing climate change*". They also say that "*without growth in nuclear power, replacing fossil fuels with*

bothered to learn how to properly evaluate technical proposals. His name is no longer mentioned on The Solutions Project's website which is likely the reason that it has since succeeded in becoming one of the 16 organizations receiving a part of the $791million first round of grants from Jeff Bezos' $10 billion "Earth Fund".(I'm not apt to be receiving one of Mr. Bezos' "*Courage and Civility Awards*" either).

[452] Again, circa 1980 France did not commit to building enough reactors to make the synfuels & batteries required to power its transportation and industrial sectors. No other country has done that either.

renewables simply decarbonizes the existing supply. It doesn't deal with the increased demand…".

That's the reason that Sweden's new Prime Minister Ulf Kristersson has just outlined a new Swedish-French partnership to build two new full sized (1.3 GWe) nuclear power plants to the six that it already possesses.

In the real world, it has been nuclear energy, not solar and/or wind farms that have decarbonized energy supplies while increasing wages and societal wealth.

And it is only nuclear that has powered high-speed trains everywhere from France to Spain to Japan to China… thereby decarbonizing transportation – the source of about one-third of anthropogenic GHG emissions. Consequently, it seems reasonable to expect that a "Green New Deal" incorporating nuclear power is apt to be more successful and certainly less environmentally impactful than one that doesn't.

However, due to a vexatious quirk of human psychology, deep-seated fear of nuclear power has become socially acceptable among those who claim to be "*following the science*." But just as today's COVID-19 vaccines haven't killed any Americans despite what its legions of deplorable anti-vaxxers claim, neither has nuclear power.

I suspect that one of nuclear renaissance's most "evil" characteristics as far as many of the western world's green true believers is concerned is that it would not require their fellow citizens to embrace their faith in the notion that a no-nuclear green energy system would not seriously compromise their descendant's lifestyles. A properly implemented nuclear renaissance would let everyone go on living in pretty much the same way that they've/we've gotten used to without having to worry about the power going down (involuntary "load shedding") in the middle of whatever we're trying to do[453].

9.2 Tribalism

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[453] Even in coal-rich countries coal power isn't necessarily reliable (Enerdata 2019). South Africa's Eskom – the African continent's biggest power utility by far - has just decided to take 4,000 MW off its power grid. On 14 March 2019, the first 800 MW unit of its Kusile power plant tripped, exacerbating a shortfall of generating capacity and prompting it to announce a "Stage 2" (2 GW) load shedding, that changed to a Stage 3 (3 GW) and finally to a Stage 4 (4 GW) load shedding, after the loss of additional power including 900 MW imported from Mozambique due to storm damage to the interconnection to its Cahora Bassa hydropower plant). Its existing plants suffer many breakdowns and the construction of two more big ones (4.8 GW each), is running years behind schedule and billions of dollars over budget. In mid-March 2019, ~12 of Eskom's 45 GWe total capacity was unavailable due to unplanned outages and its back-up diesel supplies were also under pressure. Eskom is now US$29 B in debt and South Africa's government has announced plans to restructure it and support some of its short-term debt issues.

Tribalism is paying attention only to those who think as we do and considering anyone else an "outsider" to be ignored, aka, 'groupthink': Examples include: Democrats vs Republicans; management vs workers; rich vs poor; businessmen vs technical nerds; experts vs the "dumb public"; regulators vs businesspersons; INEL's vs Hanford's radwaste experts; the Chem Plant's "true believers" vs its agnostics[454]; Shia vs Sunni; "environmentalists" vs pro nukes[455]; and finally, almost everyone vs whistleblowers.

Its two big political parties are the USA's most distinctive tribes.

However, in truth the USA has four political tribes:

. Far-left democrats ("socialists") many of whom don't behave logically (faith-based thinkers)

Moderate democrats that generally do behave logically

Moderate republicans (currently a small minority) that generally do behave logically

Right wing republicans that believe/behave much as did Hitler's brownshirts (faith-based thinkers).

Since the USA's founding fathers (no mothers were involved) over-emphasized their new constitution's "checks and balances", its law-making branch (Congress) has become incapable of making sensible but politically "tough" decisions. Our Founding Father's two hundred and thirty year old masterpiece also stresses individual "rights" (e.g., the right to own your own AR 15 assault rifle clone or refuse to get vaccinated during pandemics) but not individual responsibilities. That's why the COVID 19 pandemic will kill far more US citizens than it should. Our Constitution is also much like the Holy Bible or Koran in that its meaning is open to

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[454] By the time that I came on board, most of the Chem Plant's choicer job slots were occupied by Latter Day Saints (LDS). The reasons for this include: 1) The Church of Jesus Christ of Latter-Day Saints is that region's predominant religion; 2) LDS children are brought up to believe that the "System's leadership is always right; 3) their church encourages them to help each other out; and 4) as far as "business ethics"is concerned, anything goes as long as it's apt to benefit the "family".

[455] In 1986 long-time Greenpeace stalwart & President of Greenpeace Canada, Patrick Moore, turned in his badge because he'd concluded that the "*environmental movement had abandoned science and logic in favor of emotion and sensationalism*". He contends that "*most of the really serious environmental problems have been dealt with*", and that his ex-soulmates romanticize peasant lifestyles and "*invent doom and gloom scenarios*" as part of their anti-industrial campaign to forestall development of the world's undeveloped countries – an attitude which he characterized as "*anti-human*". The issue that set this off was Greenpeace leadership's apparent determination to outlaw the use of chlorine/hypochlorite as a disinfection and bleaching agent (Fumento 1996) – a notion that he considered as half-baked as had been its then-recent decision to reverse its stance on nuclear power. Since he is now considered to be turncoat, he's become an "unperson" (disfellowshipped) and all mention of his contributions before his epiphany have been scrubbed from Greenpeace's official history/chronologies (Moore 2011).

interpretation which, of course, we let our leaders do for us (the USA is a "representative" democracy).

Why does Africa now have 54 different countries? For that matter, why does the USA consist of 50 not-very-united states? The reason is that quirks in both its constitution and its subsequent interpretation rendered "minority rule " possible. This has in fact been the case during the same forty years that has seen China rise while the USA stagnated. It's metastasized like a cancer and is now pervasive throughout the USA's entire political system resulting in a situation where 41 GOP Senators representing ~20 percent of this country's people can stop legislation favored by Senators representing the other 80 percent. As had happened during President Barack Obama's administration, after a strong start with an ambitious Covid relief bill, vaccination rollout, reconciliation with other western world leaders, and recommitment to the promises made at the Paris Conference, President Biden has been whacked by same minority rule club wielded by the same set of Republican know-nothings[456].

Most of the factors responsible for the USA's now very much flawed democracy's inability to do what must be done if it is to remain "great" are due to the politization of almost everything involved in solving its citizen's problems. This includes much of today's dominant manifestation of the "fourth estate" (24-hour news networks). As far as I am concerned CNN & MSNBC (ultra "liberal") are almost as annoying in that respect as is FOX NEWS (ultra "conservative"). Most of their news coverage consists of that network's favorite pundits endlessly opining about the opposing tribe's current outrages – not serious discussions of facts, technical problems, and/or their possible solutions. China's Global Television Network's (CGTN) 24-hr all-news coverage is both much more informative about what's happening in the world and far less annoying[457].

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[456] In my opinion, both President Obama and President Biden were/are too "nice" to be truly effective in a country as unruly as the USA has become. Admiral Rickover wasn't nice. Mr. Trump's one & only virtue was that he wasn't afraid to offend or take advantage of the "terrible power"(A. Lincoln) that becoming POTUS had afforded him.

[457] About two months ago I was half-listening to CGTN while writing. One of its news shows ,"The Point", featured an interview with a China-based French shipping magnate who was proudly showing off his company's latest, biggest, and best Chinese-built container ship. It's 400 meters long, has a 270,000 tonne/23,000 TEU cargo capacity & an 85000 hp LNG- powered engine that can push his six-time-bigger-than-the Titanic ship through the oceans at 21 knots (same speed as the Titanic) & make the round trip between the EU and SoE Asia twice on a single "gas" fill up .It's so-powered for environmental reasons - it's much, much, cleaner than today's bunker-fueled diesel powered ships - 20% less CO2 and >99% less SO_2.

CGTN's reporters didn't mention Governor Coumo's sex life, Brittany Spears, President Trump, or how else we've been behaving stupidly over here in the USA even once!

Today (10Jan22) it told its watchers about an outfit name KIVUWATT (see [KivuWatt Power Station - Wikipedia]) that's sucking up some of the CO_2/methane accumulating at the bottom of Ruwanda's Lake Kivu, The western world's rising tide of tribalistic nationalism brings out the worst in us. Like chimpanzees, we humans are hardwired to categorize others of our own species as "thems" not "us" thereby triggering the hate, fear, disgust, violence, selfishness, etc. that we now see more of now than since WWII (Sapolsky 2019). Solving humanity's biggest technical problem (kicking our fossil fuel addiction) will require us to cooperate, not retreat further behind borders goaded by populistic (autocratic) leaders taking advantage of our all-too-human nature. History tells us that the negative aspects of our nature can be overcome by the right sort of leadership but rarely is.

One of the manifestation of that is how we've been responding to the challenges posed by "climate change". For several decades' climate scientists have been warning us that global warming will lead to more extreme weather. Because many Americans are now personally experiencing the consequences of "bad" weather events, it was reasonable for one of MIT's senior most analysts to determine whether they will support aggressive climate action Study: Extreme weather may not lead to increased support for climate action » Yale Climate Connections.

The answer was "not necessarily".

Climate change's signals are difficult for most of us to notice against the background noise of daily and seasonal weather changes.

When a neighborhood, city, or region experiences truly unusual weather, some of its residents see it as clearly connected to global warming— others don't notice that connection. Just as two people respond completely differently to political events, current fashions, or football games, two individuals come away with completely different impressions about what they've both just experienced, what caused it, and what to do about it.

"Experience" is more subjective than most of us realize. Unlike other big-brained animals, we do not simply use our senses to gather facts about our surroundings and events—we continuously interpret such inputs filtering them through our emotions, memories, culture, and especially in the case of weather/climate, our politics. We then combine them with our beliefs, attitudes, and

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burning the methane to make electricity (26 MW) & capturing/pumping the CO2 back down into a "safer" part of the lake. Its sounds a bit fishy to me but might make sense & is certainly better than just waiting until Mother Nature "burps" it out all at once killing everything around it. Yeah!!

On the other hand, the USA's CNN's talking heads remained fixated upon and seeking each other's opinions about the USA's political issues.

evaluations of past experiences to finally build a narrative consistent with what we consider to be our place in this world (that's why we often can't see the elephants that have barged into it.)

The effects of real weather and climate changes on our attitudes about global warming are subtle compared with the influence of politics. As heat, drought, massive wildlife die-offs (where have most of Southeastern Idaho's rabbits and trout gone?) and other weather-related changes continue to become more "unusual", some of us hope that more of our fellow citizens us will be persuaded to aggressively reduce their county's carbon emissions. It is encouraging to see that more of them are but discouraging to see half of us still refuse to associate flooding, hot and cold spells, and drought extremes with globe-wise warming because doing so would be inconsistent with our tribe's beliefs.

A timely example of this was going almost two years ago now (mid May 2020). The USA's Republican party's leadership (Pres. Trump, Sen. McConnell, Republican Governors, Congresspersons, Supreme Court, and most of Fox New's talking heads) had a "*a solutions focused government relations firm*", O'Donnell & Associates, put together a 57-page compilation of talking points ("Corona Big Book") to deflect questions about their leadership's failures. They did that because they had learned that if you can create a set of lies, muddle them with conspiracy theories, and have almost everyone in your party repeatedly parrot them, you can succeed in framing the political conversation and maybe gain/retain control of government[458].

Diversity of thinking is vital if a group facing a complex problem is to arrive at a competent solution.

Another unfortunate human characteristic is that we tend to see things as being totally black or white, perfect or useless, evil or saintly, good or bad, etc. rather than recognize that almost everything and everyone is some shade of grey.

A few weeks ago, *Good Morning America*" featured a 5-minute example of how awful the USA's legal system can be to people who are unable to defend themselves ("untertribe members") from a more powerful ubertribe's bureaucracy that's rewarded for punishing people and isn't punished itself when it's been proven to be wrong. Two, now middle-aged black men have been wrongfully imprisoned for 43 & 26 years respectively in Missouri's penitentiary . Their convictions were based upon evidence presented by "witnesses" who had been bribed by people representing the ubertribe and had then recanted. Both men have now been fully

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[458] The "Corona Big Book" serves the same purpose as did Chairman Mao's little red book a half century earlier. China's then omnipresent Red Guard domestic police forced everyone to speak and act in fashions consistent with his/its quotations and slogans.

exonerated but still in prison because neither has yet been able to jump through 100% of the legal hoops that that state's government requires for its prisoners to be freed. Its attorney general and Governor both refused to release them.

A half-hour later, "Face the Nation's " host spent another half hour telling us how serious the especially contagious "delta" variety of Covid 19 is becoming in those parts of the USA where most people refuse to be vaccinated. Since the worst-hit such state also happens to be Missouri, that show featured an interview with the mayor of its capital city, Springfield who was careful not to say anything that might hurt his chances of reelection.

"When stupidity is considered patriotism, it is unsafe to be intelligent."

Isaac Asimov.

Many of the USA's voters have apparently decided to turn themselves into fire-armed "brownshirts", not just stupid, hopeless, helpless, hapless, and otherwise "deplorable". In his last book, "The Demon Hunted World" published the year before cancer killed him -1995) Carl Sagan predicted what's happening here in the USA now based upon what was just beginning to become apparent then – the substitution of tabloid journalism for sober analysis of happenings and issues, the widening wealth & opportunity gaps between the rich & poor, the rise of partisanship, and the "'celebration of ignorance" which deems anyone trying to make decisions based on reason and facts as 'elitist'.

Disciplinary (tribal) boundaries often hinder scientific progress because each of its discipline's adherents resent attempts by Jack-of-several-trades outsiders to either poach upon their bailiwick or evaluate their efforts. This often manifests itself as difficulty in getting anything that might be considered "controversial" accepted/published in another discipline's peer-reviewed journals. Another very real fact is that scientific journalism's anonymous reviewers are simultaneously free to turn down such papers or research proposals, and then subsequently "discover" the concept and then study/describe it themselves[459].

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[459] That happened to me while I was a tenure-track Assistant (I wasn't "assisting" anyone) Professor of Chemistry at Marquette University. During my second year there, I had written an NSF proposal having to do with atomic fluorescence spectrometry, a field in which there was only one active research group in the USA. It was turned down of course and I discovered two years later that that group had suddenly decided that it would be a fine topic for one of its PhD candidates to work on. He subsequently just happened to be one of the people interviewed to fill my position at Marquette after I had decided to quit and go to work at INEL (his introductory/test seminar was an implemented rehash of my proposal and he subsequently admitted that his advisor's research group had "reviewed" my proposal). The prevalence of this sort of behavior is one of the reasons I decided to quit full-time academia (but not part-time, after-work, college course teaching).

Most people are reluctant to challenge the beliefs of their peer group, regardless of how unsubstantiated they might be. For example, during the early 1980's Argonne got a head start on what came to be considered its signature Generation IV project at DOE's Idaho site -the Integral Fast Reactor (IFR) . Within about five years (1984) they had become ready to demonstrate how safe their already twenty-year-old 60 MW_t liquid metal-cooled EBR II pilot plant is/was. Scientists and engineers from around the world gathered to watch what would happen when Argonne's nuclear engineers deliberately caused a total loss of coolant (liquid sodium) flow to its core. Exactly as predicted, its core temperature briefly increased and then rapidly dropped as it safely shut itself down without further intervention.

Although the IFR project was a technical success in many respects, it could not buck the protests of the USA's legion of anti-nukes & thereby address the problem that had served as its raison d'etre since circa 1948; i.e., that as it is currently being implemented, nuclear power isn't sustainable.   The majority of the USA's environmentalists (one tribe) continued to reflexively oppose any sort of nuclear power as did many of the Democratic Party's "liberals" (another tribe – pig-headedness isn't a liberal or conservative characteristic) - so the Clinton administration shut it down because "*we don't need it*" even though its topmost leader (and certainly his vice president) were aware of anthropogenic climate change & that the fossil fuels causing it represent finite resources.

The same thing happened at the beginning of President Obama's administration – funding for the GEN IV nuclear reactor R&D (GNEP) program instigated by President G.W. Bush was axed[460] and the US taxpayers' thirty-year/$15-billion-dollar investment in DOE's YM spent fuel storage site[461] was also wasted.

(see Berezow's brilliant essay "the slow suicide of American science" for more words/ideas https://www.acsh.org/news/2020/10/02/slow-suicide-american-science-15065 - also look up and read its links)

To me that was not surprising for several reasons, one of which was that two of the people responsible for authoring MIT's seminal. "*The Future of Nuclear Power*" (MIT 2003), Professors John Holdren and Ernie Moniz, subsequently served as President Obama's

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[460] Another reason for that cut-off was that the special interest-driven banking investment rule changes (regulation removal) introduced by the previous US administration had led the entire world into a deep economic recession which, of course, affected the USA's R&D spending.

[461] It's likely that if everyone had simply agreed to call YM a "monitored retrievable radioactive material storage facility" rather than a "repository", it would now be serving that purpose and thereby providing several hundred good-paying jobs for some of Nevada's "middle" class citizens.

technical/scientific advisors a half-decade later. Three of that report's conclusions were as follows:

" Placing increased emphasis on the once-through fuel cycle as best meeting the criteria of low costs and proliferation resistance

Urging DOE to establish a Nuclear System Modeling project that would collect the engineering data and perform the analysis necessary to evaluate alternative reactor concepts and fuel cycles using the criteria of cost, safety, waste, and proliferation resistance. Expensive development projects should be delayed pending the outcome of this multi-year effort

Giving countries that forego proliferation- risky enrichment and reprocessing activities a preferred position to receive nuclear fuel and waste management services from nations that operate the entire fuel cycle."

This means that President Obama, a lawyer by education and rather busy doing other things, was advised by two of his country's topmost technical experts that developing a sustainable nuclear renaissance wasn't necessary. Since to him/them, nuclear power apparently just represented part of a temporary "bridge" to the future[462]'s, "all of the above" energy system, adding a few conventional-type small modular reactors *seemed* to represent the best way to address the USA's future energy issues.

An update of MIT's report eight years later (MIT 2011) did not change its recommendations or bother to mention the molten salt-type reactors which had since garnered a great deal of attention[463].

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[462] They apparently assumed that the other, much bigger, part of that temporary bridge would be the tight gas & oil then beginning to be fracked out of the USA's underground shale, sandstone , and coal formations. In his 2014 State of the Union address, President Obama praised natural gas as "*the bridge fuel that can power our economy with less of the carbon pollution that causes climate change*." Switching from coal to gas was a key pillar of his "Clean Power Plan" to reduce climate emissions, which big environmental groups lined up to praise and fight for. We now know that methane, the primary component of natural gas, is a much more potent greenhouse gas than is carbon dioxide meaning that gas plants are, at best, no more than a marginal improvement over the coal fired plants they had replaced in that respect. Since wind and solar are the cheapest-to-build "new" energy sources, today's electricity costs us more at the retail level and the systems supplying it are less reliable than were the ones we grew up with.

[463] According to Prof. Charles Forsberg (personal communication 8Nov2020), MIT's NE department is planning to do its first experiment with a realistic MSR simulant (molten salt containing both actinide and FP surrogates) during 2021. The fact that the university from which the USA's political system seems to recruit most of its energy experts/advisors, is still only just planning its *first experiment*" with such things is another of the reasons why I no longer expect the USA's nuclear renaissance to "save the world".

"*Secret ingredient of nuclear success: Independent regulation*" By Dale Klein, Peter Lyons, and Richard Meserve is (07/23/19 05:00 PM EDT) is another self-serving opinion piece written by more of the people collectively responsible for the USA's decision to keep kicking the same old cans down the same old road. They share responsibility for President Obama's espousal of "all of the above" rather than the development of a "renewable" nuclear fuel cycle[464].

The stubborn inability of the NRC "experts" lauded by that paper's authors to evaluate anything other than conventional reactor concepts remains one of the biggest hurdles facing anyone attempting to devise superior alternatives. Qualifying a slightly modified light water reactor fuel might cost $100 to $200 million, while qualifying a new fuel and completely different coolant is apt to require $1 billion and 10-15 years of lead time. This is the reason that all the SMR concepts slated to have commercial offerings before 2025 are non-sustainable and utilizing only slightly modified fuels.

In a finite world, no one can afford to do "all of the above"– choices must be made, and the resulting action's success/failure will depend upon whether or not those choices were reasonable not just fine sounding. Fossil fuels regardless of how they are obtained do not represent a sustainable energy source, biofuels cannot replace fossil fuels, wind/solar power is and will remain ineluctably unreliable, and electrochemical-type batteries are and will remain too expensive for anything but niche applications. Mr. Obama's DOE didn't make much progress because its leadership refused to think quantitatively and make politically tough choices. Consequently, he/they got it backwards: fracked gas/oil and today's renewable energy sources should be considered temporary bridges to Hubbert and Weinberg's nuclear-powered utopia, not the other way around.

9.4 Laziness

Lazy is unwillingness to work. A "good" example of this would be how eager many people are to assign a label to whomever brings up a perplexing question so that that they can spout their peer group's established talking points and not have to worry their pretty little heads about "details" (work it out for themselves). For instance, US whistle blowers are invariably characterized as "disgruntled employees" meaning that whatever they might say can be comfortably ignored. In the DOE complex whatever a "technical" whistleblower might say is easily dismissed because it's "*just a difference in professional opinion*" from that of his/her equally credentialed[465] colleagues being paid to nominally work on the same problem. For both

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[464] It is probably not a coincidence that nuclear industry business-model consistent reactors/fuel cycle are perfectly (and only) suited to remain a *small* part of "all of the above" for the next century.

[465] There's no shortage of hungry, heavily indebted, young PhD job seekers for a DOE contractor's HR deciders to pick from.

decision makers and some of their “outside” advisors, laziness means not bothering to learn the fundamentals of whatever it is that they are supposed to be overseeing. Ignorance – especially when it is deliberate – should never represent an excuse for a failed technical project’s leadership but often does[466].

Because DOE’s “technical” decision making has been primarily driven by artificial schedules, anticipated funding levels, and immediate political considerations, its mostly generic business school-trained, top-level managers rarely bother to acquire much “subject matter expertise” about what they are currently managing. The people providing them with such counsel – mostly senior-level contractor employees – are rewarded for always saying/writing/supporting whatever their “customer” seems to want; e.g., an excuse for espousing “separations” instead of »direct vitrification» of INEL’s radwastes - and know that they will eventually be downsized if they persist in not becoming good team players[467].

The funniest example of this institutional symptom that I can remember was back when we lab rats had just been informed that INL’s (then INEL’s)“new mission” would be to become DOE’s “lead lab” in radioactive waste management and its brand-new Assistant Secretary of Energy decided to go out and meet the stakeholders[468]. When a newspaper reporter asked him to define “High Level Waste”, we & everyone else learned that...

“*Well it is a radius that is applied to it on a high level in a way that you are going to treat that way, and the way that you are then going to process it. So at the end of that, on a high level, let’s say you might have to – after processing that, you may-before you put it into the permanent storage, that may be something that you have to transport to let’s say - to where we were putting storage in new Mexico. Some other kind of waste you could be able to put in the cement and store it right there on the site. High level, we would handle that with care. We handle all of it with care.”*

That really cleared things up for us newbies to the radwaste R&D business.

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[466] a repeatedly failed project’s excuse of last resort is that it is/was “*first of a kind*”. In most such cases that is true because no other “technical” institution would have decided to try to address the problem that way. DOE’s managers routinely do so because they can almost always blame/change the contractor(s) and/or shift sideways to another equally or better compensated position. About the worst possible punishment that a >50-year-old civil servant can suffer is a comfortable early retirement - their contractor’s personnel are not similarly secure.

[467] The most common way to downsize a troublemaker was to exclude his/her expertise in the next project’s/contractor’s “personnel skills mix requirements”.

[468] That official was a generic DOE management type with a gift of gab & a PhD in something or other, I'd guess education. Reagan put him in as Assistant Secretary of Energy (Management and Administration).

9.5 Deviousness

"*Honesty: The best of all the lost arts*." — Mark Twain

We don't have to look too far to understand why people easily swayed by media do not trust their government when it comes to the handling of the pandemic, lockdowns, vaccines, health care, higher education, the economy in general, or anything having to do with nuclear power. It is imperative that institutions protect their trustworthiness but this hasn't been happening. When narratives keep changing it is difficult to trust any source - that's one of the reasons why someone like "The Donald" became POTUS.

Global power demand is roughly doubling every other decade and electricity remains the most difficult sort of energy to supply reliably. Three billion people currently live where per-capita electricity use is under that consumed by an average American household's refrigerator. How we close the colossal gap between the electricity-rich and the -poor will determine our success in addressing the issues serving as this book's raison d'etre.

In "nuke world", it is verboten to say anything negative about what is being done to come up with something better fitting current paradigms. Consequently, since many of the USA's topmost decision makers - even its nuclear contingent – currently consider nuclear power to be a relatively minor part of "all of the above", any "new" reactor concept suitable for a special niche application is enthusiastically welcomed. For instance, a technically sophisticated insider's popular pro-nuke blogsite, recently posted a breathless description of the SLIMM concept - a "disposable"[469] 10 -100 MW(thermal energy – about half that much electrical) sodium-cooled, solid fueled, reactor that would be eminently safe & simple because it would not use pumps to move its coolant around (El-Genk & Palomino 2015). That brainstorm's downsides include:

- it is terribly inefficient both resource and cost wise – "small" in terms of energy output but large in terms of fuel, steel, labor, & build-cost expenditures.
- although its design is loosely based upon Argonne's liquid metal-cooled breeder reactors, it is terribly inefficient U fuel-wise

The heat energy generated before the "big" version of that thingy must be removed/replaced (5.8 full power years (fpy) at 100 MWt) corresponds to 1.8E+16 joules which would require ~223 kg worth of fission. If that represents 20% of its core's total HM (a rather high EBR II driver fuel burnup) that equates to ~1115 kg total U. Since its fuel is to be initially 17.75% ^{235}U that translates to using 198 kg of startup fissile to generate 223 kg's worth of heat, its fuel consumption is bigger/worse than that of an equally powerful conventional PWR.

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[469] It's "disposable" because when its fuel is burned up, it is to be removed and hauled off somewhere.

A headline in the February 19, 2020, *ANS Nuclear SmartBrief* provides another example of what DOE NE's priorities seem to be:

> "**Micro-reactor developer gains access to nuclear fuel supply**" (Wagner. 2020). |.
>
> "*Oklo will be given access to recovered fuel from nuclear waste at the Department of Energy's Idaho National Laboratory in order to develop its small, advanced, fission 1.5-megawatt AURORA reactor, which is designed to use metallic fuel. INL will downblend uranium recovered from used fuel to produce "high-assay, low-enriched uranium (HALEU)" for the project ".*

This California-based startup applied for access to the material through a competitive process that INL launched in 2019. Notifications of selection were made to applicants in December 2019. The goal is to accelerate deployment of commercially viable microreactors by providing developers with access to material needed to produce fuel for their reactors.

> "*We are excited to work with Oklo Inc. and support their needs related to fuel development and microreactor demonstration," said Dr. John Wagner, associate laboratory director for INL's Nuclear Science & Technology directorate. "As the nation's nuclear energy research laboratory, we are committed to working with private companies and others to develop the technologies that will provide clean energy to the world.*"

The reactor in question is an especially compact sodium cooled fast reactor that builds upon the USA's Experimental Breeder Reactor-II and space reactor legacy. Reactor heat is to be transported from its core to a supercritical CO_2 Brayton cycle turbine power plant using heat pipes functioning as thermal superconductors.

It's especially "safe" because it is to be sited underground and its tiny core contained within several layers, including a super robust disposal cask-like module.

It's also "safe" because it generates so little energy (~4 MW_{th}) that it will never contain enough, still-hot, fission products to cause a post-shutdown meltdown like those experienced at Fukushima and Three Mile Island.

Especially advanced micro/mini reactor concepts like these represent niche-fillers for small, cost-is-no-object, probably military facilities/vehicles, not the solution to humanity's big problems any more than do squirrel-cage powered treadmills.

Since any nuclear fuel cycle capable of "saving the world" must be capable of generating <u>at least</u> 20 TWe (~40 TW's worth of heat which would require ~400,000 SLIMMs or ~13 million AURORAs), it must be breeder-based (CR=>1) because it'd be fuel-limited otherwise.

Consequently, as far as our descendants' and environment's real issues are concerned, most of today's much-heralded toy reactor concepts represent distractions, not solutions.

Technically savvy pro-nuke journalists & bloggers should keep this in mind when reporting on the latest/greatest goings on in their bailiwick.

Of course, our nation's nuclear enthusiasts aren't the only energy experts deliberately confusing things for us. For example, Berkeley Lab's October 2021 update on the USA's solar industryutility-scale_solar_2021_technical_brief.pdf (lbl.gov) reports that its total solar "capacity" is still growing apace, its "levelized cost of energy" (LCOE - the cost relevant to wholesale, not retail, energy buyers in many regions) has dropped to (but is also asymptoting off) at only ~2.5 cents/kwh, & that adding battery back-up power capacity equivalent to a solar farm's power capacity roughly quadruples its power purchase agreement (PPA) energy value from ~5 cents/kWh to 20 cents/kWh.

In the solar power business's patois, "capacity" is the number of watts produced by new panels when the sky is clear and the sun directly overhead. Here in Iowa, a PV panel-based solar farm generates a year-round average power ~20% of its nominal "capacity" - much less during winters or any sort of darkish weather spell.

However, like most of the other government-sponsored sales pitches (Berkeley lab, NREL...,) made for renewable energy "farming", that report fails to distinguish between energy & power in characterizing any back up (storage) system that the facility may have.

I'm guessing that most of the grid scale batteries being installed these days are pretty much like the $66 million/100 MW/129 MWh (then "the world's biggest ") battery pack that TESLA installed in Australia in 2017. If so, a US solar farm's battery-backed up 20 cent/kWh power would only be backed up for about 80 minutes.

Night-times average twelve hours/day everywhere in the world and daytime skies often remain cloudy for over a week, especially during cold winters[470].

I called that report's lead author. He's a reasonable-sounding guy but I quickly learned what I'd expected to hear based upon my experience with DOE's nuclear-type energy experts.

He started off by explaining what they've (DOE's Berkeley Lab) been doing with respect to characterizing the size of grid-scale batteries in their reports which explanation I cut short because I'd already read his report and knew what it literally said.

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[470] Grid scale backup battery systems are generally designed to provide their nominal power capacity for from one-half to two hours - not overnight, days, weeks, or months.

He had no answer for "*why are you characterizing an energy storage source in terms of power?*" other than "*well, most of the time" they (*meaning whoever sends him their press releases*) are assuming four-hour storage*".

That's not how Tesla's engineers (but probably not its salesmen) rated South Australia's grid-scale battery pack- they "sized" it in terms of both its power (MW) and energy storage capacity (MWh).

It's important because a supplier's claim of having "4 hours-worth of backup batteries" is meaningless if he won't tell his listeners what that figure is based upon. For example, 60 MW-rated solar farm with a "4-hour battery pack" situated where the average annual solar insolation is ~4 kWh/m^2/day, actually supplies a year-round average of 60 MW*4/24 or 10 MW to its customers. My question to such a supplier would be, "when the sun goes down, how much energy can I rely upon getting from you when the clouds roll in ? 40,000 kWh or 240,000 kWh?

That question - so far unanswered – apparently requires "*proprietary*" information.

I stressed that most of this country's decision makers apparently don't know the difference between a Joule and a horsepower and that they're going along with decisions like what's been happening here in Iowa (its new v owners are proposing to "replace" their shut-down 600 MW nuclear power plant with a ~600 MW solar farm) based upon information written the way that his report was. That means written to mislead its most important readers - not a technical nerd like me. If that's happening in DOE's renewable-type energy labs as it apparently still is in DOE's nuclear-type energy labs, it's the wickedest problem that Mr. Biden's starry-eyed "green new dealers" are facing.

The people pushing DOE's still politically correct, pie-in-the sky, fusion power schemes tend to be especially devious.

A typical example showed up in my INBOX a few months ago (4/5/2022). A startup's press release (First Light achieves world first fusion result, proving unique new target technology | First Light Fusion) led me to its website which taught that FIRST LIGHT's super gun fired "a few mm in diameter" pellet into a magic (proprietary information) target that turned its kinetic energy into enough "squeeze" & heat to set off a fusion event that generated ~50 neutrons.

Other more "open" information sources indicate that each such event would release a total of 17.6 MeV & that there are 6.34E+18 eV/Joule.

If the pellet in question was 5 millimeters in diameter and had a density of 1, it would have taken at least 1381 J worth of energy to accelerate it to 6500 m/s.(½ mV^2)

Consequently, the ratio of energy produced/energy input by that particular fusion R&D breakthrough was… 1.02E-13 (50*1/6.34E+18*17.6E+6/1381 or ~one part in ten-trillion.

A more recent press release generated exciting-sounding buzz picked up by 24-hour news channels all around the world. The folks at LLNL's "National Ignition Facility" had apparently managed to just break-even energy-wise by firing its gigantic array of lasers at a tiny pellet of deuterium and tritium. Of course, its PR folks didn't mention that that result (laser energy in/fusion power out ≥1) didn't consider the energy required to charge up those lasers or that it'd take most of a full day to do it again. If/when they had done so they'd have to have admitted (again) that they'd only gotten about a 1% energy return on their investment (& ours too because taxpayers are paying for it)[471].

That's insufficiently more productive than INL's sodium bearing waste steam reformer has been to get me all hot & bothered. Maybe that's why I've never been asked to serve as the DOE's topmost honcho as was one of that fusion energy R&D breakthrough's witnesses.

In my opinion, a nuclear solution to the world's energy-related woes isn't apt to originate here in the USA because our "privatized" political & economic systems constitute too-wicked "barriers to science", chief among which is that some of our most prominent pro nukes have gotten into the habit of being devious themselves – not putting things into proper perspective or telling the whole truth about them.

A simple calculation will reveal that the one-pass liquid metal cooled reactor/heat storage concept described in Terrapower's "Program and Technology Overview" (Program and Technology Overview, a TerraPower and GE-Hitachi technology, Chris Levesque, President and

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[471] LLNL's NIF was never designed to use energy efficiently. The stated goals of the NIF are almost entirely thermonuclear weapons related. Here is a quote from their website. "*We use NIF's lasers for several specific missions, including Stockpile Stewardship, high energy density science, Discovery Science, energy security, and building future generations of scientists. And we're researching more types of applications, including advanced lasers and photonics, additive manufacturing, and missile defense*." After watching 15Jan2023's "60 Minutes'' news blurb about it, I've concluded that what LLNL's "first of its kind" experiment simply proved is that its approach to generating fusion power never will be practical. Its array of 192 lasers each of which is longer than a football field and takeabout a day to charge up for a single "shot" must be simultaneously fired at/ hit a single ~1 mm diameter perfectly spherical artificial black diamond "eggshell" containing a tiny speck of frozen tritium/deuterium "ice". Each such target pellet takes an average of about two days to fabricate & a reactor able to generate a genuinely relevant amount of power would have to consume about 50 of them per second. DOE's NIF also doesn't possess a way to turn a "successfully" exploded pellet's fusion energy into heat that could run some sort of electricity-generating turbine. To this old ex "site worker" it's no surprise that DOE's biggest-ever "controlled fusion energy" project has turned into just another make work, press release generating boondoggle that's wasted billions of tax dollars that should have been implementing a sustainable, fission-based, nuclear renaissance.

CEO, Robert Petroski, Ph.D., Natrium Plant Design Project Manager, Massachusetts Institute of Technology Department of Nuclear Science and Engineering, October 28, 2021) is less fuel (natural uranium) efficient than are CANDU reactors and therefore doesn't represent a solution to the world's woes unless it's reconfigured to operate as a full-blown breeder.

Natrium's reactor/heat storage coupling concept does make sense in today's electricity market (but not necessarily, the Future's) & I have no reason to suspect that the fuel change mentioned in its press releases wouldn't work as well as did the IFR's already-proven Na-bonded fuel.

However, it's currently being sold to what I suspect are technically unsophisticated people as if it were such a solution using little insider tricks like comparing different reactors' fuel consumption figures based only upon the uranium making it into their fuel rods, not 100% of that mined, processed, etc. to make that fuel. Those potential buyers want to be told that they don't have worry about doing anything that's controversial or expensive & also that they can also make lots of money doing electricity arbitrage. The salespersons championing such concepts are determined to do and say whatever they can to convince investors that they can make money with gadgetry (nuclear reactors) that Putin's attack on the Ukraine has suddenly rendered almost politically correct in some circles (Bates 2021).

That's the sort of selling/thinking that got that industry into the "Rickover trap"[472] (see Cowan 1990).

We've got to become willing to put everything into proper perspective and tell the whole truth and nothing but the truth.

Because the USA's decision makers insisted upon kicking the development of its own sustainable nuclear fuel cycle on down the road until it's "too late" and probably wouldn't even think of adopting or buying anything that the Russians already developed, the USA is almost surely going to build more solar and wind farms to tide its citizens over until their/our political leaders come to their senses. However, that must be done in a way that serves those citizens, not our for-hire modeling experts, renewables entrepreneurs, and quick-buck investors looking for another tax break.

I've told everyone who's invited me to become a member of their MSR nuclear startup team that being "sneaky" about what you are proposing to do is no longer apt to win hearts and minds (certainly not mine) because too many people have been snookered too many times by the

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[472] That is implementing a huge civilian nuclear power system with blown-up versions of the same reactors that make sense for powering cost-is-no-object nuclear submarines.

nuclear industry's spokespersons & experts[473]. That cultural foible is what finally made me decide not to align myself with any of them[474] - “protecting IP" is just another excuse for devious behavior and probable cause of eventual failure. The most important thing is to tell the truth about nuclear, put everything into perspective, and build an honest pro-nuclear movement worldwide around those truths. For pro-nukes to build credibility, they must tell the truth, the whole truth, and nothing but the truth, about both nuclear power and the reasons for using it. Part of doing so is to push back against those who exaggerate climate change, suck up to the renewable energy industry like a battered wife, or sell fairy tales about magical nuclear reactors and their fuel supplies.

The USA’s 2nd “war on Iraq” is an example of the consequences of devious behavior by some of the USA’s technical experts. In 2002, then Secretary of State Gen Colin Powell didn’t have his own CIA intelligence experts and had to seek advice from Mr. Bush’s experts about what to do about the threats posed by excessive Muslim zealotry. Being a good soldier though still unconvinced, he finally saluted his commander in chief and went along with his wishes to attack a country that didn’t harbor such threats. A mistake that he had made and subsequently admitted to because the USA’s intelligence community had become too submissive to the desires of its topmost bosses. Its top dogs weren’t using intelligence to inform their judgment; they were using it as part of a campaign to justify their judgments.

In 2008 Gen Powell finally broke with his party & long-time friend, John McCain, because it/he were behaving in the fashion that has since served to prevent the US federal government from working in the best interests of most of its people; i.e., making decisions guided by the principles (“greed is good” and beating your political opponents is of paramount importance) that have engendered the partisanship & polarization that’s rendered the USA’s government dysfunctional and our country less “important” than it used to be.

This explains why when Secretary of State Powell was asked how he would most like to be addressed, he answered ”General” not with any of the other titles that his other public service jobs had entitled him to.

APPENDICES XII & XIV detail specific examples of the consequences of devious behavior within the USA’s national laboratories. Both projects wasted billions of dollars and provided anti nukes with lots of undisputable facts to fight their battles with.

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473 “A high level executive who spent billions of dollars on two South Carolina nuclear plants that never generated a watt of power and deceived regulators about their progress, has just announced that he is now “ready” to go to prison” https://apnews.com/article/state-courts-columbia-south-carolina-courts (less important people don’t have much choice about such things).

474 I did some dry-lab work for three MSR startups a few years ago but backed out when it became apparent that their goals were inconsistent with those identified in this book’s introduction.

9.6 Cowardice

This characteristic has been responsible for most of the last two century's human misery up to and including two outright world wars. It's understandable but nevertheless inexcusable for people who are nominally working as public servants in government at all levels, educational institutions, or as journalists of a country that's as "free" as our leaders claim it to be.

Ninety years ago, the German people's unwillingness to first recognize that their new Fuhrer's policies were hurting their neighbors and then act accordingly is what eventually gave rise to Hitler's Third Reich responsible for the death of ~50 million people. The cowardice of Germany, France and Italy whose leaders have done little to bring Putin into line | Daily Mail Online

Eight years ago in spite of the fact that Mr. Putin was obviously responsible for the fact that Russian "separatists" had first illegally annexed the Crimea from Ukraine and then killed ~300 innocent people by shooting down a Malaysian air liner flying over it, the heads of the western alliance's foremost nations, Great Britain, France, Germany, and the USA refused to do anything that might risk their own peoples' living standards, their country's business interests, or their own chances of being reelected.   That's what's led to today's full-fledged war in the Ukraine.

Our (USA's) position was one of cowardice akin to that evinced by Great Britain up until Hitler . attacked Poland. Although notionally the leader of both the UN and NATO, Obama's administration was extremely reluctant to get involved. Although it/we belatedly imposed new and tougher economic sanctions, those measures were lame: after Putin annexed the Crimea, just two Russian banks, two energy companies and some arms manufacturers were hit with economic sanctions.

Consequently, everything quickly became business as usual for Putin and his kleptocrat cronies when only a few of them were subjected to those wrist slaps.

Economic sanctions hurt poor, not rich, people because the latter don't have to worry about "little" things like the cost of their food, home's heating gas, or that of the house itself.   As social scientists have known for more than a century, what they do care about is that beyond a subsistence level, people will fight harder for status than they do for money. I'm seeing that now (8Mar22) in the anti-war comments and peacemaking efforts of Russia's elites: after just a few days of the West's sanctions pressure, they're behaving exactly as sociologists would expect when a group accustomed to impunity is threatened . They're angry and they're anxious but their discomfort hasn't yet persuaded Putin to stop his rape of Ukraine. However, it's a reminder that the U.S., U.K., and EU can and should confront a system that allowed Russia's current "Fuhrer" to amass so much power in the first place.

Up until Putin's February 2022 reinvasion of the Ukraine, the USA's policy seems to have been to leave German chancellor Angela Merkel, to sort out the EU's problems with Mr. Putin who was therefore able to exploit her country's economic dependence on Russia (especially for its energy) and treat his international critics with derision.

Meanwhile, Germany and Italy were happily continuing to benefit from the cheap Russian gas backing up their new windmills and heating homes and factories. Of the total of ~125 billion cubic meters of gas exported to the EU each year, Germany consumed over 40 billion .

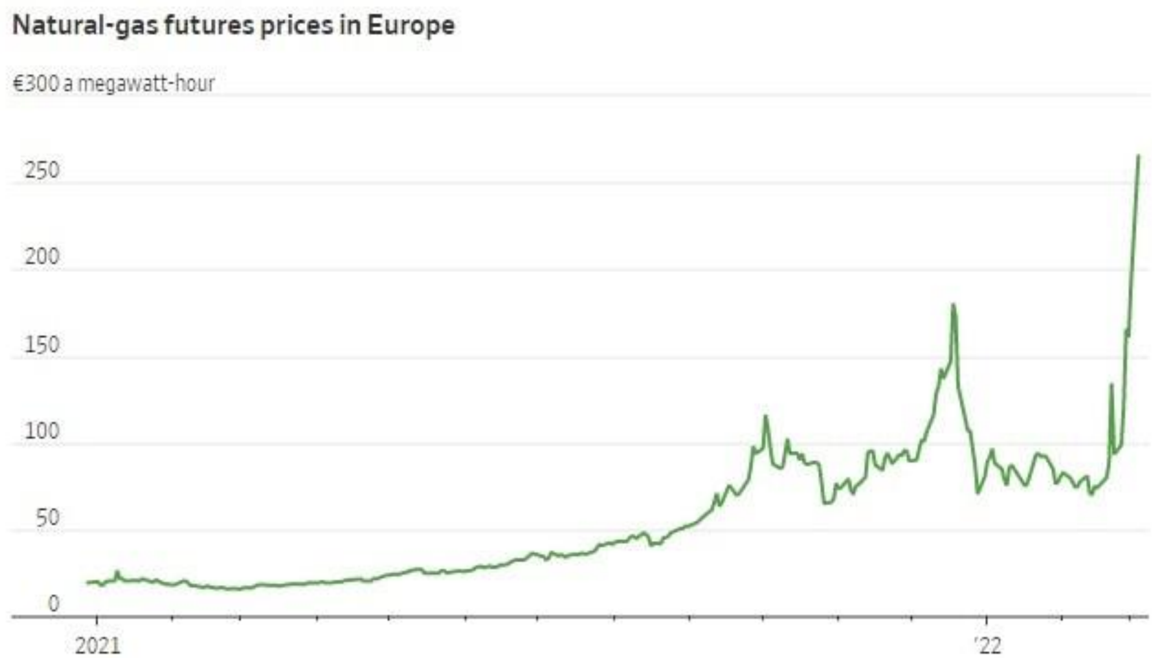

Figure 84 The consequences of the western world's energy policies.

The trade has been two-way. Germany exported 36 billion euros worth of goods to Russia last year.

The problem is that Angela Merkel knew that she could destabilize the Berlin-Moscow relationship only by discomforting her own country's most important people.

Although Germany's economy is strong relative to the rest of Europe's, it's been going through an extended period of low or no-growth because of over-evaluation of the euro and its much-heralded *Energiewende's* energy costs which had rendered its exports outside of the eurozone prohibitively expensive.

Mrs. Merkel's priority was to shore up the European Union rather than lead a principled collective international response to Russian aggression. Unfortunately, the fact that Mr. Trump had become POTUS rendered such a response almost impossible. That was unethical - Germany should have joined up with the rest of Europe and the USA to form a bulwark of

Western values including liberty and democracy, which of course means standing up to a totalitarian tyrant like Putin.

Because previous administrations had decided to "nuclearize" its power sector, France has a relatively small reliance on Russia's gas, but an increasing dependence on Russia's defense ministry to keep its armaments industry "healthy".

Putin's war and Xi's aggressive ambitions have ended the post-Cold War era and upended the global order of the past 70 years. The U.S. government must respond by reforming and strengthening our national security institutions, developing a sustainable clean energy strategy, and helping its citizens understand why events abroad matter to them.

Putin could have peacefully taken over most of Asia, Africa, South America, and Australia by simply flogging his country's "cheap" VVER-1200 reactors. His military invasion of Ukraine was a monumental error akin to Hitler's invasion of Poland. Continuing that invasion is an even bigger error.

The good thing about wars is that they have temporarily made the western world's decision makers think more realistically. Putin is doing climate change a favor by getting the world off fossil fuels at an accelerated pace. Putin is too Trump-like to realize that he's thrown away a fantastic business opportunity. That's the main problem with tyrants - they get the facts and physics all wrong and refuse to listen to people that do know such things. Let's hope the Ukrainians keep up their good fight. This war is not apt to end until either Putin runs out of "resources" or some genuinely patriotic Russian citizen decides to kill him[475].

I'm pretty sure that Russia will eventually lose this/his war: the real questions are when, how, what other countries will lose too, and what are we going to do then. That's why I still feel that we ought to make it abundantly clear to Russia's nuclear nomenklatura that they can "save' the world & redeem both themselves & their nation by selling us lots of big, cheap, sustainable-fuel-cycle nuclear reactors.

If Russian aggression is not contained, it's likely that hundreds of millions of people will pay for that failure with their lives. I applaud President Biden's policies with respect to Ukraine as advised and implemented by Lloyd Austin. They need all the support that they can get from the US public which includes stopping their belly aching about energy prices- it's now too late for "cheap" to work. Given the structure of the US economy it will take sustained high prices to

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[475] Here's another proposal that would get that war over with in a hurry: let's have the mayor of Kiev and the President of Russia fight it out like 'real men' in a MMA cage. The winner would be the guy that chucks the other's head out of the cage.

financially enable large scale deployment of sustainable nuclear power. Absent that large scale deployment, much of the world's human population will prematurely die due to the cumulative effects of climate change and conflict.

9.7 Bull/pigheadedness:

Once we humans decide to look at things a certain way (establish our personal "business model"), it's extremely difficult to change that paradigm even when it has become obvious to "outsiders" that it's not working[476]. The usual definition of bull headedness is "*determined in an obstinate and unthinking way.*"

The root causes of the Boeing 737 Max disasters and the US Federal Government's nuclear waste boondoggling, over-bureaucratization, refusal to address the genuinely "tough' issues responsible for its citizens' discontent, or prepare for anything beyond the next election funding cycle, demonstrates the same bullheadedness that led to both the Fukushima and Chernobyl nuclear "disasters" (Higgenbotham 2019) and the twentieth century's many orders-of-magnitude more impactful Great Depression and World Wars.

According to Statista.com, nuclear power is the safest of the world's clean, reliable electricity sources. In terms of deaths per kWh of electricity generated, nuclear power is 24 times safer than solar PV, 178 times safer than onshore wind, 850 times safer than offshore wind; 7,190 times safer than natural gas, 9,950 times safer than oil and 12,000 times safer than coal. Furthermore, its relatively low cost is evidenced by the fact that the world's eight largest low GHG power systems (France, Quebec, Ontario, Sweden, Norway, British Columbia, Paraguay, and Switzerland) all produce most of their power with some combination of nuclear and hydroelectric. Nevertheless, many people are convinced that a nuclear renaissance implemented with even safer reactors would be riskier than living with the consequences of trying to run a civilization that requires cheap reliable energy with expensive unreliable energy.

Where that renaissance might take us is beyond most of our imaginations. However, there would certainly be backlash. For example, most people including many "experts" do not comprehend the magnitude of the necessary changes[477]. Furthermore, nuclear power is scary to many of us

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[476] A firmly established management paradigm (business model) is more durable (impervious to change) than are most of DOE's radioactive waste forms except for some (not all) of INL's proposed (not actualized) hot isostatically pressed ceramic materials (D. D. Siemer, B. E. Scheetz, and Cliff Orcutt (of AIP), "Hot Isostatic Press (HIP) Vitrification of Radwaste Concretes", paper presented (by B. Scheetz) at NRC Vitrification Workshop, May 13, 1996, Washington, D. C.).

[477] For example, some look only at replacing a part of the energy utilized by homeowners, not the energy powering the civilization supporting both them & people that don't own their own homes.

because it's a form of energy that few understand but do “*know for sure*” could be terribly harmful.

Change is always tough for grownups to accept. Our great, great grandparents were probably saying…

“*Electricity? Are you kidding? That’s just like letting lightning into your home. I think that kerosene (whale oil?) lamps work just fine. Electricity is unnecessary. Can't it kill you? That deadly force - inside your home? We don't need this. Running those wires is costly too, and so damn expensive to build all that out*.”

It’s likely that when the use of fire was first considered by a tribe of our pre-sapient homo ancestors, some of them didn't want it. All they knew for sure is that they’d heard about how fire had destroyed a forest and that someone had been burned by infrared *radiation (*horrors*!*) when they had tried to “divert” some of it.

Here are some more examples.

9.7.1 “Middle class” politics

I’m living in a country that has become both less “important” and poorer than the one that I grew up in. There are many reasons for this, most of which have to do with the ways that we’ve chosen to look at the world and govern ourselves.

Here are some of the beliefs that a “good” American should never question:

- The USA is the greatest country ever in every respect.
- Everything in the US Constitution is perfect – don’t change anything!
- Ditto with respect to whatever is in the sacred book that your personal spiritual leader lectures you from
- All American citizens possess sacred rights; e.g., the right to “bear arms” and “tweet” blatant lies) that no government can take away from them.
- Corporations are “people” & therefore possess the same right to bribe politicians that the rest of us have (but of course, possess more “resources” to do it with)
- Selfishness is good – it is “natural” to profiteer during national disasters[478], let your neighbors remain “food insecure”, and grab up everything you can including public lands/waters & post No Trespassing signs & guards around them.

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[478]For instance, although it had similarly failed in 1989 and 2011 (FERC/NERC 2020), ERCOT’s February 2021 collapse was caused by the fact that Texas’s government, its electricity suppliers, and their regulators failed to winterize its mostly natural gas-powered grid or admit that its US-biggest wind power “capacity” cannot be relied upon. A few unimportant-enough people (current tabulations put the number at ~200) died and many billions of dollars’ worth of damage was done but the electricity suppliers that did manage to stay online made out like bandits

- Foreigners, socialists, commies, tree huggers, unwed mothers, wetbacks, gays, and "socialists" like Nancy Pelosi and Joe Biden are responsible for all of the national problems that we choose to notice.

We think of the United States as No. 1 in everything, but the UN's Social Progress Index ranks us no. 28 worldwide and one of only three countries to have gone backward since that index began a decade ago https://www.socialprogress.org/ .

Americans are less likely to graduate from high school, more likely to die young, less safe from violence, and less able to drink clean water than the citizens of many other advanced countries. Covid-19 has magnified those disparities.

I'm one of the last offspring of the USA's "greatest generation" (born 1945) many of whom eventually became "rich" because our parents were both fortunate and smart enough to choose people like Franklin D. Roosevelt & Harry Truman to lead them out of the Great Depression & world war engendered by the attitudes still exhibited by some of our world's leaders. Yet for the last half-century, we have mostly retreated, over investing in prisons and tax breaks for billionaires while under investing in public infrastructure, education, public health and the working people being left behind due to policy-driven "off sourcing". Between 1979 and 2017 the nation's productivity[479] grew six times faster than did its peoples' total hourly wages while the earnings of its elite top "0.1 percent" grew fifteen times faster than did those of its bottom 90 percent's.

Several decades ago, the USA became a "consumers' paradise" for almost everyone. That's no longer the case for many of its "millennials" and their successors. because there's now less competition, more oligopolies, & higher prices than China's people pay for their educations, homes, medicine[480], health care, airline tickets, internet access, cell phone fees etc. Corporate lobbyists and political campaign contribution rule changes (e.g., "Citizens United") have

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for the better part of a week being paid 100x their average wholesale rate (up to $9/kWh). Such profiteering translates to another ~$25-30 billion worth of damage as far as Texas's citizens are concerned.

[479] Productivity ≡ growth of output of goods and services less depreciation per hour worked.

[480][Adam Ruins the Hospital | truTV.com]() shows why the USA's health care system has become ineffective, unaffordable. and unfair. For example, each hospital or chain of them has a secret "chargemaster" featuring unrealistically high prices. However, actual billing charges depend upon where the money is to come from. Big insurance companies & Medicare (their real customers) demand/get discounts but the uninsured or anyone that's otherwise "out of network" gets charged its "chargemaster's" figures, e.g. $38 for a Tylenol tablet or $33,000 for an Xray) . The absence of effective governmental oversight financially benefits that system's "providers" (physicians, drug/equipment suppliers, hospitals & insurers) – not its consumers. Adam also points out that the reckless prescription of antibiotics is rendering them worthless.

succeeded in earning huge profits for the USA's uppermost class by enabling powerful business interests to not pay taxes and reduce their companies' labor and R&D costs.

Currently one in seven US households including ~12 million children - report that they do not have enough food because they can't afford those things that its "food sector's" leadership or their government are willing to provide[481].

During the run-up to the 2016 Presidential election, the USA's less conservative political party appeared to be ignoring the USA's working class because it didn't tell them what they wanted to hear. Its candidates lost that election because many (not all) "normal" people prefer hearing comforting lies to uncomfortable truths & vote accordingly.

An example would be the folks in the USA's "coal country". Like many of its working people, coal miners are indeed suffering financial worries that the political left didn't ignore. Presidential candidate Hillary Clinton proposed a $30 billion program that would shore up coal pension funds in failing coal companies, offer free job training to prepare their workers to move into other fields, and support coal plant modernization to make them cleaner and more efficient.

In other words, she basically said, "*Coal has almost run its course ", "you can't just keep doing what you're doing*", and "*I'll help you do something else.*"

Many people do not want to hear things like that (too much change). They would rather hear about how phony "environmentalist'" anti-coal arguments are & how great their futures would be under Mr. Trump's new administration. Now five years later (towards the end October 28, 2021) nothing's changed - Before flying off to Rome for a week of international summitry this week, the USA's new President, Joe Biden, began the day by telling his closest allies on Capitol Hill that nothing less than the fate of his Administration hung in the balance. "*I don't think it's hyperbole to say that the House and Senate majorities and my Presidency will be determined by what happens in the next week,"* he told a closed-door meeting of House Democrats. The White House had just unveiled what it said was a much-compromised "framework" agreement for a $1.75-trillion, decade-long, budget bill packed with big-ticket social spending on everything from universal pre-K to addressing the root causes of climate change. It was time, Biden insisted, to vote. Democrats gave him a standing ovation. What was not clear was whether and when they would give him the vote. No matter how urgent a looming technical issue happens to be, there's always somebody in the USA's form of government (this time around it's one of West Virginia's

[481] For instance, at the retail level it's almost impossible to purchase reasonably priced (not over twice what the farmers got) no-value-added edibles like raw potatoes, corn, carrots, tomatoes, wheat, rice, apples, soybeans, peanuts, etc.. That's no accident – consumers who have already consumed fifteen cents (2600 kcal) worth of such "whole foods" aren't nearly t as likely to buy $15 (2600 kcal's worth) of the USA's "confined animal feeding operation"- produced beef.

Senators) both willing and able to stifle any proposal that might challenge his constituents' belief that they shouldn't have to change their personal "business models").

The United States is on the verge of another massive, history-rewriting failure because Senator Joe Manchin, the Democrats' linchpin vote refuses to vote for President Biden's "Build Back Better Act", the vehicle for most of his legislative climate policy. This means that the world is now all but guaranteed to warm by over 1.5 degrees Celsius above its mean preindustrial temperature by 2040 and that the United States will all but surrender its climate relevant technological advantages to China thereby further subsidize the latter's industrial supremacy.

From a technical point of view, most of the USA's working class's precarity issues are a consequence of its both "deregulated" and privatized supply-and-demand based economic system. Humanity's clever inventions haven't steadily bettered everyone's' lives. Progress has instead moved in fits and starts - much more rapidly at some times than others and has often stopped or even regressed[482]. There was virtually no improvement in living standards for millennia up until about 1770, only slow growth during the following century, remarkably rapid growth up until about 1970, and relatively slow progress since then except in China[483]. The reason for this is that some inventions are more important than others and the last century's most significant lifestyle advances were due to a cluster of "Great Inventions" invented and/or implemented by people like Andrew Carnegie, George Westinghouse, Nikola Tesla, Thomas Edison, Albert Einstein, Marie Curie, and Alvin Weinberg all of who's contributions had something to do with energy.

Technological growth here in the West since circa 1970 has been superficially dazzling but disappointing because our advances since then mostly have to do with entertainment, communications, marketing, and the collection/processing of information. For those things that most of us really need or care about—food, clothing, shelter (especially), transportation, health, good working conditions both inside and outside of the home, and personal security for ourselves and our children —progress has since slowed to a trickle or reversed direction both qualitatively and quantitatively[484].

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[482] One of the best-ever "science" writers, Harvard Professor Stephen Jay Gould, got his scientific chops circa 1972 by co-publishing his conclusion that biological evolution (progress?) behaves the same way, i.e., not steadily but via "punctuated equilibrium".

[483] For example, would you rather fly off to visit grandma in today's or 1970's jet airliner? I'm old enough to remember champaign flights, free luggage, & plenty of butt/legroom in planes that flew as fast as today's do.

[484] However, I must admit that most of my own nerdy retirement hobbies would be almost impossible without three post-1970 technical innovations: Bill Gate's easily understandable and readily available computer software, Larry Page and Sergey Brin's GOOGLE, & Sir Tim Berners-Lee's World Wide Web ("internet").

It's become especially bad/difficult/discouraging for older folks because inflation harms their retirement prospects and employers don't want to keep them on. COVID-19 exacerbated that trend, as millions of them disproportionately lost their jobs.

This is one of the worst times to be a worker in the twilight of a career. Only half of Americans are steadily employed throughout their 50s and during 2021 over a quarter of workers aged 55 to 59 were out of the workforce meaning that they didn't have jobs to retire from.

Across the globe, full-time, stable employment that culminated in a pension has become a relic of the past. In the United States, in light a surge in inflation and uncertain retirement savings a steadily increasing number of workers can't afford to retire. A worker must now wait to age 70 to collect maximum Social Security benefits, and Congress is expected to discuss raising the age for Social Security eligibility again next year

A common measure of genuine progress is the rate at which a nation's output grows relative to its labor and capital inputs. In the USA during the last half century, those figures grew about one third as quickly as they had between 1920 and 1970. The reasons for this were policy changes that steadily directed an ever-larger proportion of its economy's benefits to the "elites" at the top of its pecking orders (Gorden 2016).

All the technologies that today's topmost billionaires' "space teams" have developed are scalable[485] and relatively affordable which has rendered the cost of getting stuff into space cheaper now than it was with NASA's government (politically) designed space shuttles[486].

As the supply of cheap immigrant labor went up and more women entered the workforce (effectively doubling the labor pool) while outsourcing and automation reduced the demand for low tech-type labor[487], what « unconnected » individual employees got paid for their efforts were well below what they had come to expect.

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[485] Bezos' sub orbital "Blue Horizon" tourist-type spaceship would be just the second stage of his "big" one

[486] After the USA abandoned its even more costly space shuttle program, its taxpayers were paying Russia ~$90 million per seat to fly its cosmonauts up to the international space station. No country is rich enough to indefinitely do things that grossly inefficiently. As of 2021 the USA can apparently purchase seats on Mr. Musk's Space X rockets for "only" about $55 million.

[487] . In my opinion it is nonsensical for the USA's rule- to encourage its businessmen to replace yet more of the USA's working class's (e.g., truck drivers) worthwhile, interesting, & often tough/complex jobs with expensive machines (AI). The reason that it's apt to happen is that even ridiculously expensive machines are cheaper for a trucking, etc. company than is paying for the "benefits" (health care, education, retirement pension, etc.) that its employees should be receiving from their government.

While this was happening, incessant advertising, multi-income families, too-easy credit, “privatized” health care, and population growth were increasing demand for consumer goods, housing, land, and new high-and not-so-high-end unregulated-but-necessary services (e.g., internet access and retail-level natural gas distribution) driving up their costs.

There , was also an “everyone must go to college” push that that combined with more too-easy credit (student loans) drove up its cost due to increased demand while the resulting oversupply devalued college degrees.[488], especially PhDs.

Those trends depressed real wages for *almost* everyone.

Many “important” people do not want to hear things like this because they’re in the uberclass benefitting from those trends. Consequently, they buy up newspapers, magazines, and TV networks and put people in charge of them that will keep a lid on such information while titillating us with tabloid-style journalism (*what is Stormy Daniels doing these days?*) and breathless reports about political mudwrestling contestants’ latest outrages.

Consequently, when Mr. Trump told the USA’s electorate that with the help of his party’s other leaders, he could quickly make America great again by undoing everything that Mr. Obama had set out to accomplish, they decided to don their shiny new MAGA hats & vote their feelings.

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[488] Unfortunately, the USA’s higher education institutions have apparently adopted the same business practices that have rendered its “health care system" prohibitively expensive (Kristoff 2018). One of the “symptoms “ responsible for this country going down the toilet is that its universities are free to “privatize” their technical-type course content and the information supporting it. Another example is that, despite growing online markets for steeply discounted other-type books, the cost of college textbooks has been rising much faster than the official inflation rate. Book inflation has recently caused 65 percent of US college students to skip buying required texts because they couldn’t afford them. Currently, the main culprit is that today’s “virtual” textbooks are usually bundled with access codes that expire at the end of the semester. This forces students to buy them at retail prices at the campus bookstore and renders them worthless for resale. Class materials used to be hard-backed books which in fact have become very much cheaper to print than they were fifty years ago (e.g., the big, beautifully illustrated, “coffee table” books on big box bookstore bargain tables). “*All of the materials that a student needs to participate in a class are increasingly put behind paywalls that you get to through a unique log-in that will expire at the end of the semester*," said Kaitlyn Vitez, higher education advocate for U.S. Public Interest Research Group. "*Students might have been able to resell textbooks in the past, but now because of expired access codes, their “used” books are worthless.*"(Kristoff 2018) APPENDIX XXXIII lists more of the good things that might come out of the ongoing COVID-19 pandemic. In the USA, the huge financial burden that anyone seeking to become a physician must assume (typically $400,000) prevents many of its young people from becoming physicians. Consequently, about 30 percent of its practicing physicians were recruited from other countries, ~7 percent of whom are still not U.S. citizens.

Some of them (especially southern-border produce/fruit farmers) might be beginning to realize that that might not have been a wise thing to do. The others, probably the majority, are apt to double down at the next election unless the "Trump recession" (the big one) sets in before then [489].

A few years ago, Rick Shenkman wrote a "disturbing" little book, "*Just How Stupid Are We? Facing the Truth About the American Voter*", that identifies the reasons why we often elect people like Benito Mussolini, Adolph Hitler, Jair Bolsonaro, and Donald Trump to lead us (Shenkman 2008). It is as painfully accurate and flattering about the USA's institutions, beliefs, and behavior as was Mark Twain's "Letters from the Earth" but not quite so funny because it's now about us, not our great, great, grandparents[490].

"I will say that I'm not surprised that somebody like Trump could get traction in our political life. He's a symptom as much as an accelerant. But if we were going to have a right-wing populist in this country, I would have expected somebody a little more appealing."

Barack Obama

Now over a year after Mr. Trump had been impeached twice and overwhelmingly lost his reelection bid in both the popular and electoral college arenas, over 50% of his fellow party members still refuse to believe it and their leaders everywhere are doing their darndest to disenfranchise enough of the other party's voters during the next election to regain power & eventually return their hero to the White house. Meanwhile, as they did with President Obama, they continue to do whatever they can to prevent Mr. Biden's United States from getting anything constructive done[491].

9.7.2 Anti-nuclear "environmentalists"

[489] When I first wrote this section, I had no idea that "Mr. Trump's recession" would be kicked off the way that it was (his/our government's response to a relatively mild Spanish flu-like pandemic) – only that something like it was inevitable. Currently (19Jul2021) that recession manifests itself as a huge uptick in living costs (food, cars, energy, building materials, housing etc.) unmatched by the "working class's" wage & benefit increases.

[490] As one reviewer put it -"with wit, passion and devastating evidence, Shenkman compels us, the praised and petted 'American people,' to look in the mirror for an explanation of why our elections are travesties of informed, intelligent debate. Lively and crucial, the book reminds us, however we vote, that there's no such animal as 'democracy for dummies.'"

[491] The USA has lost preeminence because it no longer behaves like it's "serious" about addressing many of the issues confronting both its own people and the rest of the world 's An Unserious Country (theatlantic.com). .

"Ideological certainty easily degenerates into insistence upon ignorance" Senator Daniel Patrick Moynihan

Reflexively antinuclear environmentalists are especially bull/pigheaded[492]. The real-world limitations of wind, solar, and even hydropower[493] that most of them refuse to recognize means that every time they vote/rail against nuclear power, they inevitably vote for the fossil fuel industry, especially oil and gas fracking. It's likely that those fuels' champions are delighted since they know that for the foreseeable future, the only thing that can replace nuclear power plants shut down by their activism are new coal (in Germany) and natural gas-fired plants almost everywhere else.

Since "No Nukes" became a signature cause of the Green movement in the 1970's, sympathy to nuclear power signified treason to many of its members demanding immediate action on global warming. Consequently, they are as close-minded about such solutions as are the `climate deniers & "beautiful clean coal" believers.

"350.org only speaks, never listens"

Robert Hargraves

Today's rabid antinukes are much like the people who decades ago were "enraged" about the environmental effects of the "green revolution" that has made it possible to feed about 90% of today's ~7.7 billion people reasonably well. Professor Borlaug dismissed their concerns with the following:

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[492]Paul Ehrlich, one of the environmental movement's most influential misery-mongers famously opined that giving cheap, abundant energy to humanity would be like "*giving an idiot child a machine gun*". Today's idiot children, some of whom are almost my age and recently held our nation's highest elected office, are threatening other countries with "smart" fossil-fueled drones capable of delivering "his" especially small and modular (mini/micro) nuclear weapons. In an unusually honest opinion piece, Rutgers Anthropology Professor David McDermott Hughes recently confirmed something that I've suspected for years: many mainstream environmentalists don't just want us to transition to "green energy," they want to put us on energy rationing for the good of the planet. They've apparently also decided that we should add intermittent fasting to that diet because the developed world's electricity has become too reliable for our own good! To him, "*For those seriously concerned about climate change, the inverse—the demand for electrical continuity—may be the real problem."* In other words, our desire to have electricity available 24/7 is causing a global climate catastrophe, and we should learn to live like Mogadishu's, Lebanon's, Zimbabwe's, and Puerto Rico's happy campers do now. http://bostonreview.net/science-nature/david-mcdermott-hughes-save-climate-give-demand-constant-electricity .

[493] One of the assumptions underlying Jacobsen et al's 100% WWS (Wind Water & Solar) magic energy scheme is that hydroelectric dams (their proposal's primary backup "batteries") could temporarily provide well over an order of magnitude more electricity than they could. The main problem with that assertion is that existing hydroelectric dam sites aren't big enough to accommodate an order of magnitude more power houses/turbines. Another is that the so-required sudden massive water releases would flood anything down stream of them.

"some of the environmental lobbyists of the Western nations are the salt of the earth, but many of them are elitists. They've never experienced the physical sensation of hunger. They do their lobbying from comfortable office suites in Washington or Brussels...If they lived just one month amid the misery of the developing world, as I have for fifty years, they'd be crying out for tractors and fertilizer and irrigation canals and outraged that fashionable elitists back home were trying to deny them these things."

Here's a solution to an especially timely issue (5April22) that's causing lots of handwringing. Vladimir Putin had obviously decided that he could get away with attacking the Ukraine again because 1) he'd gotten away almost scot-free with every other atrocity he's committed, and 2) his EU & NATO enemies had allowed themselves to become dependent upon Russia for their fuel supplies - both nuclear & fossil. The US had gone along with just about everything its allies did, recently backed out of its war with Afghanistan's Muslim zealots, & had also let itself become dependent upon Russian owned/controlled nuclear reactor fuel suppliers for ~18% of its electricity .

That craziness must stop along with most of the other energy related boondoggling currently going on here in the Western World.

I've shown elsewhere in my book that the USA could totally and "cleanly" power itself with about 2000 GWe's worth of breeder reactor-generated nuclear power.

One example of the sorts of "handwringing" that its anti-nukes make about nuclear power is that the USA doesn't actually mine much uranium and if it/we were to do so, thousands of acres of its beautiful western desert wilderness would have to ripped up & raped to fuel such a huge new reactor fleet.

Here's a ballpark calculation showing how nonsensical arguments like that are.

The USA's accumulation of spent LWR fuel is now ~85000 metric tonnes. If we reasonably assume that on the average, it was originally enriched from 0.7 to 4% ^{235}U, that means that there is (4-0.7)/0.7 =4.7 times as much "depleted" uranium (DU) sitting around somewhere in this county.

Since spent LWR fuel is about 96% uranium, the USA's already-mined and readily available breeder-type reactor fuel resource is now (4.7*85000+.96*85000) or 482,000 tonnes.

Assuming 40% thermal-to-electricity conversion, one GWe-years's worth of closed fuel cycle (breeder) power consumes about 1 tonne of uranium.

Consequently, if our country's leaders were to implement that sort of "Green New Deal", the USA could totally power itself for 241 years without having to mine/process/rape any "virgin" dirt anywhere. They could also stifle their constituents' handwringing about windmill-related bat/bird kills, their neighborhood's ugly & unreliable solar panel infestations, the host of evils associated with natural gas/oil fracking, and the threats posed by Mother Nature's inevitable "polar vortices".

Keith Rodan of Change.org change@e.change.org recently provided us with another example of radiation scare mongering. He/it is petitioning NY's Governor, the EPA, and God knows who else to end Marcellus Shale fracking because it "raises dangerous radon levels". That's true in the same sense as is your taking a "leak" while swimming off Malibu beach increases a San Franciscan's risk of being flooded by the Pacific Ocean. Its purpose is to frighten, not inform his listeners. All radon isotopes possess short half-lives meaning that natural gas pulled up and out of the rocks containing the Th & U from which they are derived and then pumped into homes, factories, etc. considerably later is unlikely to contain meaningful concentrations of any of them. Unfortunately, like those of many other elements, its radioisotopes are easy to detect[494] which fact provides scare mongers like Mr. Rodan with plenty of cheap ammo to fire at the rest of us.

I'm not gung-ho about fracking either but radon pollution is not the reason.

Here's another example just offered up by Alex Cannara.

A few years ago, a lawsuit was engaged by a Californian homeowner who wanted to install rooftop PV. Since his neighbor's trees were shading his roof for much of each day, he sued to have them cut back.

The court said that "*those trees weren't his and not an endangerment, so stifle*" .

This squabble sparked a brouhaha among the Californian 'environmentalists' claiming that PV was green and those holding that trees were even greener.

After lots of costly legal wrangling, much wringing of greenish-tinged hands, and rending of sloganed-up T-shirts on both sides of that issue, a law was passed giving precedence to trees over PV panels. The reason for it being that in that long ago pre-Trumpian era, science had more influence in policy-setting: in bright sunlight, a mature broadleaf tree is a ~50kW evaporative cooling machine while a 50kW PV system dumps ~200kW of waste heat into is surroundings [495]. By that time that case's judge had become aware that California's summer weather had already become too hot.

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[494] The reason for this is that the relevant, relatively long-lived (3.8 day) isotope (^{222}Rn) is an energetic alpha emitter which means that its radiation is especially easy to detect.

[495] Solar panels are "black holes" as far as solar radiation absorption is concerned. ~20% of it is converted to electricity & the rest (~80%) heats the air surrounding them. As this is being written (2Sep2022) California's electric grid managers are mandating brownouts because everything that its system (CASIO) can supply must go to powering air conditioners - hundreds of people are dying due to overheating.

However, arguments based upon observables like these usually don't affect firmly established mindsets. As these words are being written (20Aug21 see https://theferret.scot/were-barred-from-COP26-nuclear-industry-complains/) the World Nuclear Association's applications for exhibit space at the upcoming COP 26 climate summit in Glasgow were all rejected because some of that conference's decision makers contend that the nuclear industry should have "*no place*" there[496].

Pig headed attitudes/actions like these often make "environmentalists" look so silly that some people feel that nothing they say can be believed.

Here's my most up-voted QUORA answer. The question addressed was "**Why are Hiroshima and Nagasaki no longer radioactive when Chernobyl is going to be unlivable for many years to come? Wouldn't the fallout continue to contaminate the two cities?"**

"Let's begin this with a quote from a genuine environmentalist, James Lovelock[497].

"A television interviewer once asked me, "But what about nuclear waste? Will it not poison the whole biosphere and persist for millions of years?" I knew this to be a nightmare fantasy wholly without substance in the real world... One of the striking things about places heavily contaminated by radioactive nuclides is the richness of their wildlife. This is true of the land around Chernobyl, the bomb test sites of the Pacific, and areas near the United States' Savannah River nuclear weapons plant of the Second World War. Wild plants and animals do not perceive radiation as dangerous, and any slight reduction it may cause in their lifespans is far less a hazard than is the presence of people and their pets... I find it sad, but all too human, that there are vast bureaucracies concerned about nuclear waste, huge organizations devoted to decommissioning power stations, but nothing comparable to deal with that truly malign waste, carbon dioxide."

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[496] **Friends of the Earth Scotland** contended that "Having failed with the ridiculous claim that nuclear is cheap, the latest wheeze from the nuclear industry is to tell us that nuclear reactors are the answer to climate change. [Their] disastrous history of cost and time overruns show very clearly that what they offer would be too little, too expensive, and far too late. With renewables and energy efficiency cheaper and quicker to build and run than nuclear, they have already lost this argument and should have no place to spout their lies at COP26."

[497]James Ephraim Lovelock, CH CBE FRS was a very senior (born 26 July 1919 died 26July 2022) and very independent research chemist, environmentalist, and futurist best known for proposing the Gaia hypothesis. That hypothesis postulates that the Earth's organisms interact with their inorganic surroundings to form a synergistic, self-regulating, system serving to maintain and perpetuate the conditions necessary for life. His best-known book, ***Gaia's Revenge***, points out how mankind is defeating that system. He was also considered a turncoat to the environmental movement because he championed nuclear power.

Dr. Lovelock's point was that the real reason that the area around Chernobyl remains uninhabited (by people that is – there's lots of wildlife) is due to the way that we humans currently respond to any sort of nuclear "issue"[498]*. It's a lot like we used to act back in the seventeenth century when told that someone was a witch - like frightened chickens*[499]*.*

Anyway, in principle there was indeed far more radioactive stuff "released" by the Chernobyl screwup than was by the Hiroshima bomb. The fission reactions taking place within Chernobyl's RBMK 1000 reactor generated about 3.2 GWt meaning that if it had been running for one year, its core would have had a year's worth of fission products within it (about 1.2 metric tonnes) some of the more volatile fractions of which were scattered around when the thing blew up and then caught fire (most of its FP were retained by whatever's left of its core region). The 13 kt Hiroshima bomb's energy output corresponds to just 660 grams of FP. However, 100% of it was gasified and scattered everywhere immediately around, under, and downwind of that blast. Back in those days Japanese decision makers were more reasonable than they are now so Hiroshima's survivors quickly moved back in and rebuilt their city, kinda like the wildlife did around Chernobyl.

As did I, Dr. Lovelock started out his professional career as an analytical researcher endeavoring to push the detection limits for toxic substances ever lower[500]. His signature invention, the electron-capture gas chromatograph detector, permitted the measurement of refrigerant-type chlorocarbon gases in the stratosphere – a feat resulting in the policy changes constituting the single greatest success of the modern environmental movement - "*closing the ozone hole*". However, it also enabled the detection of chlorinated pesticides in foods, water, etc. at levels far lower than could possibly hurt anyone or anything. The human nature-driven consequences of the resulting policy changes plus his opinions about nuclear power eventually caused him to break ranks with most of the people spearheading the world's environmental movements (Lovelock 2006)

"The first thing we do is kill all the lawyers" — William Shakespeare

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[498] For instance, a few months ago (8Jan2021) after a student who had gotten a Geiger counter as a Christmas present displayed a piece of antique Fiestaware featuring a uranium oxide-containing glaze during science class, a team of police, fire and HAZMAT officials evacuated that high school and ransacked the student's home https://www.nj.com/camden/2021/01/nj-teens-science-project-forces-evacuation-of-high-school.html .

[499] https://www.youtube.com/watch?v=zrzMhU_4m-g (the "witch hunt" scene in Monty Python's "Holy Grail") does a fine job of describing how "low information" people behave when told that something or someone might be evil.

[500] I used to be a well-regarded atomic spectroscopist during the 1970s-80s.

The anti-nuclear campaigns of these sorts of “environmentalists” have been facilitated by the same “activist-legal complex,” responsible for scoring multibillion-dollar verdicts against some of the world’s biggest companies and therefore one of the USA’s most lucrative white-collar “service industries”.

Those activists, claiming that the food we eat, the water we drink, the air we breathe, and the high-tech products we use are all secretly killing us, are partners in that alliance.

Environmentalism’s Malthusian origins began with expressions of concern about improving the “mass’s” living conditions but then shifted towards a romantic longing to return everyone to an imaginary pre-industrial “natural” Eden. Energy enabled infrastructure improvements including flood control systems, weather prediction, sanitary systems, and healthcare have greatly extended human lifespans and reduced weather-extreme mortality rates ~100 fold. Those changes demonstrate the need for more, not less industrialization of those undeveloped countries most threatened by anthropogenic climate change.

The Limits to Growth (***LTG***) is a 1972 report about the consequences of exponential economic and population growth with a finite supply of resources (Meadows et all 1972) . Commissioned by the Club of Rome, that study’s findings were first presented at international gatherings in Moscow and Rio de Janeiro in the summer of 1971. The report's authors represented a team of 17 researchers[501].

Their report concluded that, without substantial changes in resource consumption, "*the most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity*". Although its methods and premises were challenged upon its publication,

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[501] That “club” was founded in 1969 to convince policymakers that the world has too many people. Reports from it and affiliated think tanks opined that science and technology could not alleviate “overpopulation” and that, in any case, the technologies required to support them would have too many negative consequences. The passage of the National Environmental Policy Act that year deemed the effects that economic projects would have upon plants, insects, and animals more important than how they would benefit human beings. The 1973 Middle East War and ensuing manipulated “oil crisis,” threw energy policy and planning into turmoil. Overnight, oil prices quadrupled, and coal—until then the mainstay of electricity generation—also rose in price. Under his Project Independence program, President Richard Nixon called for the building of 1,000 nuclear reactors by the year 2000 to increase domestic energy supplies. But Nixon was soon out of office, and his own Administration’s anti-nukes had already planned the demise of nuclear energy. Within days of becoming the head of the Atomic Energy Commission in 1971, James Schlesinger who had come to Washington from the RAND Corporation, overturned a critical AEC decision by allowing the Natural Resources Defense Council to “intervene” via lawsuits to stop the construction of the Calvert Cliffs nuclear plant in southern Maryland. His rationale was that the plant would damage the environment. This laid the basis for several decades of legal maneuvering by environmentalists to keep wannabe nuclear utilities tied up in court with bogus environmental and safety concerns which rendered the completion of many of their already-started plants impossible. With the election of Jimmy Carter as President in 1976, anti-nuclear, pro-environmental policy was brought right into the center of White House.

subsequent work continued to confirm that insufficient changes have been made since 1972 to significantly alter their nature.

Since 1972, 30 million copies of that book in many different languages have been purchased. It continues to generate debate and has been followed by several subsequent publications: *Beyond the Limits and The Limits to Growth: The 30-Year Update* were published in 1992 and 2004 respectively, and in 2012, a 40-year forecast written by one of the book's original authors, was published as "*2052: A Global Forecast for the Next Forty Years (*Randers 2012).

The USA's "activist-legal complex"(another of its lucrative service industries) deliberately perverts scientific uncertainty (which uncertainty is a good and necessary attitude for real scientists) to serve their own selfish purposes by magnifying hypothetical risks and downplaying relevant factors such as exposure/dose levels. They exploit today's widespread misunderstanding of science and hatred of "corporations"& the experts working for them – especially those that manufacture chemicals, drugs, and numerous other consumer products – to instill fear into the public.

Its other partner is a legal services industry that employs activist scaremongering to win jackpot verdicts. Its practitioners identify sympathetic-looking patients suffering from cancer or another common disease and blame their maladies on an institution with especially deep pockets. They vie with the USA's political-service and insurance industries for television commercial time slots to recruit more "victims" for their inevitable class-action lawsuits.

Their formula works nearly every time resulting in another big pot of money for the lawyers and lawyer wannabes. That's how the activist-legal complex recently won a $4.7 billion lawsuit against Johnson & Johnson's baby powder for causing ovarian cancer and a $2 billion lawsuit (subsequently reduced to a mere $87 million) against Monsanto's glyphosate for "causing" non-Hodgkin's lymphoma. There is no credible scientific evidence to support either verdict but that does not matter much in a legal system that allows a litigant's lawyers to pick his jurors (Berezow and Bloom 2019).

Excessive legal costs are one of the reasons that many US manufacturing industries were driven offshore. One of its effects is that the USA's "war powers act" no longer serves its purpose. First, most of the time a shortage of anything is because the supply chain for one or more of its components ends in China (in practice, the term "supply chain" has become a code phrase for "China"). China's leaders, like those of any competent government have an "my country first" policy.

Second, if a US company's goal is to maximize profit, it will ramp up its production lines to meet demand. It makes no economic sense to sell to our (US) federal government if a big enough commercial market exists (too many strings attached) .

The exception is when legal liability is an issue —such as the Covid 19 epidemic's demand for medical respirators. GM ramped up their production under the war powers act because if it makes a reasonably good faith effort to manufacture them, the feds are legally responsible for failure ("*if the government made me do it, I'm not responsible for the consequences*"). GM would not go into the medical equipment business otherwise because in the US, that commercial sector's legal liabilities are huge per dollar of sales—all of its tort lawyers want a chance to sue GM because of its very deep pockets. Because it is much cheaper to do so, most of the so-attacked institutions/companies settle out of court which is another way for lawyers to score easy wins. It is unlikely that there would now be a single case under the War Powers Act not driven by legal liability.

Another consequence is that some of the things that the rest of society really does need (e.g., a lot more nuclear power) are rendered either totally unavailable or impossibly expensive.

9.7.3 Hyper secrecy

Many scientists and engineers equate arbitrary and often poor human-made decisions with Nature's laws. Unfortunately, nuclear power was an afterthought of a post WWII rush to develop super bombs and submarines that could stay down indefinitely, move quickly, and break things. Of course, as such, everything about it/them was considered a secret that only a few rigorously "cleared" experts and authorities could access. That degree of secrecy was then new, unusual, controversial, and was/is always contested by especially idealistic/rational people like Robert Oppenheimer, Albert Einstein, and Alvin Weinberg. It was foreign to both American science and American democracy and potentially incompatible with because if it were to become the norm, how would science survive?

Secrecy within the DOE complex has been gradually getting worse ever since the end of the Clinton administration. Mr. Trump's DOE performed the coup de grace by completely pulling its public-facing employee directory and organizational charts ("DOE Phonebook") behind an impenetrable firewall, thereby rendering it almost impossible for "outsiders" to obtain the email addresses and/or phone numbers of its employees both civil service and contractor. Consequently, it has become almost impossible to determine who is responsible for accomplishing anything at its laboratories[502].

[502] Even information obtained via a "Freedom of Information Act" (FOIA) request usually protects governmental decision makers via imposition of self-serving redactions. An example of this came to light when lawyers representing two of Idaho's ex governors (Batt and Andrus) made a freedom of information request to DOE about specific questions regarding its obviously already-made decisions regarding shipments of spent fuel rods to INL prior to any independent environmental analysis or public input: "*The response is a joke,"*(?) Lucas said. *"They have redacted almost all their supposed answers and are claiming national security concerns on almost every question. Literally, DOE has not produced a single document that was not already public," violating the Freedom of Information Act.*" (Advocates 2015). If DOE can respond that way to

It is getting even worse. Today (18May2020), while trying to discover who currently might be managing whatever INL might be doing with respect to developing MSRs, my laptop responded with

"Warning: Potential Security Risk Ahead.

Firefox detected a potential security threat and did not continue to www.id.doe.gov. If you visit this site, attackers could try to steal information like your passwords, emails, or credit card details.

Rendering federal scientists and policy makers hard to contact is not a trivial matter[503]. Its firewalls shield taxpayer-funded government employees from the outside world, meaning that they don't experience much outside feedback and can therefore continue to do whatever they please. This is one of the reasons that everything about nuclear power development has become even more tarred with the same brush as has nuclear weapons development. The seeds of Chernobyl's tragedy were secrecy, opacity, and lack of accountability. A nuclear power plant cannot explode like a nuclear bomb[504], but many people think/feel that it could and, quite justifiably in my opinion, no longer trust that industry's managers, helpers, and spokespersons.

The US federal government's compulsion to "classify" anything even remotely new having to do with nuclear power is one of the reasons that the USA neither leads the world in that field nor is apt to regain that distinction. In my opinion, this compulsion has been rendered more destructive

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[503] The people collectively responsible for writing the USA's "rules" do the same thing. For instance, it is now nearly impossible to contact anyone in the US House of Representatives who isn't your own region's representative. This means that that very important part of our federal government (it writes our laws) has decided that it is perfectly fine for its membership to ignore anyone outside of their own immediate and often tiny personal bailiwicks (e.g., New York City has 13 different congressional enclaves). This means that the only top-level person in our federal government nominally responsible for representing everyone is POTUS. Of course, that doesn't happen either because he's (Trump, anyway) much more interested in satisfying only his "base". The USA has become a "pretend democracy", and its political system has degenerated to a winner-take-all mud wrestling match.

[504] The two reactor "explosions" that I'm aware of – that of the US Army's SL-1(Stationary Low-Power (3 MWt) Reactor Number One**)** and the USSR's genuine Chernobyl disaster - were steam, not nuclear, explosions that immediately shut down both. For example, it's been reported that the probably deliberate (suicidal) "transient" that shut down/destroyed SL-1 generated about 20 GW for about four milliseconds (SL-1 2019). That sums up to 8E+7 joules which means that that explosion consumed about one milligram of that reactor's fissile fuel – a <u>small</u> nuclear bomb's genuinely atomic explosion fissions/burns 5 - 6 orders of magnitude more fissile. A nuclear explosion requires sufficient force to hold the reacting nuclides close together for a short but necessary time. In a nuclear fission-based weapon that's accomplished by surrounding the core with a carefully engineered tamper (typically U-238), and a shaped explosive charge. This, along with other subsystems keep the supercritical mass together long enough for sufficient generations of the fission reaction to produce the desired energy yield. Lacking such restraints to hold its vaporized core components together, those of a power reactor immediately fly apart which stops the reaction. The "event's" still unpleasant consequences are a steam explosion and badly damaged reactor core, but not the type/size of explosion routinely achieved with nuclear weapons.

by its government's decision to pit "outside" entrepreneurs against each other to engender the renaissance that its government's managers should develope themselves[505]. Consequently, those "best and brightest" of US citizens most capable of implementing the necessary changes are forced to not cooperate with each other to protect their "intellectual property"[506]. That is, of course, perfectly OK with the secrecy-obsessed governmental managers responsible for "helping" a few of those go-getters with research grants and/or vouchers redeemable only at DOE's national laboratories thereby giving their own "government" employees fine-sounding missions to charge their timecard work hours to. This paradigm tacitly assumes that people in other countries are incapable of either doing such research for themselves or even reading reports published by the citizens of countries that have not chosen to similarly hamstring themselves. Those people of course went on ahead with their development plans and two of them (Russia and France) have even built/operated full sized "breeder" (sustainable) power reactors.

It also happens to be contrary to the advice that Alvin Weinberg gave his colleagues at ORNL over fifty-years ago:

"*Good people from diverse fields working together can make scientific discoveries that are denied to solitary geniuses working in isolation. Such coherence in applied research projects is even more important.*"

The thing that most impresses me about how the EU's researchers have gone about doing their GEN IV NE R&D is that they collaborate, not compete, with each other and are neither excessively secretive nor trying to "sell" anything but facts & truth (e.g., Merle 2017). However, its researchers work for politicians driven by the same attitudes evinced by most of the USA's and have therefore also not been funded sufficiently to do enough experimental work to "prove" anything – a situation that now seems to be getting even worse.

Meanwhile It looks like Kenya is apt to succeed in electrifying its peoples' POVs before we do .

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[505] The US federal government is encouraging people who grew up during a time when exploiting "intellectual property" (IP) had become the "obvious" way to quickly become rich and famous, to decide what it should be "studying". There is a lot more to implementing a sustainable nuclear renaissance than creating/cornering IP. Pitting entrepreneurs and/or contractors against each other to do the government's job simply sets up another business competition in which the biggest liar is apt to "win". The development of a reactor/fuel cycle able to affect Weinberg's "Age of Substitutability" is too big, too important, and too potentially dangerous to turn over to people/institutions primarily motivated by potential personal gain/profits or immediate political drivers. Everything we know about achieving it should immediately become "open access" and permanently kept that way.

[506] This is the reason that most of the people who used to contribute to the fascinating technical discussions held on Kirk Sorenson's "*energyfromthorium*" website have quit doing so. The reason for this is that most of the best & brightest of those folks ended up working for nuclear startups all of which force their employees/consultants to sign non-disclosure agreements.

China's 24 hour news channel, CGTN, had a little blurb today about its decision makers' already made decision to implement EV motorcycle battery exchange infrastructure : i.e., "spent" standardized 13 kg batteries are exchanged at lots of "filling stations" for 300 Kenyan shillings (that's 30 US pennies). Someone there who uses his/her bike all day long doing things like delivering packages or "Ubering" passengers around would typically use/exchange two batteries per day costing him/her 60 cents. That ain't bad especially when we consider that the bike itself only costs about $1500 US.

Some old fart named "Edison" proposed something like that for his 4 wheeled EVs a long time ago, but we Americans had just discovered how nicely Ford's cheap cars would run on that even cheaper byproduct of this country's kerosene industry, "gas". That established a business model that's never been changed and isn't likely to if our government's decision makers continue to kowtow to established businesses.

9.7.4 Over blown proliferation concerns

Many of the West's nuclear decision makers refuse to consider anything that might lead to greater "proliferation risk". For instance, they might say that "*your reactor concept/scenario is impossible because its fissile isn't 'denatured'*[507] *enough*."

That assertion makes about as much sense as claiming that it would be impossible to revive the USA's space exploration program because its decision makers would prefer that NASA's launch vehicles be powered with conservation rather than rocket fuel. First, since it tacitly assumes that any new reactors would be subject to the same set of arbitrary and apparently immutable man-made rules as are today's, it also tacitly assumes that the world will always need the uranium enrichment facilities that represent a far greater proliferation threat than does the fissile material within any nuclear reactor. Second, diluting (denaturing) the ^{233}U in, let's say, the MSFR or LFTR's salt streams with ~8x as much ^{238}U would: 1) render its fuel cycle unsustainable and therefore obviate the main reason for trying to implement a nuclear renaissance; 2) greatly complicate the reactor's operation thereby increasing its electricity's cost (and, likely also, its operators' radiation exposures); and 3) turn the resulting converter-type reactor into just another large-scale transuranic radwaste (plutonium etc.) maker. It's also hypocritical because the US federal government – a signator and vociferous proponent of the Nuclear Non-Proliferation Treaty – has been operating many HEU-fueled (naval) reactors for ~sixty years and is likely to continue to do so. There have been no "diversions" of their bomb-grade fissile by terrorists and it

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507 In this contest denatured means that the actinide isotope(s) constituting the system's fissile is diluted with enough of that element's non readily fissionable isotope (s) (e.g., ^{235}U or ^{233}U with ^{238}U) that it would be impossible for imaginary terrorists to make a bomb of "diverted" fuel unless they become simultaneously able to "enrich" their ill-gotten stuff too. The mandated degree of dilution is <20% for ^{235}U and <12% for ^{233}U. The latter hyper conservative criterion rules out development of any genuinely sustainable thorium-based nuclear fuel cycle.

is unrealistic to assume that any within a power reactor sited in any first world country would be either.

Any uranium-fueled reactor breeds some plutonium[508] which could in principle be recovered and perhaps – if there's enough of it and it's >90% ^{239}Pu, not "reactor grade" plutonium – could become the "pit" of a nuclear weapon. Some folks who ought to know better (possess earned PhD's) therefore claim that any sort of fuel "reprocessing" (an absolute necessity for any sort of genuinely sustainable nuclear fuel cycle) would dramatically increase the risk of nuclear war. It's true in that it is "possible" but also very much less likely than is runaway global warming due to their/our refusal to stop such dithering or North Korea's (which has no power reactors) leader deciding to nuke US military bases in South Korea and Japan. Choosing to develop a nuclear arsenal is a political decision, not a technological imperative. All of today's technologically advanced nations could build nuclear weapons if they choose to do so. Of the world's 40 such nations, nine have decided to build/maintain nuclear arsenals. The others chose not to do so and most have signed a solemn treaty to that effect. Citizens, politicians, institutions, and nations don't have to act stupidly and/or selfishly – they choose to do so[509].

9.7.5 My own bullheadedness

A final example would be my own refusal to pretend to just go along with whatever "the system" was apparently determined to do and try to change things from the inside rather than as an outsider (see APPENDICES VII &VIII). That may have even worked, who knows?

For instance, I've never become a full-fledged[510] member of the American Nuclear Society (ANS) despite having several papers relating to several aspects of how a fission-based nuclear renaissance might be implemented accepted/published in its peer-reviewed journals & conference "proceedings". The main reason[511] for this is that the ANS is dominated by

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[508] About 40% of a typical uranium-fueled LWR's heat energy is generated by in-situ bred/burned ^{239}Pu. It's about enough to compensate for the fact that a hefty fraction of the fissile in natural uranium is discarded during "enrichment".°

[509] For instance, North Korea, a poor nation refused admission into the "nuclear energy club", built its own tiny (5 MW) "production" reactor to make its own plutonium bomb pits. Israel had already done the same thing with its little Canadian-designed CANDU reactor. It's much richer sister nation, South Korea, has generated several thousand times as much nuclear energy to power its economy but has refused to make bombs.

[510] Full-fledged means paying dues other than those required to present something at its conferences.

[511] Another is that it charges its membership \$150 yearly dues which are not covered by DOE's contracts with its M&O contractors. A third is that it refuses to point out how silly that some of the USA's policies have become, e.g., its experts' recent conclusion that the best thing to do with 34 tonnes of almost pure fissile (^{239}Pu) would be to "dilute and dispose" of it.

people/institutions that are in one way or another, responsible for that discipline's technical stagnation. For example, the person who headed-up US DOE's nuclear engineering R&D program during the latter half of the Obama administration (it's "NE 1") was chosen to give a plenary talk at the 2017 National ANS meeting. As far as I was able to tell, throughout his tenure, both he and his counterpart on DOE's "waste" side (its "EM 1"), just kept kicking their respective cans on down the same road to nowhere without apparent interest in learning why they shouldn't do so. People receiving such honors from organizations like the ANS tend to be exceptionally well-organized and/or charismatic (good looking?)[512] "team players", not visionary technical experts. Unfortunately, the top-down driven institutions employing them (DOE, its contractors, and other business partners) impose blinders upon their employees that keep them from doing anything inconsistent with their employer's immediate desires which, in turn, are determined by the policies/attitudes of the USA's political leadership. My lack of political skills/instincts rendered my career far less successful than it could have been. Consequently, when things got too much to take at INL[513], I had to retire early (at 62) rather than move latterly to another job elsewhere that I am constitutionally better suited for.

Dr. Charles Forsberg another ex-DOE Site worker, has been and continues to be far wiser and more successful than I've been - when things got similarly tough for him to take at ORNL he was invited to assume a Research Professorship at MIT.

9.8 Human nature's consequences

Before I describe several examples of the consequences of poor management, let's ponder this little essay sent to me by Jerry Cuttler[514].

Camels are on the horizon

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[512] That's the reason that I can't "hate" Jane Fonda like a good pro nuke Vietnam war veteran should after she'd also decided to star in **The China Syndrome**. **Barbarella**'s opening scene and all of **Cat Ballou** had already convinced me that her contributions to Mankind's happiness outweighs anything evil that she might do. Besides, like me, she's another still-living member of America's "Greatest Generation" & therefore a "national treasure" in that respect too.

[513] Neither DOE's new "lead nuclear engineering laboratory's" M&O contractor nor its "waste side" contractor could find anything for me to do so I ended up back over at the Chem Plant sitting in a cubicle all day long cruising the internet and writing letters to its Inspector General's lawyers and the local newspaper. The bottom line is that nobody was (or is) willing to do anything that might interfere with the study-money flow.

[514] Jerry Cutler DSc, President, Cuttler & Associates Inc, former President of the Canadian Nuclear Society, and member of the American Council on Science and Health Board of Scientific Advisors.

The founder of Dubai, Sheikh Rashid, was asked about the future of his country, and he replied, "My grandfather rode a camel, my father rode a camel, I ride a Mercedes, my son rides a Land Rover, and my grandson is going to ride a Land Rover...but my great-grandson is going to have to ride a camel again."

Why is that, he was asked? And his reply was, "Hard times create strong men, strong men create easy times. Easy times create weak men, weak men create difficult times. Many will not understand it, but you have to raise warriors, not parasites."

And add to that the historical reality that all great empires...the Persians, the Trojans, the Egyptians, the Greeks, the Romans, and in later years, the British...all rose and perished within 240 years. They were not conquered by external enemies; they rotted from within.

America has now passed that 240-year mark, and the rot is starting to be visible and is accelerating. We are past the Mercedes and Land Rover Years....the camels are on the horizon.

9.8.1 INEL's calciner's off gas "opacity issue"

One of DOE's Idaho laboratory's most distinguishing features was that when its nuclear fuel reprocessing plant's waste calciner was being productive, a huge, somewhat toxic[515], golden-brown plume of NO_x would stretch out for miles downwind of its ~300 ft. high "smoke" stack. That plume would occasionally wander over the ~25 miles-away "Craters of the Moon" national monument thereby engendering an "opacity issue" inconsistent with the EPA's (not Idaho's) guidelines.

INL's calciner operated at about 500ºC and was heated by squirting kerosene along with the liquid waste into the bottom of an excess-air fluidized bed reactor[516]. All of the liquid wastes so calcined consisted of mixtures of water, nitrate salts, nitric acid, and, often, some fluoride salts too. With "high fluoride" wastes, a great deal of calcium and aluminum nitrate salts (more

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[515] Both its odor and effects are similar to those of chlorine gas. However, it's a great fertilizer which Mother Nature also provides via her lightning storms.

[516] In a fluidized bed reactor, a fluid (usually a gas) is passed up through a "bed" of solid granular material (e.g., already-formed calcine) at a velocity sufficiently high to suspend the particles causing the system to behave as if it contains a well-mixed, low viscosity, fluid. They are used to carry out a wide variety of chemical reactions.

nitrate) were added to “complex” it (reduces corrosivity[517]) while it was still liquid and suppress HF volatilization during its subsequent calcination. Under those conditions, most nitrate salts[518] and all of the solution’s free nitric acid decompose to form a mix of NO and NO_2 which along with excess air, elemental nitrogen, water vapor, and CO_2 was filtered and then sent up the stack. Because a lot of INEEL’s liquid radwaste (anything created by reprocessing zirconium-clad fuel assemblies) did indeed contain fluoride, a great deal of calcium nitrate was added most of which was imported from Sweden because it was cheaper than that sold by US suppliers. As that was going on, the site’s reprocessing plant’s fuel dissolution experts were importing lots of nitric acid as well.

In the late 1980’s I pointed out to my management that the NO_x in the calciner’s off gas would be easy to recover/purify[519] and that doing so would be advantageous to them/us in several ways. One was that because NO_x is both visible (impossible to hide during the daylight hours) and toxic, it was generating “stakeholder complaints” - by that time, it was illegal to emit nearly that much NO_x anywhere else in the USA. The other was that scrubbing/condensing it out of the calciner’s off gas to make the nitric acid and calcium nitrate that we would otherwise have to import would certainly be politically correct and might even save us some money. However, because Site management did not want to change procedures or complicate their jobs[520], that suggestion was ignored – the Federal government could flout its own laws then and apparently still can[521]. Similarly, a few years later when it became apparent that INL (then INEEL) should immediately calcine its million gallon inventory of still-liquid, several decade old, “sodium

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[517] Aluminum readily forms fluoride complexes thereby reducing the concentration of ultra-corrosive “free” HF in solutions.

[518] Alkali metal (sodium and potassium) nitrate salts are the exception: at the calciner’s 500°C they melt - not decompose - to form a glue-like liquid that “agglomerates” (aka “rocks up”) the sand-like particles comprising its fluidized bed which eventually shuts it down.

[519] Nitric acid is normally made by scrubbing an oxygen-plus-NO_x gas mixture with water which means that the only “new” technology required would have been a more-or-less off-the-shelf gas scrubber. The INL’s Chem Plant already possessed a large distillation system which could have purified/concentrated that acid for recycle back to its dissolvers.

[520] Like bananas & granite countertops, any acid and/or salts made with so-recycled nitrate/NOx would likely contain harmless but easily detected levels of several radionuclides, primarily tritium, Tritium’s beta-type radiation is so weak (0.018 MeV) that it can’t penetrate a sheet of paper. However, it’s nevertheless both real and detectible which means that nitrate recycling is inconsistent with ALARA which constitutes another fine-sounding excuse for not doing it.

[521] Forcing people to work without pay is something that only our federal government’s topmost executives, businesspersons, and rule-writing experts can do.

bearing waste", its management chose to shut that calciner down rather than change their plans[522] which eventually led to the billion-plus dollar SBW "steam reforming" boondoggle that I've described elsewhere (update: as of march2022, it's still going on) .

The most important consequence of INL's billion-dollar "oops" is that it's demonstrated that the USA's lead NE R&D lab couldn't deal with its own reprocessing waste.

9.8.2 Argonne Idaho's IFR waste management scheme.

Nearly five decades ago the United States decided to focus its sustainable reactor development efforts exclusively upon Argonne National Laboratory's plutonium-breeding, liquid metal–cooled, fast reactor. Consequently, that concept currently represents the only genuinely sustainable nuclear fuel cycle that could be implemented "quickly" (and then only if we were to suddenly become willing to buy Russian-designed/built reactors). Unfortunately, as developed, LMFBRs possess several drawbacks that have rendered sustainable nuclear power a tough sell to electrical utility CEOs and outside reviewers.

One of those drawbacks is that the fission product-containing salt waste generated by Argonne's "electrorefiner" was to be converted to a Ceramic Waste Form (CWF) rather than glass[523]. CWF is a mixture of a low melting powdered glass "glue" and a synthetic sodalite powder made from the electrorefiner's "hot" (radiologically contaminated) LiCl/KCl electrolyte plus a zeolite which is hot sintered together to form a ceramic monolith. The problem with it is that CWF is simultaneously difficult/expensive to make, not very durable (leach resistant), and can contain only a small fraction of the fission product waste that the glass-type waste forms produced by the world's still-functioning reprocessing facilities can.

In other words, an IFR-based nuclear fuel cycle applying CWF to its reprocessing/recycling waste streams would generate 15 to 19 times more high-level waste (HLW) form material/GWe-

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[522] INL's calciner was fed from a 10,000-gallon tank containing a mix of liquid waste plus whatever else was deemed necessary to so-treat it (e.g., calcium nitrate to complex fluoride-containing wastes to suppress HF volatilization). Mixing such volumes of ~8 molar nitrate salt/nitric acid with enough sugar to prevent calciner bed particle agglomeration could become "dangerous" if, for some reason, that mixture wasn't quickly calcined - it's thermodynamically unstable and therefore might "explode". Of course, that's certainly not the best or only way to add such sugar (e.g., add molasses via a mixing tee added to the pipe running between the waste tank and the calciner) but any proposal's trumped-up "safety issues" provided Site management with a fine-sounding excuse to not change their plans or procedures.

[523] Glass making (vitrification) has come out on top of every independent evaluation of US HLW treatment options save one. That exception concluded that concretes made with "properly pretreated" (whatever that means) wastes would be equally satisfactory and somewhat cheaper. The reasons for that near-consensus are that glasses are compact, sufficiently water-leach resistant, and making them (vitrification) is much safer, simpler, and cheaper to do than is separating the stuff going into them.

yr than do today's once through LWRs coupled to a modern Purex-based reprocessing facility. By volume, that disparity would be even greater because CWF is considerably lighter, ~2 g/cm^3, than are glasses, ~2.6-3.0 g/cm^3.

Turning around situations like that requires a critical examination of all assumptions inherent to its paradigm to identify/challenge/change those which render it unnecessarily inefficient.

In that case, the key wrong assumption was that an electrorefiner salt's waste form must immobilize chloride. That assumption is unnecessary because it is neither toxic nor radioactive nor difficult to separate[524]. It is also crippling because none of the durable natural minerals that waste form material developers set out to emulate can accommodate over a few weight percent chlorine. Since sodalite [$Na_8(AlSiO_4)_6Cl_2$] represents the best of a poor lot in that respect (7.2 wt% Cl), ANL's materials scientists set out to produce an artificial sodalite and therefore ended up with CWF (Simpson 2001).

My first retirement hobby project was to develop a better way to deal with such waste. That effort involved performing a basement-laboratory demonstration of how it could be treated in basically the same way that I subsequently learned that the USSR had already adopted/implemented at its Mayak reprocessing facility: i.e., mix the waste salts with phosphoric acid and aluminum (Russia's additive) or ferric oxide (Day and Kim 2005) and then vitrify it (in a (my case, with a homemade kiln. That process is simple to do, generates an exceptionally leach resistant and compact glass waste form material, and renders chlorine separation/capture/recycle simple. (Recycling is th*e* best way to deal with any sort of industrial waste.[525]) It was tough to get that paper accepted/published because its anonymous peer-reviewers were the same experts involved with the development of CWF – however, that Journal's (Nuclear Technology's) editor finally decided to overrule them and accept/publish it anyway (Siemer 2012). He even waived his journal's customary page charges[526].

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[524] On the other hand, separating radioactive cesium from its far more abundant harmless chemical cousin, potassium, is difficult/expensive.

[525] For example, TERRAPOWER and ELYSIUM's MCFRs would surely run better with fuel salts containing more-or-less pure ^{37}Cl – not natural chlorine. Since making such salts will not be cheap, their chlorine should be recycled, not "encapsulated" within some sort of discarded waste form. Heating any halide salt with phosphoric acid boils it off as gaseous HX where X=Cl, Br, or I, all of which are easily separated from the other gases that might be generated.

[526] In science-type journalism, authors are expected to pay publishers. Both your paper's reviewers and (usually) the journal's editor are expected to volunteer their services - not be paid for their work. The editor who committed the above-related breach of custom, decided to retire from that job a year or so later. I have one principle that I won't compromise on - I refuse to pay anyone to publish my work whether it be a letter to the editor, journal article, or book. For an aspiring young academic that's like embracing seppuku.

Not surprisingly, whenever any of INL's erstwhile fast reactor development experts (most of them have either retired or gotten academic jobs) have subsequently rendered an opinion or written a paper) about how such waste should be treated, they can't seem to remember that there's been a reasonable alternative to CWF already described/published. The last such paper I've seen (Simpson 2013) recommended direct geological disposal of that intensely radioactive[527], water soluble, waste salt mixture rather than trying to turn it into CWF (the only other alternative to direct dumping mentioned was an exotic tellurite glass with about the same waste loading limitations as CWF).

9.8.3 DOE's radwaste classification system

Because we humans invariably take far too long to change our opinions (including rules and laws) when they prove inconsistent with natural laws, we routinely waste lots of time and money (usually other peoples') when things do not work out. An especially silly example is the USA's radwaste classification system. Such waste comes in four flavors: commercial spent nuclear fuel (SNF), high-level nuclear waste (HLW) and transuranic waste (TRU) — both from weapons making — and low-level radioactive waste (LLW) generated by the USA's mining, medical, and energy industries. A minor amount of other "different" sort of radioactive wastes (e.g., those possessing toxic "codes" (components like lead or cadmium) too) further complicate radwaste's treatment/disposal issues which of course requires/justifies more "study money".

The HLW currently serving to rationalize most of the DOE Complex's radwaste boondoggling is "high" because it contains some stuff originally within a waste stream (raffinate) coming out of a reprocessing facility's "first cycle" liquid-liquid extraction system (see APPENDIX I). In other words, the "highness" of a waste storage tank's contents is determined by the label assigned to the worst fraction of whatever happened to have ended up within it, not by how "hot" (radioactive) or chemically toxic it might be. The good thing about radioactive-type wastes is that they inevitably become less radioactive as time goes by which is one of the reasons why Hanford's ~55 million gallons of production /test reactor-generated HLW is in fact 30 to 50 times less radioactive than is class C "low level" radioactive waste (see APPENDIX IX). That fact doesn't matter to most of the folks planning, performing, or overseeing DOE's waste management projects because to them, "*it's 'high' because that's what they say it is which means we can pretend that that it's really dangerous and act accordingly*".

James Conca has recently written a fine explanation of why the USA's classification system needs a radical overhaul (Conca 2019). Categorizing a waste by its contents rather than its

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527 Such salt would be at least as "hot" as the HLW being vitrified in modern European fuel reprocessing facilities (see APPENDIX IX).

origins or associations would bring the U.S. into the international fold and begin to solve a nationwide nuclear waste logjam that has left communities and facilities in limbo.

Let's end this dismal sub-chapter with a joke that I've been told by another ex INL employee (Dolan 2019) was popular among the INEEL's in-crowd when they got together at their favorite watering holes after work.

After the old manager was fired, he gave his replacement (another senior contractor employee) *three envelopes along with this advice: "When you get in trouble, open the first envelope."*

After several weeks the new manager needed to open the first envelope.

The note inside said "Blame your predecessor." That worked well for a while.

Months later he needed to open the second envelope, which said, "Reorganize your department." He did, and it worked for several more months.

Finally, his blunders created a desperate situation. He opened the third envelope.

It said, "Prepare three envelopes."

9.8.4 DOE's "ethics training"

Circa 1994 DOE decided to teach everyone working at its national laboratories about ethics in response to the outsider backlash generated by its decision to replace its Idaho Site's M&O (management and operation) contractor, Exxon, with another (Lockheed) that had recently embarrassed our government's officials by with getting caught bribing a foreign government's officials. Its idea seemed to be that if the people that its new contractor was now managing (us) learned about ethics, their (our) new topmost bosses would no longer behave unethically(?). As far as most of us were concerned, it was just another nuisance management fad that would be providing us with an especially valid number to charge our working "hours" to. Suffering through it made most of my fellow worker bees' eyes glaze over which likely rendered them a bit dumber but certainly better-rested. I found those lessons useful (even took notes) because they were empowering me to "legally" rationalize my heck-raising about how DOE's "lead" & follower labs were serving the public.

I had never become an insider because I had always insisted upon looking at technical issues from a point of view defined by the "mission statement" & whatever technical-type facts I could gather about possible options. Consequently, as soon as I began to get involved with the "chem plant's" processes, not just its ancillary analytical stuff, I began to become a "poor team player" & therefore never became an insider granted access to its especially important secrets. When that eventually turned me into a whistle blower, the Site's managers tried to get rid of me circa 1998. However, the "outside" official picked by DOE's Inspector General to arbitrate that disagreement forced my bosses to give me a promotion, a little cash settlement, & a promise to quit hassling me.

DOE's decision to teach me about ethics eventually also had negative consequences for several of INL's decision makers some of whom apparently decided to retire early too. Thank God for ethics![528]

Of course, since the Site's next M&O contractor site-managers didn't have to honor their predecessor's promises, during their reorganization I ended up in what one of its VPs incautiously characterized as its superfluous-employee "parking lot"[529]. The next few months' worth of lonely cubicle-sitting is what finally convinced me to voluntarily retire.

9.8.5 DOE's ongoing HALEU fiasco

This section was written by the founder of the THORCON nuclear startup and copied from his website, "The Gordian Knot News" on February 16, 2023. It goes into another of the reasons why it's unlikely that the US will end up leading the development of a sustainable nuclear power system – the hyper politization of its contracting policies renders it unlikely that the USA will be able to fuel the reactors that DOE has been encouraging its best and brightest technical entrepreneurs to invent.

THE CENTRUS FUEL FIASCO

by Jack Devanney

Here's an example of the kind of nuclear ``subsidy'' that has killed nuclear in the USA and is now stomping on its grave, an example that shows the nuclear power establishment is far more interested in gobbling up taxpayer money, than producing cheap, low CO_2 electricity. Here's what I wrote in 2020.

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[528] Unfortunately, most of the USA's working scientists don't work for tax-funded organizations that have publicly preached about ethics. In their world, bosses don't have to worry about the possible consequences of firing poor team players.

[529] As is usually the case in these situations, DOE's M&O (Management and Operations) contractor had to shoulder 100% of the blame for the malfeasance that I'd been dutifully reporting to the IG even though I'd made it abundantly clear that its managers had been following unwritten(?) orders.

Under our stifling regulatory system, nuclear power technology has stagnated for 50 years. The light water reactor plants being built in Georgia today look and are very similar to the plants that were built in the 1970's. The light water reactor is a klunky, brute force technology. There are a number of concepts that have been proposed that promise to provide nuclear electricity more cheaply and efficiently. Many of these designs work best on nuclear fuel that has been enriched in U-235 to just below the legal limit of 20%. This fuel is known as HALEU. For starters, at least 40 tons of HALEU is required, just to test these designs. But as of 2019, no USA enrichment facility was licensed to produce more than 5% U-235, the preferred fuel of the light water reactor.

In 2019, DOE awarded a $115 million dollar contract to Centrus Energy to produce ``up to 600 kg'' of 19.75% enriched fuel. Centrus is supposed to produce this fuel with a 16-machine cascade using AC-100M centrifuges. These experimental centrifuges, whose development was funded by the US taxpayer, have never worked to spec and have never produced a commercial ounce of enriched fuel of any percentage.

The President of Centrus is Daniel Poneman, who took that job in 2015. Prior to that, Poneman had been the Deputy Secretary of Energy at DOE. Under his tenure in 2012, DOE transferred 300 million dollars of uranium from the US stockpile to Centrus, then known as USEC, to be enriched in a failed attempt to prop up the enterprise. The Government Accountability Office found that DOE had no authority to do this and these transfers violated federal law. In 2013 USEC declared bankruptcy.

USEC was the old DOE gas diffusion enrichment facilities at Paducah, Kentucky and Piketon, Ohio which had been privatized in 1998. Gas diffusion enrichment is an energy hog and in the 1990's and early 2000's was replaced by centrifuging which requires 50 times less energy. USEC was not able to make that transition, despite or perhaps because it was continually being propped up by the DOE with taxpayer money, much of it doled out by Poneman. When USEC came out of bankruptcy in 2014, the clouded name was changed to Centrus.

The DOE could have awarded the HALEU contract to an outfit called Urenco. Or, better, allowed Urenco to bid on the job. Urenco has a large, successful commercial enrichment facility in Eunice, New Mexico.

(To produce HALEU from an existing cascade of centrifuges only requires that the cascade be operated in a different configuration. The Russians design their cascades with the proper piping and valving, so that they can produce a range of enrichments with the same cascade.)

Urenco was prepared to quote a fixed price for whatever amount of HALEU DOE wanted to buy with delivery starting in 2021. The reason given by DOE for selecting Centrus is that it was the only US owned entity that is capable of producing HALEU. Leaving aside the fact that Centrus's capability has not been demonstrated --- quite the contrary --- Urenco is majority owned by the UK, Dutch and French governments, America's close allies. Moreover, the Urenco plant is in

New Mexico licensed by and under the total control of the US government. It is staffed almost entirely by Americans.

Centrus will produce little or no HALEU. It is not in the business of producing enriched fuel and has not been for a long time. It is in the business of funneling taxpayer money to a particular congressional district, some lobbyists, and some politically connected executives. Poneman went from making $178,000 per year at DOE to 1.5 million at Centrus. Much worse, Urenco is now prohibited from producing HALEU in the US. DOE policy ensures that there will be no affordable HALEU produced in the US in the foreseeable future. This is the kind of nuclear ``subsidy'' that has killed nuclear in the USA and is now stomping on its grave.

The above words were written in 2020. What has happened since then? The 2019 contract, which was supposed to produce ``up to 600kg'' has produced zero HALEU. That 119 million dollars has disappeared. So in December, 2022, the DOE signed an additional $150 million dollar contract with Centrus. Under the first phase of the contract, Centrus is supposed to produce 20 kg of HALEU by December, 2023. Under the second phase, Centrus is supposed to produce 0.9 tons of HALEU in 2024. For 269 million taxpayer dollars, the country might get 0.92 tons of HALEU.

The developers of the new technologies knew that Centrus was never going to deliver 40 tons of HALEU. They had another, far cheaper, far more reliable source, the Russians. Now with that source cut off by the Ukraine war, new nuclear technology in the US is dead in the water. The Department of Energy and its beneficiaries are congratulating themselves.

Chapter 10.

The reasons why the Western world's erstwhile leader in nuclear energy must embrace change[530]

While I believe that the government itself shouldn't build or run things like the cement plants that should be providing us with jobs, a critically important construction material , and addressing our combustible waste (e.g., paper & plastics) issues - its job is to establish policies

[530] This section begins with an extensive rewrite of "*America's beleaguered middle class*", an article originally written by Richard Larsen & published by the "Idaho State Journal", February 22, 2014. However, Mr. Larson's proposed solution to their/our problems differs from mine.

that encourage/enable its citizens to do constructive things themselves - the hard truth about nuclear energy is that it requires especially strong government backing which the western world's leading "pretend democracy" refuses to supply. A new reactor concept may have been conceived by great scientists/engineers and backed by a large and reputable company, but to succeed in the electricity business sector, it must also have a stamp of approval from a credible regulator. The Russians are building reactors all around the world through a state-owned company, Rosatom. That backing has also given them a head start in the SMR race. In December, Rosatom began providing electricity to the Arctic port town of Pevek by way of a ship moored there featuring a pair of little ~35 MWe LWRs like those powering Russia's icebreakers. If the USA wants to resume its traditional role in that business sector, its decision makers must embrace several "radical' paradigm shifts.

10.1 The US "middle" class's issues

The USA is currently facing an economic crisis like that which first kicked off the 20th century's Great Depression and then WWII. To make things worse, thousands of its citizens are dying each day due to its leadership's mishandling of this century's worst pandemic. Its thankfully now ex-President along with his enablers consistently fanned delusions that fueled division, violence, and finally an insurrection when their witless stooges stormed its national capital to protest the fact that he'd lost his bid for reelection. The reasons for this sad situation harken back to a half-century ago.

Because President's Roosevelt's New Deal along with several unusually wise post-WWII policies had kicked off a 35-year burst of growth that had made it the world's richest country, the United States possessed a virtual monopoly upon technological innovation and industrial productivity up until about 1970. However, by the mid-1970s most of that war's physical and economic devastation elsewhere in the world had finally been overcome while the USA's industrial infrastructure was becoming antiquated. That along with governmental policies and regulations that had incentivized it shifted much of the USA's industrial production to Asia where cheaper labor, shipping, communications, overhead, and, by that time, lower total production costs obtained[531]. That changed the USA's economic system from one based upon the production of its own goods to one based upon the "consumption" of all sorts of new "services" including the selling of much marked-up foreign-made goods to US citizens.

During that decade millions of foreigners willing to work for wages lower than those that its current citizens expected immigrated to the USA so that they could consume more too. Additionally, millions of recently emancipated women and by then grown-up baby boomers

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[531] A good deal of the copper in the consumer goods imported from the Far East had been stripped out of abandoned US factories and the homes that their employees had lived in.

entered the same labor force. These demographic changes combined with the globalization of manufacturing and automation of production everywhere effectively froze real (properly inflation-adjusted) wages for the first time in US history.

Additionally, because new policies had made it profitable to do so, the USA voluntarily gave up its ability to provide some of its own citizens' needs with locally-sourced mining, manufacturing, and agriculture—or even to extend the life of such products through reuse, repair, and repurposing. For example, the rare earth elements (REE) needed to make things like TV screens, computer hard drives, hybrid car motors &batteries, wind tower alternators, etc., are no longer

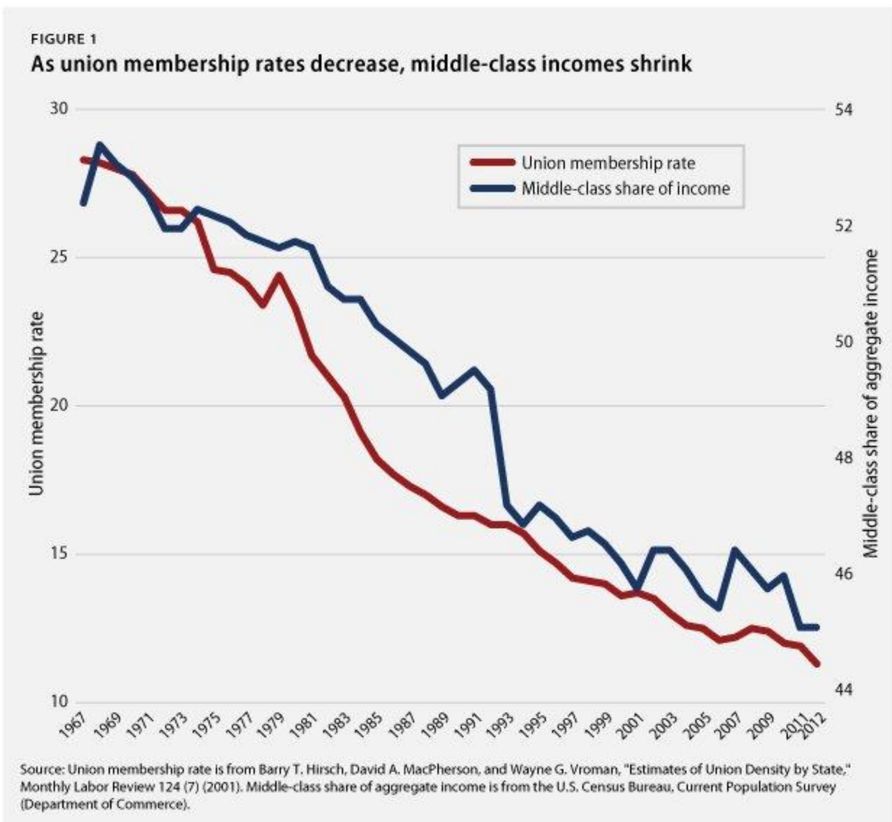

Figure 85 five decades worth of progress

produced in the USA because the ore bodies containing them also contain enough of the chemically similar thorium along with its "daughters" to render them slightly radioactive which rendered working with them in its over-regulatory environment prohibitively expensive [532].

[532] Natural thorium's half-life (14 billion years) is three times the age of the Earth meaning that it's only nominally radioactive. However, because it is generally in secular equilibrium with ~ten decay product isotopes ("daughters"), any thorium containing ore's total radioactivity is about an order of magnitude greater than that of the thorium itself

The USA no longer mines/processes/enriches most of the uranium fueling its nuclear reactors for that same reason[533]. Furthermore, over the last four decades global per capita consumption of several key industrial commodities has grown eight to twelve times faster than has human population. After this century's inevitable post-peak-fossil fuel summits, interruptions in the flow of such goods will be profoundly destabilizing to what had once been the USA's uniquely large & prosperous "middle class". They and their parents had become accustomed to enjoying extra consumption via a combination of both their and their government's addictions to deficit spending plus the "off sourcing" enabling low-cost expropriation of other nations'/people's share of the Earth's natural resources[534]. Demographics, the outsourcing of energy-intensive industries plus automation of many of the remaining ones has severely impacted the people that had worked in them, thereby generating poverty, insecurity, and the angst responsible for many of them deciding to embrace populistic political scapegoating[535]. The rules determining institutional behavior are rigged in favor of the ultra-wealthy people and corporations meaning that its working (middle) class has been getting the short end of the stick. Today's average US CEO-to-worker compensation ratio is **351-to-1.** That has been widening the gap between very high earners and everyone else. While worker productivity grew by **61.7%** between 1979 and 2020, their median wages grew by **only 23.1% and for** Black and Hispanic workers, wage growth was even slower. Because heavily taxed wages, not low-taxed investments, are the working middle class's primary source of income, the pronounced reduction in the bargaining power of ordinary American has blocked living standards growth for most US citizens since ~1979. Rising inequality—anemic wage growth for most, substantial wage gains for those at the

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and therefore easily detected. The radioactivity of a typical rare earth ore containing 2.5% thorium is ~1000 Bq/g which figure is high enough to render working with it in the USA's regulatory environment more expensive and troublesome than it's worth.

[533] Since the collapse of Soviet Union >19,000 Russian warheads have been dismantled and their highly enriched uranium (HEU) "bomb pits" diluted with cheap depleted or natural to make low (3 to 5%) enrichment fuel for the USA's LWRs. The manufacture of most US reactor fuel was also outsourced and over one half of the fissile (^{235}U) within it was purchased from Russia.

[534] The latter has become especially convenient to the USA's political leadership because they could claim that "*it's them foreigners, not us, that are really polluting the atmosphere*".

[535] We now routinely blame African Americans, Latino Americans, gays, lesbians, Arabs, China, Persians, women, too-young people, too-old people, unwed mothers, Muslims, tree-huggers, whistleblowers, & "socialists" for our issues. The real problem is that the USA's "privatized" political system; 1) enables its already-fat hogs to determine who gets whatever remains in its trough, 2) routinely ignores the wishes of most of its citizens, and 3) is primarily concerned with getting/retaining both political and economic dominance, not with furthering the long-term best interests of their country's people. That unfortunate fact is evinced by the USA's chronic ~$600 billion annual deficit largely due to not paying what they owe due to 1) tax exemptions favoring high income taxpayers, 2) much lower topmost marginal tax rates than they were from about 1940 to 1985, 3) and lax enforcement of existing laws. This is blatantly unfair to low income working taxpayers which further exacerbates political unrest.

very top, and a tax system that increasingly favored the rich — left millions of Americans with an ever-shrinking portion of the nation's wealth. The effects of burgeoning inequality have afflicted men and women at all education levels with even many of the college-educated now just barely treading water.

Where did the USA's "neo-Malthusian" mindset come from? In August 2018 Senator Elizabeth Warren introduced a piece of legislation called the "Accountable Capitalism Act" that provides us with an outline of how it happened. Here's the gist of what it says:

For most of our country's history, American corporations balanced their responsibilities to all their stakeholders – employees, shareholders, & communities – in corporate decisions. Up to about 1980, America's biggest companies dedicated less than half of their profits to shareholders reinvesting the rest in the company but then a "new" idea took hold: American corporations should focus solely upon maximizing returns to their shareholders; i.e., the rich must become richer. Consequently, big American companies currently dedicate ~93% of earnings to shareholders thereby directing trillions of dollars that could/should have gone to their employees and investments in their company's (and nation's) infrastructure. The easiest way to increase profit margins is via automation, especially when downsizing your workers means that you can stop paying for the pensions and health insurance that their government should be responsible for[536].

The key to making big money is to minimize your employees' wages, which is the reason that many corporations currently force them to sign noncompete clauses. Analysts estimate that tens of millions of private-sector workers are under some form of noncompete clause which prevents them from leaving their jobs to either work for or start a competing business within certain time periods.

While noncompete clauses traditionally protected only closely guarded business secrets in high-income fields, they now touch all income levels, even low-wage service work. They are only 'agreements' in theory, because refusing to sign one means not getting a job,

Noncompete clauses are ubiquitous, reduce wages and competition, and part of a growing employer trend that forces workers to sign away more of what should be their rights.

[536] In an improperly regulated/motivated capitalistic human society, such behavior is as inevitable as entropy. The provision of a civilized society's education, healthcare, old age pensions, and education should be the responsibility of its government, not its businessmen.

Consequently, the rich have gotten richer, and many middle-class jobs are now pensionless gigs that leave the USA's workforce increasingly insecure[537]. Minimum wage, in real terms, dropped over thirty per cent relative to what it was fifty years ago. A recent Economic Policy Report concluded that it would be over $22 per hour had it tracked with productivity increases over the last five decades.

Contrary to common perceptions, most of the 32 million U.S. workers who would be getting get a raise if the federal minimum wage were raised to $15/hour by 2025 would be, on average, 35 years old; female, and working full-time., not young people working part-time jobs to augment their allowances.

The 1990's most famously dysfunctional US family, Homer Simpson, his wife Marge and their children, Bart, Lisa, and Maggie enjoyed a secure lifestyle that's become out of reach for many middle-class Americans. Homer, a high-school graduate whose simple unionized job at the local nuclear-power plant required little technical smarts, comfortably supported a family of five. Their home, a car, food, regular doctor's appointments, with lots left over for lots of beer at the local bar were all paid for with Homer's single working-class salary. Unlike many of today's children, Bart and Lisa did not have to worry that their parents would lose their home or couldn't feed them.

Homer's family would likely feel less secure these days because the USA's greed-is-good energy policies are eliminating jobs and destroying the communities surrounding & supported by its nuclear power plants. Homer's hometown, "Springfield", is like Iowa's "Palo" was before its owners decided to shut down that state's only NPP. For example, Wiscasset Maine's "Maine Yankee" power plant employed over 500 workers most of whom lived within 20 miles of it. At the time of its closure, it contributed $12 million annually in local taxes which covered 90% of Wiscasset's municipal budget for schools, fire protection, and other public services. Its employees' salaries annually contributed another ~40 million dollars to the local economy.

Homer is the kind of guy that might eventually decide to get together with his other so-downsized drinking buddies and go storm the Hallowed Halls of Congress.

Much of the USA's erstwhile middle class hasn't come to grips with the whys of their situation and have responded in the same way that Italy and Germany's people did a century ago as

[537] Some of them became destitute, most became cynical, and a few of them became angry enough to don their riot gear, pick up their clubs & MAGA hats, & go storm the US Capitol Building – the place where the people responsible for their discontent and possessing the power to remake the "system" to work properly have their pissing contests.

evidenced by the outcome of its 2016 presidential election, i.e., vote for someone that heaps the blame upon "elites" & "outsiders*", especially foreigners*[538].

Consequently, the USA's genuine middle class is shrinking quantitatively in terms of its population percentage, and qualitatively, in terms of both security and quality-of-life. Many of them are being squeezed by declining real incomes and rising expenses as they increasingly shoulder the inflationary costs of both corporate greed and multiple layers of inefficient, special interest-driven, and self-serving government(s).

This all came to a head with the COVID-19 crisis. By mid-May 2020, as large sections of the global economy had shut down, over thirty-three million Americans have filed for unemployment. Many people with the sorts of jobs not deemed essential, or which render

foodstuff	retail source*	retail cost	USkg/ha	$/acre**	commodity $	markup
carrots	Aldi	$1.55/2 lb	38173	$26,350	$0.16/lb	4.84
yellow onions	Aldi	3#/$2.09	56000	$34,749	$0.14/lb	4.98
rice	Aldi	3# $2.09	8420	$5,183	$5.27/bu	5.95
pinto beans	Aldi	2# /$1.55	1965	$1,356	$0.38/#	2.04
potatoes	Aldi	10#/$3.75	49737	$16,613	$7/100lb	5.36
peanuts	Walmart	1# /$1.98	3409	$4,509	$425/ton	7.62
molasses	Walmart	12 oz/$3.24	NA	NA	$220/ton	63.36
molasses	Walmart	$20/gallon	NA	NA	$1.29/gal	15.50
molasses	Tractor Supply	$7.99/gallon	NA	NA	$1.29/gal	6.19
white sugar	Walmart	$3.56/4 lb	NA	NA	$0.43/#	2.07

* lowest local (DesMoines) advertised supermarket price

** farmer's return/acre if sold @ retail cost

Table 17 US food commodity-to-retail cost multipliers

telework impossible, are suddenly without work, and, often, without savings because they were just barely getting by before the roof fell in on them. According to the CEO of "Feeding America", this pandemic is likely to leave an additional seventeen million Americans needing food assistance in the next six months. Recently, in cities across the entire nation people have been waiting outside food pantries in several mile-long lines and tens of thousands who can't pay

[538] "*Remember, remember always, that all of us, and you and I especially, are descended from immigrants* " Franklin D. Roosevelt

their bills have gone on rent strikes. Their food issues are almost entirely due to the fact that the retail cost of basic foodstuffs is tremendously inflated - there's lots of money to be made in the USA's food business for everyone except the farmers that produced its basic components (grains, fruits, and vegetables) . The figures in Table 17 reflect both how much a food shopper pays for US-produced commodities and what its farmers got for producing them. Its third column lists the number of dollars that a single acre (0.405 ha) of land would generate for its owner if he/she could sell its output for what the USA's food shoppers must pay for it. This table exemplifies one of the reasons why the USA's nominal GDP is so large: most of it consists of services that are supposed to "add value" to its cheap raw materials, natural resources, and commodities. For example, still-in-the-shell ("stock") peanuts that US farmers might get ~21 cents per pound for, sell for ~two dollars/pound at its food supermarkets. The USA's food sector's middlepersons don't add much value to stuff like whole peanuts, raw carrots, onions, potatoes, etc. but such "services" dominate their retail costs and, like any sort of cost inflation, reduces their citizen-consumers' living standards.

Since most of the money that its citizens pay for things go to "service providers" (middlemen), many of the USA's workers, entrepreneurs, and the people educating/training them have concluded that it doesn't make much sense for them to actually ***make*** anything[539]. Consequently, more of our factories get shut down meaning that the things they made - steel, cement, aluminum, glass, etc. must be imported, become more expensive, & the people that used to work in them lose their jobs and homes.

Meanwhile, their housing and food costs have more than caught up with what they were at the height of the US-initiated real estate bubble that led to the world-wide 2008 financial crisis/recession - more than doubling since 2000. Their prices in many major market areas around the country have reached nosebleed levels (e.g., $4.29/lb Granny Smith apples here in DesMoines).

Another looming issue is the fact that the cost of energy - gasoline, heating oil, and natural gas is rapidly rising and apt to cause severe hardships - especially `during winter cold spells - to everyone that isn't "rich". One of the reasons for this is that investment in fossil fuels has fallen faster than renewable replacements have come on - line especially during the COVID 19 pandemic's worldwide economic turndown. In capitalistic countries, over the long run it is necessary that such fuels become increasingly expensive, but peaks and volatility are destructive to anyone without the wherewithal required to ride through the transition . Governments need to

[539] For example, a good-quality modern replacement house window worth/costing about $200, 2021-type dollars at a home improvement store would typically cost US homeowners ~$700 by the time that a professional window contractor had installed it – something that likely took his/her employees under 45 minutes to accomplish.

build more buffers into their current systems as well as hasten the development & implementation of alternatives.

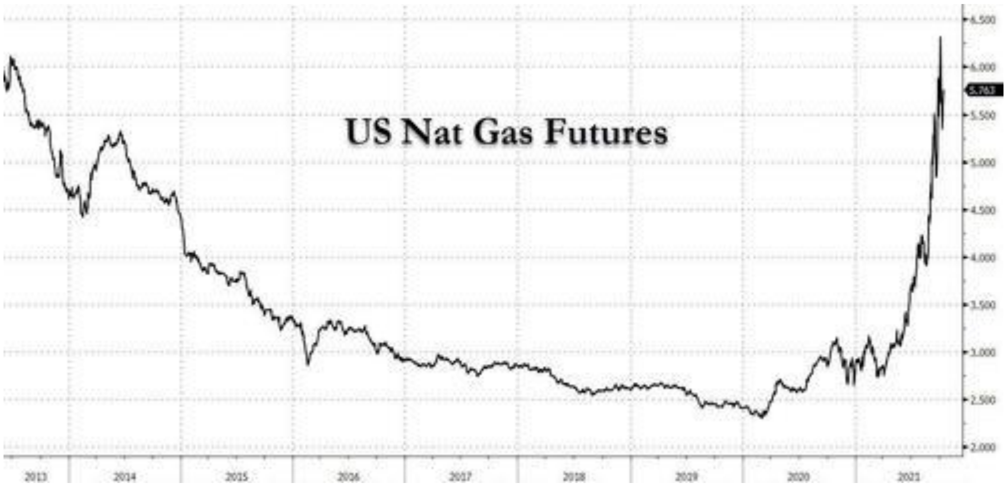

Figure 86 US natural gas cost (fracking isn't going to "save "us)

Another problem is that many of the people appointed to serve on Public Utility Commissions seem to feel that (& certainly act as if) their job is to see that their region's utility company (natural gas, electricity, water, etc.) stockholders remain happy with their investments. Consequently, they routinely OK much higher retail-level rate increases than is justified by wholesale cost changes along with the imposition of lots of mysterious "service" fees that their customers neither want, understand, nor need.

Such cost inflation represents a substantial fraction of the USA's GDP growth and will be difficult to sustain with so many of its people either un or under employed (e.g., PhD Uber-cab drivers).

Today's huge decline in housing affordability will only make matters worse for the USA's economy and the people employed by it[540].

Not everyone can get rich enough to buy one of today's houses, cars, or even hamburgers making, selling, or delivering "my pillows", tacos, "Medicare Advantage" insurance, organic fad foods, and/or male/female enhancement products.

> "*When people say they live paycheck to paycheck, it's not that they're managing their money poorly. Instead, their housing costs are taking up a disproportionate share of their incomes*."

[540] The primary reasons for this include: 1) new houses are much bigger than they need be 2) local zoning authorities often prohibit the construction of affordable housing 3) US homes both new and old are often poorly engineered and therefore expensive/difficult to heat, cool, and/or maintain.

Sharon Parrott, vice-president, Center on Budget and Policy Priorities

Rampant inflation causes pervasive financial insecurity, aka “precarity”: a couple years ago forty per cent of Americans did not have four hundred dollars cash to spare in an emergency and would have to rely upon credit cards or friends or family to come up with even that pittance. One of the economic consequences of the USA’s mismanagement of the COVID-19 crisis is that even more of its grown-up children (~thirty years old) have moved back to live with their parents. That fraction has risen from under 30% two years ago to over 50% now (October 2020). Most of their parents were able to “leave the nest” ten years earlier than that. .

“*We know for low-wage workers, three unpaid days away from a job threatens their ability to buy food for a month,*”

Vicki Shabo, a policy expert at New America, a nonprofit think tank,

“*This is worse and weirder than anything I’ve ever seen. We know how to wrap our brains around the bursting of an asset bubble of seven trillion dollars in the housing market, or the end of the dot-com boom, but don’t have practice in dealing with the fallout from pandemics. We are beginning to see who will be most affected by the economic downturn. Women are losing jobs at a higher rate, because there are more of them in the service sectors most affected by the virus. The crisis has also been increasing racial economic disparities: black and Latino workers are more likely to work service-industry jobs—in restaurants, bars, hotels—and that sector was the first to shut down, and the least likely to fully reopen in the near term. We always see this during recessions, but this one is likely to be worse,”*

Heidi Shierholz, director of policy, Economic Policy Institute

The COVID-19 epidemic has also made it crystal clear that the more “essential” (vital) your government deems your job to be, the less you are likely to be well paid, the more insecure is your employment, and the more at risk you are to catch and die of a pandemic.

Another serious issue is that the USA has been moving away from being a “meritocracy”. Wealth inequality has been increasing at a greater rate than it has any other time in its history while economic mobility has been shrinking. Roughly 60 percent of America's wealth is inherited and, like most privileges, heavily skewed to increasingly exclusive groups[541]. In 2012,

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[541] For instance, Justin Farrel’s, “Billionaire Wilderness: The Ultra Wealthy and the Remaking of the America West” (Princeton 2020) reports that the average annual income of the top 1% of the people living in and around Jackson Hole, Wyoming (~80 miles from where I recently lived) is $28 million while the average person working there, earns ~$40,000 – not enough to own their own mobile home or tiny lot to park it on. The same thing has happened elsewhere in the USA’s Western states; e.g., Big Sky MT, Ketchum/Sun Valley ID, Park City UT, Vail/Colorado Springs/Breckenridge CO, etc.). Another manifestation of the consequences of greed run amok, wealth inequality, and a health care system that has become “a cancer at the heart of the economy”, is an uptick in

PBS's Bill Moyer pointed out that the real median US household income was under what it was at the end of the '80s and down 9 percent from its peak in 1999, with the biggest part of that decline, 8.3%, occurring during the preceding five years. The median net worth of a family in 2010 was $77,300, compared to $126,400 just three years earlier because the too-big house that their government's leadership and policies had encouraged them to over-invest in didn't pay for itself. In 46 of the USA's states, the poverty rate had increased during the previous five years, and the national rate had remained >15% for the fourth year running. More and more families are dropping from the ranks of the USA's once proud and confident middle class into precarity[542].

One of the factors adversely affecting median household incomes is the scarcity of "good" jobs exacerbated by extended periods of unemployment including the deliberate federal government shutdowns occurring whenever US Congresspersons refuse to do their jobs. More and more of its people are forced to accept "gigs" rather than secure jobs paying enough for them to live the same American Dream – real (not pretend[543]) home and car ownership, etc. – that their parents (my generation & the "boomers") had enjoyed.

This picture isn't much prettier with respect to the cost of the goods and services that everyone must consume to live securely with dignity. The USA's Consumer Price Index (CPI) is the most relied upon figure for calculating the inflation rates used to determine pay raises and adjust some pension benefits. According to Forbes, the USA's Bureau of Labor Statistics (BLS) changed the way it calculates the CPI twenty times during the past 30 years, including new formulas and

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"deaths of despair" including suicides, drug overdoses, and alcoholism of middle-aged, middle class, white American citizens.

The Bloomberg Billionaires Index has just recorded its largest annual gain in the list's history, with a 31% increase in the wealth of the richest people. The richest 500 people on the planet added $1.8 trillion to their combined wealth in 2020 bring their total net worth to $7.6 trillion. This wealth hoarding occurred while the world was/is confronting the coronavirus-driven economic crisis characterized by the United Nations as a "tipping point" apt to send > 207 million more people into extreme poverty during the next decade—bringing the total to one billion. In the United States, the rapidly widening gap between its rich and poor became more apparent. As Dan Price, an entrepreneur and advocate for fair wages, tweeted, the 500 richest people in the world amassed as much wealth in 2020 as "the poorest 165 million Americans have earned in their entire lives."

[542] i.e., low pay, high blackmailability, intermittent incomes, etc., and of course, the social consequences of poverty combined with relentless cost-of-living inflation. This fosters a pervasive sense of insecurity which is the reason that so much of the advertising bombarding us is for various sorts of "insurance".

[543] Nothing is really owned until the last lien against it has been paid off. The average US homeowner's equity is currently under 50%. The traditional "American dream" is now out of reach for most of its working people. For far too many, what should be basic rights, like having a secure job with a livable wage and good benefits, are just that—a dream.

indices that separated the more "volatile" food and energy sectors (e.g., the cost of building nuclear reactors) to arrive at an official "core inflation rate". Those changes resulted in a significant dissociation between what its figures suggest and what the USA's middle class see when purchasing required goods (e.g., homes) and services[544].

In 2014 Forbes declared, that "*The CPI is not a measurement of rising prices, rather it tracks consumer spending patterns that change as prices change. The CPI doesn't consider the falling value of money. If it did, the CPI would look much different*."

According to the BLS the CPI had gone up 1.6% that year and had hovered between 1-4% for the preceding five years. However, if the inflation rate were calculated in the same way as it had been circa 1980, it would have averaged over 5% per year. For example, out-of-pocket healthcare costs had nearly doubled in the preceding seven years because increasingly special interest-driven policies enabled/encouraged "health care providers" and drug manufacturers to continue to charge whatever they can get away with[545].

Between its recessions the USA's retail domestic energy prices have likewise increased. During the last decade, energy prices have more than doubled as governmental policies became increasingly ideological and counterintuitive. Energy and food cost inflation disproportionately affects the middle and lower classes. When I first arrived in Idaho Falls 43 years ago electricity was so cheap ($0.008/kWh) that most of its new and almost-new houses were simultaneously poorly insulated and "all electric" with resistive-type heating. Electrical power was cheap because President Roosevelt's new deal dam-building campaigns had rendered it so and population growth hadn't yet pushed regional power demand beyond that government-built power system's capability.

ALICE, (the United Way's acronym for **A**sset **L**imited, **I**ncome **C**onstrained, **E**mployed) which represents individuals and families who are working, but unable to afford the basic necessities of housing, food, childcare, health care, and transportation), determined that nearly a quarter of a

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[544] For instance, about 12 years ago I decided to replace my home's too-weathered and under "engineered" (not enough fiber-binding glue), wood fiber-based lap siding with the same sort of stucco-over–polystyrene foam board siding that renders Las Vegas' "marble" buildings so well-insulated. However, when I discovered that having a professional do it for me would cost about $3.75/ ft^2, I decided to do it myself using a cheap ($15/50# sack) polymer-reinforced white "thinset" stucco, spread over 2" thick, 4' by 8' foam boards nailed to the studs with 4" long galvanized nails & homemade galvanized steel washers. Those foamboards cost $8/sheet then (25cents/ft^2) and $19 (at Menards, more elsewhere) now. Similarly, the cost of shingles has doubled since I reroofed it myself ~15 years ago.

[545] When pain and/or early death is the likely alternative, a service provider's sales pitch carries more weight than it does in most situations. Doctors and hospitals are paid for providing us with the "services" they choose to notic, not for curing us.

million of Idaho's households – 40 percent – could not afford those needs in 2016 (ALICE 2018). While most Americans still think of the US as being a country of great economic mobility and opportunity, that mobility is now one of the developed world's worst. In the US people whose fathers were in the bottom income quartile have a 40% chance of staying in that quartile and only about an 8% chance of making it to the top one which is half of the average moving-up probability of the countries analyzed. In a country with genuine (not pretend) equal opportunity, that would not be the case (Dalio 2019).

The USA's childhood poverty rate has remained ~14% for several decades[546]. In 2017, around 12% of the USA's children lived in food-insecure homes meaning that at least one family member was unable to acquire adequate food (USDA 2020).

An up-to-date summary of the reasons behind the USA's middle class's angst was published by The Atlantic 7Feb2020, "***The great affordability crisis that is breaking America** - In one of the best decades the American economy has ever recorded, families were bled dry*" (Lowrey 2020).

It's not just the US middle class's money problems. Heather Curl author of "The Culture Shock of Social Mobility: Complications and Costs of The American Dream," points out that money ranked second to the "visceral experiences" defining the USA's social classes. The key distinction between the USA's poor, working, middle, upper, and "1%" classes is the type of work done rather than its remuneration. Neither income nor consumption are the best measures of class difference, because technologies get better and borrowing money has become cheaper as time has passed if you don't do so by not paying off your credit card bill every month . A job without decision-making empowerment usually defines its poor and working classes'. Possessing even pretend assets, like "owning" a home or car that a lender, taxing body, or medical service cost-decider can easily confiscate may officially place you in the middle class even if you have a low paying, low prestige, working-class job that doesn't keep you up with real cost-of-living inflation.

This chapter paints a distressing picture of the USA's middle class's situation. Prospects for improvement are also poor because the basis of their problems is causally connected with policies emanating from and firmly entrenched within the USA's sundry governments at every level. Because Congress still has the power to make laws and overcome vetoes and US citizens

[546] Another of the USA's dirty little secrets has been revealed by the current corona virus pandemic. When NY's mayor decided to shut down its schools to "flatten the infection curve" the major concern raised was how the ~700,000 of its nation-biggest school system's ~1.1 million children were to be fed the two meals per day that their parents apparently couldn't provide for them.

can, in principle[547] , still choose who leads them, it is not just due to its last President's (Trump's) mishandling of almost everything required to address our country's energy, social, health, and environmental conundrums. The USA's Republican Party is determined to restore economic feudalism and its Democratic Party tends to overly politicize science and stifle progress by championing over-regulation and "magic" (technically unrealistic) solutions. Capitalists typically do not know how to properly divide the economic pie and socialists typically don't know how to grow it. When such economic polarity and poor conditions obtain, the USA's leaders should pull together to reform the system. Instead, they become progressively more polarized, fighting more rather than less resulting in today's almost total deadlock on many important issues (Dalio 2019). This book's subjects are too important to continue to either ignore or wring hands about. Everyone must become willing to do the "homework" required to understand the seriousness and urgency of their situations and properly evaluate proposed technological fixes.

The person whose 1988 Congressional testimony sparked widespread awareness of global warming and its causes, Dr. James Hansen, was critical of Hillary Clinton's intention to put ~500,000,000 solar panels on rooftops across the USA:

"*You cannot solve the problem without a fundamental change, which means you have to make the price of fossil fuels honest. Subsidizing solar panels will not solve the problem. We have two political parties and neither wants to face reality. Conservatives pretend it's all a hoax, and liberals propose solutions that are non-solutions*[548]."

Unfortunately, another of human nature's quirks is that in today's political environment, bloviating, uber-capitalistic, demagogues can employ Hitler's "populist" tactics to seize command of government and exacerbate things for everyone except their real "base" (other

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[547] Congressional district gerrymandering, "winner take all" vs proportional legislative representation, and the ridiculous persistence of the Electoral College effectively serve to disenfranchise many millions of Americans. Another reality defeating the spirit of democracy is that the Republican Party has repeatedly succeeded in discouraging people to vote by rendering it difficult or even dangerous to do. For example, Wisconsin's 7Apr2020 election represents about the worst possible way to run an election during a pandemic (close most of the polling places thereby forcing everyone stubborn enough to insist upon voting to stand in several mile-long queues for hours). That state's Democratic lieutenant governor called it a "shitshow" while its Republican "Speaker of the House" wearing full protective gear from head to toe was trying to convince his colleagues that in-person voting during pandemics is "incredibly safe".

[548] Jacobsen et al. refer to their campaign as a WWS (wind water and solar)-powered "*Solutions Project*". Other people not so heavily invested in its marvelous assumptions consider it a "*Non Solutions Project*" (Beckers 2017). One of its tenets *seems* to be that a WWS-based Green New Deal could be implemented within ten (sometimes twelve) years. That's impossible – every major transformation in how our civilization goes about powering itself has taken about 50 years & this one won't be an exception (Rhodes 2018).

especially important people that feel the same way they do). Since the early 1980s that's been exacerbated by the growth of US media conglomerates resulting in lower investigative and all other sorts of serious journalism budgets. A 2002 study concluded "that investigative journalism has all but disappeared from the nation's commercial airwaves" consistent with the conflicts of interest between those conglomerates' profitability and unbiased, dispassionate journalism because advertisers don't support media that report too many unfavorable details of what's going on in their region . Consequently, magazines, newspapers, and television stations have concentrated upon downsizing their "people costs" while retaining/entertaining their audiences without the risk of offending advertisers.

For example, a former Washington Post Beijing correspondent (Pomfret 2019) recently pointed out that our federal government's recent spate of charges against China's leading telecom company, Huawei, are a smokescreen for its real concern: U.S. security officials are afraid that Huawei's technology will become the global standard for "5G"—a development with huge implications, both military and economic, for the global balance of power. This is a legitimate fear for which America's leadership has mostly itself to blame. The technology behind 5G is complicated, but not rocket science and depends mostly upon network density. A successful 5G network would require thousands[549] of small "servers" scattered everywhere across the entire country. China has elevated the construction of such networks to the equivalent of the USA's 1960's-era moon landing project thereby outspending the U.S. by $24 billion since 2015. In other words, China's advantage in technical infrastructure building lies not in superior scientific genius but political will. That sort of contest favors nations capable of doing the sorts of things at which China has come to excel and the USA no longer even attempts[550].

I've been running into that situation here in my new hometown too – none of the "journalists" working for the DesMoines Register or any of its sister news outlets wants to hear anything about how the people and institutions implementing Iowa's predominant business models are exacerbating its citizens cost-of-living inflation and "food insecurity" issues.

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[549]The reason for this is that a 5G communication network's equipment utilizes much higher electromagnetic frequencies than does a 4G system which renders its broadcast signals more directional, almost "line of sight. The way that the USA is going about implementing its "system" is also apt to compromise its ability to forecast serious storms because Mr Trump's FCC chairperson allowed developers to utilize a frequency band (24 GHz) too close to that used for weather satellite communications, 23.8 GHz, to assure that latters' necessarily weak signals won't be drowned out by ground "noise" (Sci Am 2020).

[550] For example, every few years (weeks, in some cases) almost everyone in the USA must submit to arbitrary, corporate-driven, intrusive, and often disruptive changes in their personal computer's security system and email, word processing, and spreadsheet applications (I'm so suffering now).

Fundamentally, it's just a question of values. In the 1930s and '40s, the general sentiment was that the nation would be better off if everyone had reasonably comparable electricity and telephone services. Consequently, the USA's then apparently more "socialistic" federal government established a system of loans and grants to ensure universal access to those utilities[551]. To help, the FCC set up a system to charge businesses and urban customers slightly higher fees to subsidize the higher costs associated with bringing phone lines to rural areas. It's doing stuff like that made that era's American citizens, its "Greatest Generation".

The question facing the U.S. now is whether it is willing to commit to providing affordable broadband service equitably to everyone regardless of who they are or where they live – many of us now do not have access to or can't afford even 3G service[552].

"If we do not have the capacity to distinguish what's true from what's false, then by definition the marketplace of ideas doesn't work. And by definition our democracy doesn't work. We are entering into an epistemological crisis.
Barak Obama

Pulitzer Prize-winning investigative reporters Donald Barlett and James Steele explain in their book, "The Betrayal of the American Dream" that what's been happening to America's middle class isn't inevitable. It's the direct result of government policy and could be changed by government/political actions."

The USA's ultra-conservative Smoot–Hawley Tariff Act of 1930 implemented protectionist trade policies by increasing ~900 import tariffs by ~40%. It worsened the Great Depression and thusly should instruct today's political leaders. It doesn't - President Trump set off another trade war that's apt to accomplish the same thing that Mr. Hoover's policies did ("*beggar your neighbor*, *beggar yourself*") and might even lead to another world war.

The USA's underlying conditions - corrupt political class, sclerotic bureaucracies, a heartless economy, and a both divided and distracted public—was revealed by the ongoing (May 2020)

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[551] Our federal government had made a similar commitment many decades earlier when it established a US Postal service to enable everyone to quickly communicate with each other at the cost of a one-cent stamp. The USA's Postal service is now far less efficient (more costly and slower) than it was fifty years ago, can't afford to update itself, and the USA's best & brightest young job seekers do not want to work for a public service organization that their government no longer supports.

[552] The primary reason that broadband access – an absolute necessity for success in most of today's world – costs more in the USA than in other first world nations is because it's another key utility that's been privatized in regions with little or no competition between providers (https://www.bbc.com/news/magazine-24528383). The US needs to elect another "trust busting" President and establish public utility regulations that serve the country, not its businessmen.

COVID 19 pandemic. Its people had learned to live uncomfortably with those symptoms, but that pandemic's scale and intimacy has exposed their severity. That crisis demanded a swift, rational, and collective response but instead has revealed shoddy infrastructure and dysfunctional governing systems with leadership too corrupt and/or stupid to head off mass death and suffering. Its president saw the crisis almost entirely in personal and political terms and therefore responded with willful blindness, scapegoating, boasts, conspiracy theories, magic-thinking, and outright lies. A few senators and corporate executives acted quickly upon insider information to profit from it.

COVID 19 is this century's third major crisis. The first, on September 11, 2001, came about when some of America's topmost leadership still remembered the previous century's depression and both its hot and cold wars. Partisan politics and poorly conceived policies, especially the Iraq War, erased our sense of national unity and fed bitterness towards the political class and other "elites" that's continued to grow. The ensuing 2008 financial crisis greatly intensified those feelings. For many of the USA's "elite", that crash might be considered a success because the US Congress, outgoing Bush-administration officials and incoming Obama administration passed a bipartisan bailout bill that saved the USA's financial system but did not punish the people responsible for the crash. The Federal Reserve' and Treasury Department's monetary and fiscal policies prevented a second Great Depression but didn't address root causes. Leading bankers were shamed but not prosecuted; most kept their fortunes and some even kept their jobs. Before long, they were back in business –to most of them that crisis just represented a "speed bump."

All of its lasting pain was felt by people in the middle and lower classes who had taken on the debt that their government's policies had encouraged and then lost their jobs, homes, and retirement savings. Many of them never recovered and the young people who came of age during that (not so) "great" recession were doomed to be poorer than their parents. Inequality—the fundamental, growing, and relentless force in American life since the late 1970s—grew worse.

The economic devastation attributed to the Covid 19 flu epidemic did not happen in a vacuum. It occurred in a context of profound and rising inequality that has been driving a wedge between the wages of typical US workers and those of its high earners for over four decades. That inequality is the result of market forces created/driven by distinct and intentional governmental policy changes/choices (see https://www.epi.org/press/workers-would-be-earning-10-hour-more-if-their-wages-had-kept-up-with-the-increase-in-productivity/) and could/should be eliminated/addressed by more policy changes.

Another little-known consequence of the Trump administration's foreign trade war is that it is hurting academics as well as the people working in economic sectors (e.g., agriculture) immediately affected by its tariffs.

The following is a note received recently (8/12/2019) from a high school friend who ended up becoming a professor in the University of Minnesota's agricultural department:

"Many of us have had the rug pulled out from under our research. Most of our grant support came from "commodity group" checkoff funds which means we drew from a pool funded through the cash value of sales of a crop, corn, soybeans, wheat etc. Mine came from sales of Minnesota soybeans. Unfortunately, most of Minnesota's soybeans became exports to China. Because of the tariffs about 60% of last year's crop is still in storage and any sales have been at a much-reduced price. The checkoff pool is pretty thin. In December I'll probably be terminating the researchers employed on my project unless a miracle occurs.

Roger Johnson, President of the USA's National Farmers Union, is another person immediately affected by Mr. Trump's approach to making America great again. According to him…–

. "*Today's market uncertainties have halved net US farm incomes*". (CNN interview, 8/13/19)

10.2 The USA's over, under, and stupid regulations

One of the things stifling US job growth is the overreach of special interest-driven governmental regulations because of the way that the Congresspersons we elect to represent us fund their political campaigns[553]. In 2013, a U.S. Chamber of Commerce survey showed that 74% of small businesses were positioning themselves to slash employment hours, lay off workers, or both due to how the USA had gone about implementing its "Affordable Care Act"[554] . Nearly 300 large companies admitted to reducing hours for their employees to get below its mandated 32 hour/week threshold. That is the result of just one piece of poorly thought-out, special interest contributor-driven (health insurance, pharmaceutical, and medical industries[555]) governmental rule making.

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553 For example, the 2010 Republican-pushed/won, "Citizens United" legal battle overturned the McCain–Feingold Act which had prohibited corporations from funding "electioneering communications" and thereby effectively removed limits to the degree that that political party's real "base" could help elect business-friendly candidates. *"Government by organized money is just as dangerous as Government by organized mob*." Franklin D. Roosevelt

554 Aka "Obamacare" by the Republican Congresspersons who had ensured that the ACA would end up doing that, not by President Obama himself. He would have much preferred a single payer system which would have served everyone equitably and reduced costs, not just shovel more money into the same special interest-dominated system.

555 In 1965, the US federal government created Medicare and Medicaid to provide health care services for its elderly and poor. These programs currently provide some degree of security for ~38 percent of its total population. Unfortunately, the loopholes deliberately left in that legislation and the fact that they didn't cover everyone means that the USA's mostly privatized health care system has become ridiculously expensive, leaving 41 million US citizens underinsured and 28 million with no coverage at all. A single payer ("Medicare for All") system would foster real competition, provide health care to everyone and, by taking price-setting out of the hands of insurance companies and for-profit hospital managers, drastically reduce administrative, drug, and professional care costs. It would also remove a huge overhead burden from doctors and employers which, in turn, would encourage job/business growth.

In 2012, the USA's House (of Representatives) Committee on Oversight and Government Reform published a report revealing the role that government has played in suppressing job growth. It concluded that, "*Many regulations and legislation – both existing and proposed – exacerbate the uncertainties created by today's volatile economic environment. Virtually every new rule/regulation has an impact on recovery, competitiveness, and job creation*." President Obama's own Economic Advisory Panel came to the same conclusion, saying that "*regulations are harming businesses and job creation*." His panel went on to suggest several measures that could be implemented to quell the expansion of such job/economy-destroying rules and regulations.

No other sector of the USA's economy is as much suppressed by bureaucratic overreach as is nuclear power. The chief impediment being the Nuclear Regulatory Commission empowered to determine whether any real or proposed activity involving "special materials" falls under its purview and then charge whoever wants to do anything with them a fee for what it feels that its licensing and overseeing is worth (see NRC 2019). It is also notoriously slow in responding to requests for such help/advice/permissions, which holds up projects raising their overhead costs.

If you want to innovate and build a fission reactor you must have- -

1) a NRC design certification ensuring that your concept is safe – cost ~$200 million

2) A COL license allowing you to construct and operate it – cost ~ $60 million

3) Once licensed, you will have to pay an "operating fee" of ~$5 million regardless of whether your reactor is running.

4) A license to obtain fuel for your prototype must be obtained from NRC - private sale or purchase of nuclear fuels is illegal and may result in jail time.

5) A Waste Confidence Environmental Impact Statement describing how you plan to sequester any nuclear waste produced by your prototype must be prepared and submitted to NRC. That plan must be approved before you can let your reactor to go critical and generate power. You must pay the NRC staff members evaluating that Environmental Impact Statement at a rate of $265 an hour until such time that they are entirely satisfied with it.

6) When you have decided that you no longer need to operate your prototype reactor, you will then have to pay NRC staff members at a rate of $265 per hour while they oversee your decommissioning efforts.

These are some of the issues that have caused DOE's NE decision makers to try to substitute "modeling" for experimentation which, of course, didn't work out because most modeling doesn't demonstrate anything other than more garbage in means more garbage out[556].

The reason for this is that the U.S. Nuclear Regulatory Commission (NRC) is statutorily required to recover most of its budget authority through fees assessed to applicants for an NRC license and to holders of NRC licenses. In other words, the USA's lawmakers have addressed its government's responsibility to see that the nuclear industry behaves responsibly by issuing a license to steal to some of its own employees.

Unfortunately, the root causes of this situation are unlikely to change under the Biden administration. On March 21, 2022, the Securities and Exchange Commission (SEC) proposed sweeping new climate-related disclosure requirements for publicly reporting companies. To me, the SEC's 510-page document seems more like a make-work project for lawyers, MBA's, bureaucrats, and "reliable" technical experts than anything apt to solve the problems responsible for both climate change and environmental degradation.

Its proposed rules would require both domestic and foreign registrants to:

- Provide narrative disclosures describing climate-related risks and the actual or likely material impact on the registrant's business, strategy, and outlook;
- Discuss the registrant's governance and risk management processes with regards to climate-related risks;
- Quantify and disclose the registrant's direct and indirect greenhouse gas (GHG) emissions which, for some registrants, would be subject to third-party assurance;
- Include certain climate-related metrics and disclosures in a separate note to its audited financial statements; and
- Disclose information about climate-related goals and transition plans, if any.

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[556] My first post-retirement peer-reviewed publication was the one (Siemer 2012) having to do with demonstrating a more reasonable way of dealing with sorts of radwastes generated if Argonne's "Integral Fast Reactor ' (IFR) concept were to be reduced to practice. I'd previously written up/submitted a paper study "proving" that it should work based upon what was already known/proven about each of its individual steps. It was rejected because I hadn't "demonstrated" that the whole system would work. I fumed about that for a while but then realized that it represented another of the "opportunities for excellence" that one of the site contractors I'd worked for (Westinghouse) had defined its/our "problems" to be (in that, it was right!). In 2011 that inspired me to put together my own little basement laboratory, perform, and then describe in a subsequent submission to the same journal the results of experiments that proved that the linked-together scheme would work. That journal's editor's response was unusually gratifying.

Canada's nuclear regulatory system is less obstructive than the USA's. A few years ago, an official with a company developing an SMR said that his outfit chose to domicile in Canada because it didn't see a plausible path to licensing in the United States. In 2015, the U.S. Government Accountability Office concluded that obtaining certification from the NRC for a new reactor is "a multi-decade process, with costs up to over $1 billion, to design, certify, and maybe eventually license it.

Periods of rising middle-class income coincide with periods of economic expansion and growth like those prevailing from several years before the beginning of WW II up until about 1970. During that era the USA's tax system prevented the super-rich from hogging the majority of the nation's wealth (top marginal tax rates were over 90%) and its government employed that money to embark upon the massive infrastructure-building projects that made America greater- Hoover Dam and the string of others that tamed the Mississippi and Columbia, the Tennessee Valley Authority, our interstate highway system, etc., etc., while ensuring that it would be cheap/easy for its citizens – especially its military veterans - to buy homes and get low cost educations all the way up through college. During that era, our government won that biggest of all wars yet and neither micromanaged the projects that its taxpayers and bond buyers were funding nor imposed efficiency-killing rules and laws. To the contrary, that era's government (not today's) put people in charge who were willing to insist that its contractors did the job that were being paid to do – not decide for themselves what that job should be[557]. That's one of the reasons why the AEC's NRTS in Idaho, was able to design, build, test, and then safely decommission >50 nuclear reactors and repeatedly recycle the fissile (highly enriched uranium) so used during its first two decades.

The other reason is that failure has become expected (acceptable) within the DOE's nuclear complex because almost everyone within it realizes/accepts that it has become almost impossible to do anything that's either "risky" or inconsistent with extant political drivers. Consequently, even though DOE now spends more money now (about $32 billion/year) and the need for such work is even greater than it was six decades ago, it has become incapable of either doing or managing the sorts of projects that the AEC's contractors quickly accomplished back in the "good old days".

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[557] The USA's national laboratories no longer devise its nuclear technologies: Instead, DOE first seeks and then chooses between the offerings of entrepreneurial contractors. The leadership of each of the DOE's national laboratories is chosen by its M&O contractor's top management (e.g., Bechtel's CEO and board members), not DOE. Additionally, that contractor's personnel, not DOE's often technically clueless bureaucrats, make most of the technical decisions based upon how much money can be made rather than how their efforts will further their site's nominal mission. Since DOE's managers pick the contractors, during the duration of each contract they adjust goal lines so that their service providers can receive almost 100% of their potential "award fee" while simultaneously failing to accomplish the originally professed "mission" – hence INL's and Hanford's interminable reprocessing radwaste management boondoggling.

It's not just us here in the good ol' USA. Here's something that was "hot off the press" 4May2020

https://world-nuclear-news.org/Articles/Further-delay-in-completion-of-Onagawa-2-safety-up?

"*The completion of safety countermeasures at unit 2 of the Onagawa nuclear power plant in Miyagi Prefecture, in Japan- a 796 MWe boiling water reactor (BWR built 1991-1994) will not be completed until March 2023, two years later than previously scheduled, Tohoku Electric Power Company announced on 30 April. Japan's nuclear regulator concluded in February the unit meets revised safety standards, clearing the way for it to resume operation Tohoku expects to spend about JPY340 billion (USD 3.2 billion)… The company had originally planned to complete this construction work by April 2017, but the schedule has been pushed back a number of times. The latest plan had been for the countermeasures to be in place by the end of financial year 2020 (ending March 2021).*"

Like Fukushima's multiple reactor site, that site's single reactor was sited upon land created by carving away a natural cliff to make it easier to build and bit cheaper to run. However, Japan's decision makers/regulators have since come up with a rationalization for its ratepayers/taxpayers to rebuild a small part of that cliff (its new concrete seawall) at a cost far greater than required to remove the entire cliff face in the first place. GOOGLE Earth tells us that TEPCO's decision makers had originally decided to carve the original cliff down to about 10 meters above sea level to build that plant. A concrete wall 15 meters high (total height over 10 meters higher than that tsunami), 3 meters thick & long enough to enclose the entire plant (~890 meters) would require about 53,000 yd^3 of concrete. At \$150/yd (~current US price) that much concrete should cost just under \$8 million or 0.25% of \$3.2 billion. I also suspect that a Chinese contractor could underbid any US or Japanese contractor on any project having to do with pouring lots of concrete[558].

We homos – especially some of our politicians, decision makers, and "experts" - do not seem to be especially sapient regardless of where we live.

Mankind's history is littered with examples of once-dominant nations that had overreached with poorly thought-out policies and sclerotic bureaucracies that crippled their economies eventually leading to collapse due to gross inefficiencies. That's why China didn't go on to completely dominate the world during the fifteenth century AD. Great Britain's "Brexit" secession from the EU is due to the excesses of "Brussel's" bureaucracy[559]. That's the same reason that many of the

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[558] Fortunately, its leaders eventually (circa 1980) became willing to change how they managed everyone. Consequently, from a flat-footed start, within three decades they've "made China Great Again" (GAGA?); e.g., during 2011-2013, China's people made/poured more concrete than had the USA's during the entire 20th century.

[559] The COVID -19 pandemic provides an example of the whys of Brexit. Britain signed up early to buy the Oxford-AstraZeneca vaccine and approved it swiftly. The EU's leadership: first, accused the British of cutting corners on

Texans suffering through its latest polar vortex-caused unnatural disaster had recently moved there from California.

However, as much as both over and stupid regulation must be curbed, there are some things that do need "centralized planning" among which are those upon which the ultimate success of any technological civilization depends – the educational, health care, and energy systems that enable its people to succeed[560]. The real problem is bad rules, policies, and regulations, not their number.

Regulation – about the only positive thing I ever saw come out of Mr. Trump's government is that some of the USA's sillier laws, rules, customs, and regulations were reviewed and/or ignored, e.g., its approach to labeling its radwaste accumulations. If such laws, rules, customs, and regulations are not replaced with equally inane ones (to be determined) that certainly would be a worthwhile achievement. President Trump & his successors must encourage research by cutting the regulatory red tape crippling innovation in any/all nuclear fields. A company wastes up to ten years and $100 million dollars in fees to obtain the Nuclear Regulatory Commission (NRC) permits necessary to conduct research into critical advanced nuclear technologies. The deleterious effect of the USA's regulatory burden on its energy innovation and baseload security cannot be understated. Red tape has driven ThorCon and Terrapower's people and investment dollars to research facilities situated in Indonesia and China[561], respectively. Streamlining the permitting process for advanced nuclear research will keep atomic energy leadership and jobs here in America.

As much as I am both confused by and disgusted with how the USA's "conservative" (Republican) politicians behave, some of what they do/propose with respect to addressing this book's technical issues makes more sense than do the proposals embraced by their "liberal" rivals. The USA has become hamstrung by its federal government's self-serving over-regulation

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safety, thusly encouraging anti-vax nonsense; second, moved themselves to the back of the queue after negotiating a bad deal; third, took an age to approve it in a display of astounding bureaucratic lethargy; fourth, castigated AstraZeneca for failing to give in to pressure to allow them to jump the queue; and fifth, tried to impose a hard border in Ireland just to stop the Northern Irish from getting vaccines. These are not the actions of a friendly ally. (This footnote is a rewrite of a recent "rational optimist" (Matt Ridley) blog posting).

[560] For instance, the reason that the USA's citizenry can continue to drive long distances in huge cars is that their government had previously mandated that such vehicles become more efficient. Mr. Trump and his charisma(?) dazzled supporters sought to eliminate such meddling with the US business sector's brilliant instincts.

[561] Terrapower made a deal to build the first TWR in China, but Trump's trade war ended that. Its Plan B. is to join with GE to jointly design the INL's Versatile Test Rector so that it could test its TWR's IFR-like fuel assemblies. It's also working on its molten chloride fast reactor concept - another once through "almost breeder" with reasonably efficient U utilization. Simple physics, complicated chemistry" (Charles Forsberg 1/25/2020)

and make-work "research" foot-dragging(for example see this book's last-added APPENDIX). The key to addressing both its and the rest of the world's especially wicked energy-related problem – implementing a sustainable nuclear renaissance – showed some sign of getting back on track again during our ex "maximum leader's" administration, i.e., "*President Donald Trump's proposed fiscal 2021 budget does not include funding for the Yucca Mountain nuclear-waste repository in Nevada, but it does earmark $1.2 billion for nuclear-energy research and development, an increase over last year's proposed $824 million. The increased funding aims to promote "revitalization of the domestic industry and the ability of domestic technologies to compete abroad*" https://www.theverge.com/2020/2/10/21131701/trump-budget-proposal-nuclear-energy-programs-spending

However, most of the people that Mr. Trump chose to head his science/technology-related agencies were determined to undermine them than see to it that they function properly, i.e., insisted upon throwing out babies along with their bath water. For example, in 2018 Republican Sean Sullivan, then chairman of the Defense Nuclear Facilities Safety Board (DNFSB - an "independent" panel charged with protecting workers and local stakeholders at DOE's nuclear weapons facilities) told Mr. Trump that he recommends abolishing that group, despite recent radiation and workplace safety problems at several of those sites. The main reasons for this were: 1) it'd save taxpayers about $31M/a (true); 2) DOE's contractors & their Congressional supporters don't like to have their decisions second-guessed (true); and 3) like the other groups nominally overseeing DOE's sundry activities (e.g., Nuclear Waste Technical Review Board (NWTRB) and Site Specific Citizen Advisory Boards), its recommendations are "advisory" (window dressing) – DOE doesn't actually have to act upon its advice (also true).

Some (not many) of the USA's agencies should become more, not less, proscriptive/powerful: for instance, *almost* everyone[562] would be better off if the US were to mandate the use of just one measurement system (metric), limit the number of screw/bolt head choices that manufacturers can employ, and force manufacturers to at least label the "black boxes" controlling the gadgetry (e.g., cars) that we all depend upon. Why do taxpayers pay for a "NIST" that's not empowered to set rational standards? Any house sold should come complete with blueprints informing their purchasers where its pipes, wires, septic tank, etc. are located. At the very least, such information

[562] For example. anyone trying to tackle this book's homework problems would find it much easier/simpler if the USA's powers-that-be had insisted that everyone use a single set of energy, power, volume, and length units. It seems that every "business" has established its own way of expressing such things (e.g., Joules, calories, BOE, electron volt, horsepower hours, both normal and "Sears-type" horsepower, MBTU etc.) which fact causes almost everything we do/use/build to be unnecessarily complicated/expensive/inefficient & often causes disastrous mistakes (BBC 2014). People benefiting from it are the businessmen selling the often superfluous goods and services that the absence of standardization and dearth of consumer-friendly information render necessary.

should be freely available from the governmental body originally paid to issue its building permit.

In my opinion, the imposition of such regulation would be welcomed by most of this country's businessmen because they could then go ahead and provide genuinely good products & services, without having to worry that they'll be losing money because their competitors are free to cut corners and lie about it.

The USA's "deregulated" energy sector is especially in need of some discipline. Several folks & I spent about three days trying to determine just what the term "storage" means in today's renewable energy market. I then contacted two of the authors of the report that had sparked that discussion saying that we hadn't been able to discover a referenceable, authoritative source defining what a MW's worth of grid-scale battery backup is in terms of a specific source-type's nominal (i.e., peak) "capacity" (not the grid's demand) and that it'd help us a lot if government reports like the one that had set us off translated whatever its compilers were sent into the same units that we were taught to use in high school and continue to see in our utility bills: Watts, kW, or MW for power & joules, watt hours, kWh, or MWh for energy.

I also asked, "what is the relationship between a MW's worth of a solar farm's battery backup capacity a MW's worth of its nominal, i.e., peak, "capacity" (MWh/MW)? Is it adjusted for differences in solar insolation? Would it be the same for a co-located wind farm in a place like Iowa? Is it adjusted for seasonal variations in renewable-type source CFs? ???

If, "'yes" to any of the last three questions, who does the adjusting?"

The answers I received were what I'd come to expect by then; in other words, each group, market, or organization in the USA's booming renewable energy business can apparently define what "power" and "energy" mean in any fashion that best suits their own interests.

That means doing it in a way that reassures nosey outsiders, especially politicians & the people who elect them, " that everything is going great & there's no reason that you shouldn't want to help us grow our business."

Backup storage systems (battery packs) should be characterized with both their energy storage capacity and prolonged period (e.g., 4 hour) power delivery capability. A renewable source's power should be characterized in terms of both its maximum "capacity" & what it can deliver to its customers and/or storage system over a ***defined*** time period.

A power/energy salesperson's claim of "4 hours' worth of backup batteries" not accompanied with equivalent energy or an unambiguous power figure isn't of much use to planners or customers.

If the businessmen submitting information to the government's report writers refuse to reveal their installation's characteristics in a straightforward fashion because it's "proprietary" that fact should be mentioned in its reports.

That exercise provided another example of the kind of time waste & confusion generated by our government's refusal to prohibit its businesspersons from reinventing new definitions, names, and acronyms for things like energy & power[563]. Doing so might seem "good" for a particular business but that's neither the reason that we pay for National Laboratories or of much help in determining the best way for our country to become clean and green.

Transportation - the most practical way of replacing today's internal combustion engine-powered cars with battery-fueled electric vehicles (BEVs) would be to mandate standardized battery packs that could be as quickly switched-out at refueling stations as ten gallons of gas can be pumped into a tank.

Health – today's tremendously overhead-burdened health care system could be rendered much more efficient, fairer, cheaper, and effective by simply adopting a single-payer "medidental" care system for everyone and eliminating the 20% coverage gap (loophole) currently serving to foster most of today's privatized "Medicare Plus" insurance scamming. Doing so would permit business owners and their employees to concentrate upon work and running their businesses, not worry about or compete with each other about "benefits". People choosing to work in the healthcare sector should provide health care services – not spend

[563] My old shop-type vacuum cleaner had a 5 "Sears-type" horsepower motor and ran just fine when plugged into a 15 amp-breakered, 120 volt wall socket. One horsepower =747 watts meaning that the maximum "real" power one can draw from such a socket is 2.4 horsepower [120*15/747] However, since it's apparently legal to do so and redefining that unit might convince shoppers to purchase its especially brawny vacuum cleaner, Sear's salespersons did so and it worked - I bought one! .

most of their time trying to please the horde of bean counters, lawyers, hospital/insurance company shareholders & CEOs, etc. currently being employed by that sector.

Although Mr. Trump's approach to "fixing" the USA's governmental pathologies is/was imitated by similarly motivated politicians elsewhere, it has not worked out well for his/their country's citizens. The people we elect should govern in a way that will enable both us and our descendants to live long, successful, constructive, and happy lives. That means guiding educating, inspiring, and empowering everyone to do so – not just spend most of the time satisfying your electoral “base” by demonizing anyone/anything that its membership doesn’t like.

On the other hand, Russia’s President Putin did get “good value” from his support of President Trump who seemed to act more like one of the “captains” reporting to mob boss Tony Soprano than as the “Leader of the Western World”.

The 2020 Edelman Trust Barometer report revealed that despite a strong global economy and near full employment most respondents in every developed market do not believe they will be better off in five years’ time, and 56 percent believe that capitalism in its current form is now doing more harm than good in the world. “*We are living in a trust paradox,*” said Richard Edelman, CEO of Edelman, most respondents in every developed market do not believe they will be better. “*Since we began measuring trust 20 years ago, economic growth has fostered rising trust. This continues in Asia and the Middle East but not in developed markets, where national income inequality is now the more important factor*[564]*. Fears are stifling hope, and long-held assumptions about hard work leading to upward mobility are now invalid.* ”The concerns are wide-ranging and deep. Most employees (83 percent) globally are worried about job loss due to automation, a looming recession, lack of training, cheaper foreign competition, immigration, and the gig economy that’s been replacing the “middle class’s” secure jobs (Edelman 2020)**.**

Making free enterprise work as it should, will require reducing bureaucratic overhead thereby allowing individuals to focus upon running their businesses, not “compliance”[565]. Currently, many US citizens are locked into terrible jobs because they cannot risk losing their family’s health care benefits. Our employers should not be expected to take care of our routine health care anymore than they should be expected to see to it that our kids have good public schools – both represent services that our government(s) should provide.

Leveling the playing field between “small” and large businesses will require cutting business-related red tape, simplifying the tax code, ending loopholes, and (maybe[566]) reducing the overall

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564 For example, the 590th ranked person in Forbe’s 2020 list of richest persons in each US state was relatively poor at having accumulated *only* $3.3 billion.

565 INEL/INEEL/INL’s employees were (are?) constantly reminded that “compliance” is their immediate employer’s overriding mission.

566 “Maybe” because replacing the USA’s self-serving health care system with one that better serves its people would require that its costs be paid with taxed, not after-tax, dollars. Its citizens total out-of-pocket expense would surely be less, but they would no longer be free to choose between premature death/misery and supporting a “socialistic” health care system that might prove be even more terrible for them than social security! One of China’s responses to the coronavirus pandemic is that it’s apparently finally decided to fully fund its public health system and thereby no longer subject its poorer citizens to the tender mercies of privatized medicine.

tax rate. Currently, although the USA's large businesses are nominally more heavily regulated, in practice they pay less taxes – sometimes none at all - than do small businesses because they can afford to out/off source more things and pay hordes of accountants, lawyers, and political campaign donations to create loopholes for them[567]. Industry-wide unions should be encouraged. Sweden's unions negotiate wages and therefore neither has nor needs minimum wage laws. Germany's big businesses have worker councils in which everyone comes together to cordially discuss how things should be run. Japan's auto industry did/does the same thing which is one of the reasons why its cars are so well designed, well made, and affordable[568].

Education – everyone should be given a fair and reasonable chance of getting whatever education from kindergarten to PhD they're both interested in and capable of absorbing[569] for nothing other than the willingness to work hard. Civics lessons should become a much more important part of that education (Shenkman 2008) and a voter registration requirement. A year or so of public service should also become a part of everyone's education. The "draft" used to serve that purpose for young US males neither rich nor "connected" enough to suffer from bone spurs. Many draftees learned skills/trades while so serving that subsequently became their means of livelihood[570]. Today's approach to school funding encourages/enables the super-rich to send

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[567] That's almost surely the reason that the USA's most recent businessman-president has consistently refused to release his personal income tax information.

[568] The sometimes-troublesome unions like those that the USA used to have would never have been necessary if its government had insisted that the majority of any business's "team" (e.g., its "associates') couldn't be treated as if they were expendable. Things are expendable, not people.

[569] This means free to anyone ready, willing, and able to learn what must be learned to master worthwhile subjects – no more "parapsychology" majors, social promotions, and parents buying their kids into exclusive schools (*"... today, FBI Authorities say its operation, dubbed Varsity Blues, uncovered 33 parents described as a 'catalog of wealth and privilege' had collectively paid $25 million to a college admissions counsel who , who had pleaded guilty and agreed to cooperate in an investigation into the 'widening corruption of elite college admissions'"* (NYTIMES 2019)). The USA's "best" colleges and universities – even state-supported ones - have been allowed to become too frivolous and too expensive (exclusive). On the other hand, Germans believe that education should not be considered a commercial product, its colleges shouldn't develop/support semi-professional sports teams, and that free access to higher education ensures economic growth and welfare for everyone.

[570] While I was completing the US Army's basic training during the Vietnam War, its leaders decided that I could best serve the nation (them) by becoming a hospital laboratory technician. The ensuing 3-4 month, on-the-job educational experience at Fort Ord's hospital was the second-most efficient that I'd ever experienced. (I'd been drafted out of graduate school and already had a brand-new MS in chemistry – my most efficient such experience had come a half decade earlier when two weeks of on-the-job training had turned me into the State of North Dakota's chief well water analyst). I soon became one of Ft Ord Army hospital's "night men" entrusted to handle any of the STAT requests that might come in during the 16 hours of each day when no one else was there. Of course, as soon as my two-year military obligation was up, I was no longer "qualified" to do such work anywhere else in the USA because each individual state allows its already-licensed civilian med techs to determine who might compete with them (that profession is just one of the USA's service-related "closed shops". US medical/dental/etc. schools are so expensive that many of its own bright young people can't afford to enter those fields).

their children to prestigious private schools and colleges while simultaneously doing whatever they can to short-change other peoples' kids[571]. It is not good for anyone except the people selling or providing such high-end services.

Energy – as I've tried to teach in this book, the amount of useful energy serving each person determines his/her lifestyle: happy/sad, rich/poor, free/entrapped, secure/precarious, etc. That energy must be "clean", cheap, reliable, genuinely sustainable, and sufficiently abundant to provide everyone with a lifestyle comparable to that of today's average European. That combination of characteristics could realistically be realized only with a properly implemented nuclear renaissance – not with biofuels, windmills, solar panel/towers or a few more-of-the-same unsustainable reactors.   This means that implementing this book's version of Goeller and Weinberg's "Age of Substitutability" represents a way for the next couple of generations of US citizens to do for themselves the same sorts of things that Franklin Roosevelt's "new dealing" empowered their great grandparents to do. DOE's management culture fosters poor team player[572] harassment which stifles innovation and enables the people nominally responsible for making such a renaissance possible to ignore that mission to better serve more immediate political/cultural/financial/personal interests.

10.3 Why the USA needs a Nuclear Green New Deal

The solution to the USA's malaise is relatively simple and should be recognized by everyone from the chairman of the Federal Reserve to the AFL-CIO's leadership. In fact, that labor organization perhaps worded it most succinctly in a piece titled, "How do we fix the U.S.

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[571] For instance, the most expensive/exclusive (currently ~$168,000/~2-year MBA degree) private business college is the University of Pennsylvania's Wharton School. That school is now especially famous because one of its professors (William Kelley) had famously opined that,   "*Donald Trump was the dumbest goddamn student I ever had*".

[572] In many cases simply asking "why" when unethical/unreasonable actions were observed resulted in harassment and shunning. I survived but did not thrive for over a decade after I'd crossed that Rubicon   (INEEL 1997, INEL 1996) because I was careful to initially submit my observations/suggestions up through the proper chain of command while reminding it/them that doing so is exactly what DOE's "ethics" trainers" had told us was the right thing to do. When I first began to wonder about how I should respond to some of the things that were happening, I had the good fortune to stumble upon a brilliantly written book, "The High Priests of Waste", authored by the US Federal Government's most successful defense-contracting system whistle blower (Fitzgerald 1972). When he was predictably fired for rocking the US Air Force's business-boat too much, Mr. Fitzgerald appealed to the Civil Service Commission and subsequently won reinstatement and promotion to the Senior Executive Service where he spent the next thirty years reminding his bosses that their favorite "pet elephants" ("too big to fail" contractors) were supposed to abide by the same rules that everyone else had to. Nevertheless, whenever those pets (e.g., Lockheed) were going through lean spells between big defense contacts, their close friends in high places continued to make sure that they could make a few bucks managing little things like the USA's national laboratories. For an up-to-date example of how that continues to serve taxpayers see https://www.rt.com/usa/451098-hanford-nuclear-lockheed-lawsuit

economy?" They declared that the first step must be "*to put America back to work because high unemployment keeps wages down. Our goal should be 'full employment', meaning everybody who wants to work should be able to find a decent job*."

It is up to our government's policy setters to incentivize the USA's employers & entrepreneurs to provide jobs to its citizens that are as worthwhile as they are "decent".

It's also up to that government's topmost bosses to see to it that its own employees do their jobs – answer their phones, respond to enquiries, and serve the purpose(s) that their department/agency was originally created to deal with – not just whatever they & their immediate supervisors want to do. For instance, during the last two years, it's been essentially impossible for an outsider like me to contact anyone at any of the USDA's offices, local, state, or federal, or any of DOE's national laboratories via the phone numbers listed on the websites - no one seems to be working at any of them "Working from home due to COVID" shouldn't mean not doing your job (if you don't believe me, give it a try.)

The Green New Deal has recently become a big part of policy debates in the US largely due to the efforts of Rep. Alexandria Ocasio-Cortez (D-NY), the youngest woman ever to be elected to the House of Representatives and expected to run for president in 2024. Her ambitious proposals address environmental issues that 60% of Americans say are already affecting their local community and promises to tackle economic inequality through the creation of unionized high-quality jobs. The Green New Deal has also been helped by the youth-oriented grassroots outfit Sunrise Movement, which organized a protest at Sen. Dianne Feinstein's office in February 2019.

That same month, Ocasio-Cortez and Sen. Ed Markey (D-Mass.) introduced a 14-page nonbinding resolution calling for the federal government to create a "Green New Deal". That resolution has over 100 Congressional co-sponsors, including several Democratic presidential candidates.

While the ideas behind a Green New Deal and the threat of climate change have been known to US politicians for almost two decades, it represents the most detailed plan yet to transform the economy presented to the American people, even though it really just is a congressional resolution outlining a set of principles and goals rather than definite policies. It calls upon Congress to pursue a "*10-year national mobilization*" that would zero out carbon emissions, reinforce our nation's infrastructure to better withstand natural disasters, develop an energy-efficient smart grid, upgrade all buildings to achieve maximum energy and water efficiency, and the list goes on, including guaranteeing everyone a "family-sustaining wage" and access to quality health care. Republicans characterize the resolution as a socialist plot to ban freedom and destroy capitalism. That's not hard to understand because it is a fundamental reimagining of the role of government harkening clear back to FDR.'s New Deal. It is also a rethinking of how to go about breaking Washington's climate policy logjam. Instead of fighting incremental battles on cap-and-trade and carbon taxes, it seeks to ignite a popular movement that would break through the USA's toxic partisanship with sheer will.

Unfortunately, like many other amateur environmentalists, Alexandria Ocasio-Cortez goes overboard saying things like, "The world is going to end in twelve years if we don't address climate change." Britain's most high-profile environmental group claims that "Climate Change Kills Children " and the world's most influential green journalist, Bill McKibben, considers it "greatest challenge humans have ever faced" and that it would "wipe out civilizations."

Mainstream journalists repeatedly report that the Amazon is "the lungs of the world," and likened deforestation to a nuclear war.

As a result, half of the people surveyed around the world last year said they thought climate change would make humanity extinct[573]. And in January 2021, one out of five British children told pollsters they were having nightmares about climate change.

To its supporters, climate change is a message telling us that many of Western culture's most cherished ideas are no longer viable. They view that crisis as one "*born of the central fiction on which our economic model is based: that nature is limitless, that we will always be able to find more of what we need*." Instead, the days of those Enlightenment ideals are over, our current world is "built on false promises, discounted futures and sacrificial people; and rigged to blow from the start and that capitalism must "*shift to a dramatically more humane economic model*".

I agree with most of their conclusions but certainly don't believe that creatures as clever as we will go totally extinct.

Circa 1980 the USA's espousal of "trickle-down economics" which was supposed to help everyone on our planet has instead demonstrated indifference to humans expressed in the exploitation of individual workers, the decimation of mountains, forests, aquifers, and rivers, and has instead trickled the world's wealth upwards to owner-investors intent upon swallowing everything of value. Things must change in the right direction because today's chaotic world could otherwise descend into a Mad Max barbarism evidenced by even more mass shootings, terrorism, and the rise of a doomsday eco-fascism that sees migrants driven out of their homeland by climate change as dangerous invaders. Unless there is radical change in the underlying values governing its politics, the wealthy world is apt to 'adapt' to more climate

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[573] Humans are too tough and resourceful to be totally wiped out by climate change. However, today's civilization along with most of its people could be wiped out by conflict and starvation if we don't address this book's issues ASAP.

disruption by unleashing toxic ideologies that rank the relative value of different peoples' lives to justify discarding the poorest to "save the planet".

The Green New Deal resolution does not mention how a country (meaning us) that's already ~$30trillion in debt (~30% greater than its current GDP) would pay for whatever it might cost.

In short, it states that the U.S. must take a leading role in reducing emissions because it is both technologically advanced and responsible for a disproportionate fraction of anthropogenic greenhouse gas emissions. That is correct because the very real "existential threat" to the planet posed by the continuation of "business as usual" renders that mission statement difficult (for some of us) to either ignore or dismiss. However, critics have called it too socialistic, too extreme, and/or too impractical. I concur with only the last of those characterizations because achieving its goals solely with more of today's politically acceptable renewable energy sources would be extremely difficult/expensive.

Michael Moore's latest and probably most controversial documentary, "Planet of the Humans" points out that the green energy movement's (e.g., the Sierra Clubs "Beyond Coal") biofuels, windmills & solar panels aren't going to save us from ourselves - "*It'll take something different*" (Moore & Gibbs 2020). That documentary characterizes green A-listers like Bill McKibben, Al Gore, Van Jones, Robert F Kennedy Jr, and Mark Jacobsen[574] as pompous environmental movement priests shilling for a fossil fuel industry that has somehow convinced them that burning "natural (fracked) gas" is perfectly OK as long as it's enabling our renewable energy entrepreneurs to build more windmills, solar panels, and woodchip/switchgrass/palm oil farms.

Another new movie, "*Juice: How Electricity Explains the World*" (AMAZON Prime $3.99) emphasizes the human story of electricity and explains why electrical power equals human power. It is based upon Robert Bryce's book, "A Question of Power" which goes into detail about renewable energy sources, battery storage, nuclear and other issues having to do with meeting the future's energy demand. It arrives at the same conclusions that Michael Shellenberger, James Hansen, Vlaclav Smil, Alvin Weinberg, and James Lovelock have about the need for a nuclear renaissance emphasizing its ethical/moral factors. The movie's makers gathered forty interviews with people from seven countries on five continents. Those interviews explain how electricity explains everything from women's rights and climate change to Bitcoin mining and indoor marijuana production. It also explains who has electricity, who's going to get it, and how developing countries are trying to bring their people out of the dark and into the light.

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[574] Dr Jacobsen unknowingly wrote one of the best wind power jokes I've heard yet when he suggested that installing thousands of offshore wind machines on the USA's Atlantic coast would diminish hurricane energy and thereby eliminate onshore damage. He apparently didn't realize or care how expensive such wind wreckage would be or how propellers don't slow winds unless their shafts are loaded and generators don't load shafts unless their electrical outputs are loaded. A wind turbine's self-protection system prevents either from happening during gale, let alone hurricane, force winds (Alex Cannara).

It includes a section pointing out the flaws in the modeling behind the claims supporting 100% renewables. What makes that film and book more useful than Moore's "Planet of the Humans" is that it puts human and social values first. Many of us are not used to thinking quantitatively about technical things but can recognize and do want to promote social justice. Moore's movie is not as useful because it does not provide hope to anyone unable to connect its obvious (to-me) dots leading to a conclusion that nuclear power represents the most promising pathway forward. After identifying the reasons that wind, solar, and batteries wouldn't work, its producers basically just conclude that we are all doomed.

Unfortunately, in addition to the Democratic left's addiction to indignation and impractical politics, it seems to also have an aversion to quantitative reasoning as evidenced by

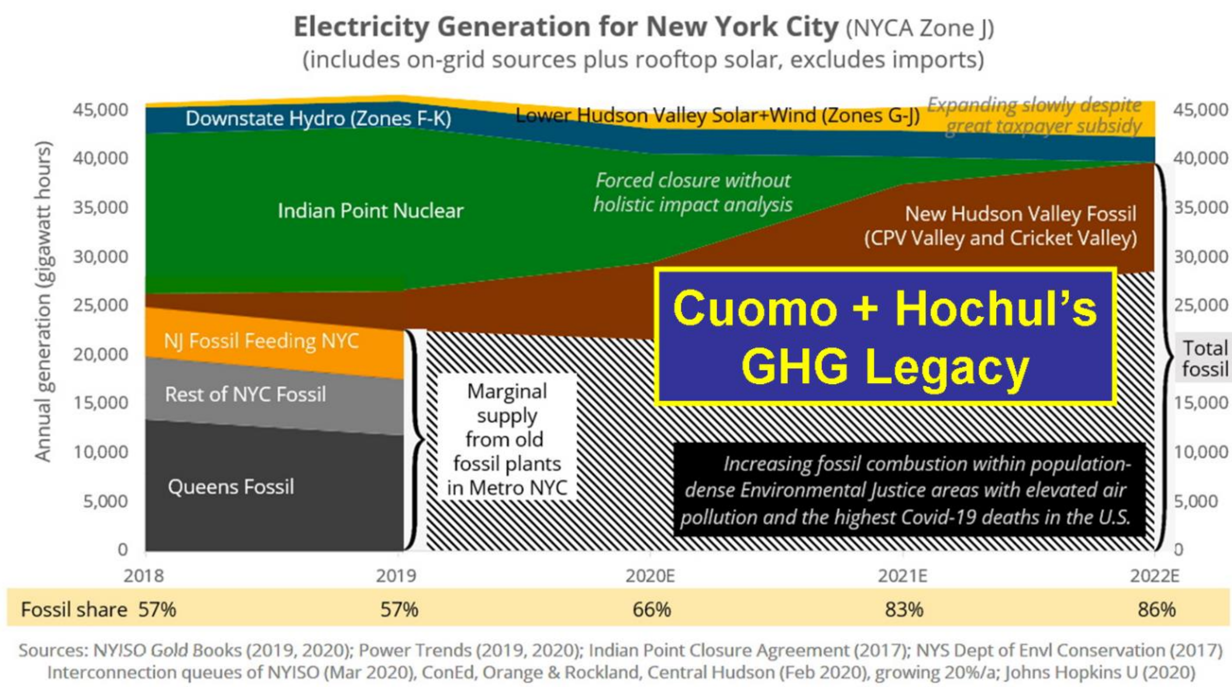

Figure 87 Cuomo's GHG legacy

New York Governor's decision of shut down his state's Indian Point nuclear reactor (Figure 87). I'm hoping that the current crop of liberal presidential candidates lobbying for a "green new deal" take another look at the assumptions underlying their apparent faith in Amory Lovins , Bill McKibben, Al Gore & Mark Z. Jacobson et al.'s technically unrealistic 100% renewable energy schemes.

The clean electricity payment program outlined in Mr. Biden's 10-year $3.5 trillion budget framework would incentivize utilities to source 80% of their power from carbon-free sources by 2030. A quarter of US greenhouse gas emissions arise from its electrical energy sector and most of its climate experts agree that it's vital to transition to carbon-free sources including nuclear power for all of its economy's "sectors" ASAP – preferably instantaneously.

Protecting the environment and lifting the developing world out of poverty are progressive causes which hopefully will cause millennials and Gen Xer's to rethink opinions that their boomer parents have not reexamined since they grooved at the Doobie Brothers' "No Nukes concert" forty years ago. Most of them would be delighted to don blue MAGA hats if the technologies underlying the Democratic Party's "green" proposals had a better chance of serving their nominal purposes.

As the enormity of the Anthropocene's climate crisis finally sinks in and the hoped-for carbon savings from politically correct renewable energy "farms" aren't realized (Moore 2020), a properly implemented nuclear fuel cycle could become the "new green". However, that can happen if & only if the people responsible for working out its "technical details" and making decisions do their jobs which is unlikely unless their employers begin to insist that they do. They should all be prioritizing sustainability, resiliency, equity, reliability, and security, not short-term expedience, particular technologies, or green-sounding slogans.

The following paragraph was cut & pasted from an essay that the UCS (Union of concerned scientists sent me about two months ago (12/12/2020) - it pretty much explains why we're not apt to be leading the world in that field or anything else that's "controversial" when 2050 rolls around.

"*It is also critical to consider that such changes, while appearing reasonable, are unlikely to occur. In many ways, the American system of government is failing. It no longer appears capable of operating for the benefit of the public, even when threatened by external forces. Indeed, there appears to be no incentive for elected leaders to even try to look out for the public. The connection between representation and electability has been broken by the two-party system. Ideally in a democracy, there is a connection between leaders and constituents, whereby leaders hope to lift themselves up by serving their country and helping to improve the lives of their followers. But the two-party system in the United States has circumvented that connection, creating rules to consolidate power in contradiction to the implementation of effective governance. Elected leaders are more loyal to their party than to their country or their constituents, and the system ensures that they are punished by their party more than by their constituents. When a government cannot protect its people, then it has failed at its most central and important task. Many argue that COVID is such an example*."
https://thebulletin.org/2020/12/revenge-is-a-dish-best-served-nuclear-us-deterrence-depends-on-it/?utm_source=Newsletter&utm_medium=Email&utm_campaign=ThursdayNewsletter10102020&utm_content=NuclearRisk_RevengeServedNuclear_12042020

Finally, I also hope that the nuclear establishment's ayatollahs become willing to question their own assumptions and dictates. Nuclear power should, could, and must become "renewable, not just a temporary bridge to a future primarily powered with "all of the above" ***except*** nuclear energy.

Electrifying the USA's residential, industrial, agricultural, and transportation sectors via the development and implementation of an appropriately scaled and genuinely sustainable nuclear renaissance would provide millions of genuinely good jobs/professions for its citizens – not just more short-term service-type gigs.

10.4 The Chinese Juggernaut

The final reason that the USA must change is that China has already succeeded in making itself great again and can now do "technical" things much more efficiently than we can. Under the rule of Deng Xiaoping, Beijing began to reform its economy by encouraging private enterprise, liberalizing trade and investment regulations, and investing in industrial production. Through those long-term efforts, China has been able to maintain vastly greater levels of productivity growth than either the USA or Soviet Union. Its powerful economy means that China is better equipped to withstand the stresses of prolonged geopolitical competition with the West than is Russia. In contrast to the West's perpetual dithering, overregulation, cost overruns, and bankruptcies, China has been steadily firing up state-of-the-art light water reactors, its new fast reactor went to full power before Christmas 2014 and has begun construction of a new high-temperature gas-cooled nuclear reactor (Chinese HTR) in April (2015) (Forbes 2015). Nuclear power's percentage of China's total installed power capacity doubled between 2014 and 2019 and that growth rate is expected to continue for several decades. Plans are for 200 GW installed by 2030 and 1500 GW by the end of the century, most of which are to be some sort of fast breeder .

According to Professor Charles Forsberg

> "*China's energy strategy is simple - push all possibly credible energy technologies up to and including full sized pilot plants because the cost of such development will be small compared to deploying any technology at a scale relevant to meeting its energy demand. Even if some of those development efforts don't pan out, the overall cost savings at full deployment of those that do will far exceed total technology development costs. At China's scale it's a simple and cost-effective strategy that will render it difficult for any western country to compete in international energy markets. Consequently, China will likely dominate the future's energy production technology market in every field from PV to nuclear*[575].

Most of the USA's current energy gurus don't have a clue of either what it will take to solve the world's energy conundrum or what their competition really is.

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[575] Between 1860 and 1920 the U.S. dominated global rail equipment markets because of its then-huge home market's economics of scale.

Consequently, since circa 1978 China has been demonstrating that it is possible to incentivize its entrepreneurs to do whatever is necessary to address its peoples' "technical issues" without ceding control of those efforts' goals and directions. That has been done by lending state support to targeted industries and technologies, particularly those infrastructure-related activities required to address those issues. We should also not forget that China is already heavily involved in African development as a part of its 65-nation "Belt and Road" initiative. The opinion of some Western World politicians that such activity is necessarily "greedy and evil" is wrong-headed. It is a excellent example of "*help-your-neighbor globalization, not colonization, and African agency, not Chinese rapacity* "(Bräutigam 2018).

China's current GHG pollution rate currently exceeds that of all other wealthy-countries combined but its leaders have seized upon all new/cleaner energy technologies for reasons largely *unrelated* to climate change - not because they want to become climate heroes. Because of China's dependence on Middle Eastern oil and American natural gas, its government has encouraged the development of as many energy resources of all sorts within its borders as possible, the majority of which was and remains coal. The damage engendered by the resulting toxic air pollution has encouraged to develop as much low-emissions energy as possible. Consequently, President Xi Jinping has pledged to bring China's total wind and solar capacity up to 1200 GW and to cap its carbon emission to a peak by 2030. See China aims to build 450 GW of solar, wind power on Gobi desert, Energy News, ET EnergyWorld (indiatimes.com).

With respect to addressing both its and the rest of the world's environmental issues "Bloomberg New Energy Finance" https://www.theguardian.com/business/2021/mar/10/china-leads-world-increase-wind-power-capacity-windfarms reports that China built more new "clean" power plants in 2020 (58 GW's worth of wind plants alone) than did the rest of the world combined during 2019 . That effort contributed to a new world-wide windfarm installation record (100 GW) despite of its recognizing/reporting the first cases of what US President Trump called "the Chyna Flu" (Covid-19). Most of its new windfarms were built onshore because it's much cheaper to both build and maintain them there which more than offsets a 20% drop in capacity if built at sea instead.

China's wind power surge coincided with a much smaller US boom where its developers rushed to install another 16.5 GW of new wind capacity before the phase-out of another of our government's tax credit subsidies.

The USA's 2020 windfarm installation rate was three-quarters higher than during 2019 and well ahead of its previous new installation record set in 2012 just before another investor-bait subsidy was phased out.

China's leaders realize that countries that develop a technology first tend to benefit the most and, that by acting early, their industries will learn to make the next-generation's cleaner gadgetry more quickly, cheaply, and efficiently and thereby gain competitive advantage over its international competitors.

They are also willing to change priorities if something doesn't work out as anticipated – not keep hammering away trying to do it in the same fashion. Consequently, the priority of the People's Republic of China (PRC) biofuels projects continue to wane and investment in the sector has declined. Post estimates China's 2022 ethanol blend rate at 1.8 percent, down from 2021 and well below the peak blend rate of 2.8 percent eleven years ago. To back up its massive buildout of wind and solar energy plants in its western provinces, it's also apparently decided to ramp up nuclear plant expansion from a targeted six to eight to 10 reactors per year China's Nuclear Industry Says It Can Accelerate Expansion Plans - Bloomberg

The USA used to be good at developing new ideas and then converting them to commercially successful products. In the 20th century, Americans invented the key technologies underpinning the automobile, the airplane, nuclear reactors, transistors, computer chips and then successfully commercialized them. It's still a research/innovation leader but not a *technological* leader. Very little of the high-tech gadgetry that even its own citizens routinely rely upon - cellphones, TVs, computers, microwave ovens, etc., etc., roll off American assembly lines. The US has lost the ability to translate much of its citizens' world-class ideas and research into marketable goods that they buy. For example, U.S.-funded research at U.S. labs produced the first solar panel in the 1950s. However, its government declined to develop a market for them which means that by the 1980s, it was Japanese, not American, firms that successfully brought solar panels to market. Since then China has come to dominate that market too as it has with lithium ion batteries, integrated circuits, light emitting diodes, etc. The USA needs to embrace the policies – tax credits, purchase guarantees, and subsidies *funded in the Build Back Better bill* to assure its researchers, entrepreneurs, and investors that a market will exist for any new innovations that they can develop into competitive products.

China's nascent nuclear renaissance represents the kind of wholesale energy transformation that the Western democracies — with their self-imposed budget constraints, short attention spans, lack of political will, bribable politicians, and confused public opinions — can only dream about. It could also support China's goal to export its technology to the developing world and beyond, buoyed by 2021-2022's energy crunch that's been highlighting both the fragility of other clean power sources and the costs of fossil fuels. Slower winds and low rainfall have led to lower-than-expected supply from Europe's dams and wind farms, worsening their crises, and expensive coal and natural gas have led to power curbs at factories in the EU, China, and India.

China keeps exact costs a state secret, but analysts including Bloomberg NEF and the World Nuclear Association estimate that it can build new reactors for about $2,500 to $3,000 per kilowatt, under one-third of the cost of recent projects in the U.S. and France.

One of the reasons for this is that about 70% of the cost of Chinese reactors are covered by loans from state-backed banks, at far lower rates than other nations' reactor builders can secure. That makes a huge difference because most of the cost of new atomic energy is upfront reactor construction costs. At 1.4% interest, about the minimum for infrastructure projects in places like China or Russia, "new" nuclear power costs about $42 per megawatt-hour, far cheaper than coal and natural gas in much of the world.

To help address its need for cleaner electrical power while its affordable breeding-capable reactors are being developed, China is relying upon 27 conventional nuclear reactors and another 25 Generation III+ LWRs currently under construction. It also intends to build an additional fifty-seven more to generate a total nuclear power capacity of ~200 GW_e by 2030 – twice that of the USA. China's decision to greatly accelerate nuclear power plant construction was prompted in part by broader energy security concerns. Its planners remain convinced that China's capital investment–led growth model would continue to assure high economic growth, if underpinned by a commensurate increase in its ability to supply base load (reliable) electricity[576]. Its leadership is also aware of the fact that all fossil fuels will soon "peak out" and that it would be better for everyone if we all quit using the atmosphere as a waste dump.

In 2008 China officially adopted the Westinghouse-designed Gen III+ AP 1000 as its standard for inland nuclear projects In April 2009, it started building the first of four new units reflecting that decision. The first two of them were constructed at the Sanmen Nuclear Power Plant in Zhejiang and the third and fourth at the Haiyang Nuclear Power Plant in Shandong, China.

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[576] On the other hand, the USA's energy marketing-based business models are rapidly "retiring" its most reliable clean power plants. Of the ~9 GWe's worth of non-intermittent generation capacity scheduled to be shut down in 2021,   5.1 GW represents five nuclear reactors and sets a record for the most annual nuclear capacity loss ever. https://www.worldcoal.com/coal/13012021/eia-nuclear-and-coal-to-account-for-majority-of-us-generating-capacity-retirements-in-2021/

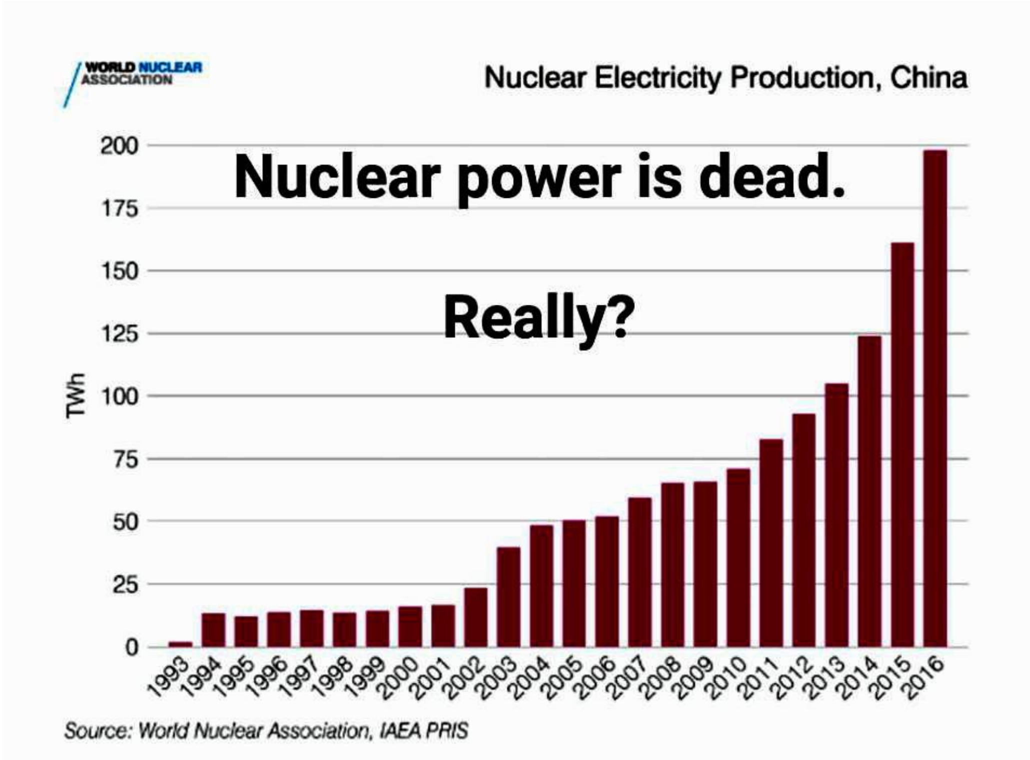

Figure 88 China's solution to global warming

The Sanmen Unit 1 and Unit 2 AP1000s started commercial operation on September 21, 2018, and November 5, 2018, respectively. Haiyang Unit 1started commercial operation on October 22, 2018, as did its Unit 2 on January 9, 2019.

Following Westinghouse's bankruptcy in 2017, China decided in 2019 to build the domestically “optimized ”Hualong One reactor rather than the AP1000 at Zhangzhou.

The state-run China National Nuclear Corporation (CNNC) China has started construction of the first commercial onshore small modular reactor (SMR) nuclear project using its homegrown “Linglong One” 125 MWe design. That reactor also known as the ACP100, was the first SMR to be approved by the International Atomic Energy Agency back in 2016.

It was designed to complement CNNC’s full-size, third-generation 1,170 MW “Hualong One” LWR-type reactor, which China is planning to rapidly roll out at home and promote overseas.

SMRs are cheaper and quicker to build than are traditional reactors and can be deployed in remote regions and on ships. Their “modular” format means they could be shipped by container from the factory and installed relatively quickly on any proposed site.

China has been looking into using them to provide urban heating in the north, run desalination facilities along its coastline, and support construction activities in disputed parts of the South China Sea.

https://www.reuters.com/world/china/china-launches-first-commercial-onshore-small-reactor-project-2021-07-13/

Chinese fast reactor research and development began in 1964. Its 65MWt/20 MWe CEFR was designed by 2003 and built by Russia's OKBM Afrikantov in cooperation with OKB GIDROPRESS, the NN Dollezhal Research & Development Institute of Power Engineering (Nikiet) and the Kurchatov Instituteclinton CEFR. It achieved criticality in July 2010 and connected to the grid in July 2011. Its core is 45 cm high and contains 150 kg of reactor grade plutonium (~ 98 kg of fissile ^{239}Pu).

In 2017 China National Nuclear Corporation (CNNC) started construction of its CFR-600 pool type sodium-cooled fast reactor in Xiapu County, Fujian province. (China's leadership considers a 600 MWe, 1500 MWt reactor to be a (big) pilot plant.) It 's a medium-sized fourth-generation advanced nuclear reactor featuring two coolant loops and esigned to operate with 380°C and 550°C of inlet and outlet core temperatures, respectively.

It will be first loaded with uranium oxide (UO_2) and then converted to run on mixed oxide (MOX) fuel. The breeding ratio of the reactor will be 1:2.

The CFR-600 demonstration fast neutron reactor is anticipated to increase the utilization rate of natural uranium resources from the current one percent to more than 60 percent.

The instrumentation and control systems of the reactor will be digitized and optimized based on the data collected from its predecessor, the China Experimental Fast Reactor system.

The reactor vessel, main vessel, and protection vessel designs will follow the ones used in the CEFR.

In December 2020 construction of a second CFR-600 began at the same site. Their fuel is to be supplied by Russia's fuel company TVEL (part of Rosatom) under a contract signed in 2019 with CNLY, a subsidiary of China National Nuclear Corporation (CNNC). TVEL already supplies fuel for the China Experimental Fast Reactor (CEFR) at the China Institute of Atomic Energy (CIAE) in Beijing under a contract with China Nuclear Energy Industry Corporation (NEI 2021).

"*The scale of engineering work, tight schedule, construction difficulties and other adverse conditions have been overcome to achieve the planned goal", the report said. "All builders will continue to work hard on the Fast Reactor Demonstration Project to fulfil the "historic mission of making China a historic nuclear industrial power that contributes even more*".

CIAE's CFR-600 "demonstrations" represent the next step in China's reactor development program. The first of its two pool-type LMFBRs is slated to come online in 2023. They will have two sodium coolant circuits and shutdown systems with passive residual heat removal. To begin with, both will utilize mixed oxide (MOX) fuels with burnups of ~100 GWd/t but are slated to switch over to metallic fuels with burnups of ~120 GWd/t. Their ~1.1 breeding ratios will demonstrate China's commitment to establishing a closed, genuinely sustainable, nuclear fuel cycle.

A larger, commercial-scale (to China), CFR-1000 LMFBR is on the drawing board.

Even more important, China has decided to commit 22 billion yuan ($3.3 billion) to developing the molten salt reactor concept that the US abandoned almost 50 years ago. That effort will no doubt be facilitated by its decision (25March 2019) to collaborate with France – a move that is likely be welcomed by the folks responsible for developing/studying the MSFR. Two almost-hot-off-the press videos (November 2020) demonstrate the difference between the Western World's and China's approach to solving their "sustainability" issues.

One of them (https://www.youtube.com/watch?v=wSfSC3Y81zU) shows China quickly building a huge $multibillion molten salt reactor (MSR) R&D Complex which is to be immediately staffed with its best & brightest, already-educated, scientists and engineers[577]. Its first reactor the 2MWt TMSR-LF1 - Wikipedia has just been finished & will be starting up before the end of 2022. It's an updated, breeding blanket equipped "copy" of ORNL's MSRE utilizing a graphite moderated : FLiBe (>99.95% Li-7) fuel salt contining the fluorides of zirconium, uranium (HALEU: 19.75% U-235), and thorium

On the other hand, here in the USA our Department of Energy (DOE) is issuing "letters of support" to colleges that hope to eventually succeed in convincing its Nuclear Regulatory Agency (NRC) to allow them to build a much-compromised version of the tiny (8 MW) "Molten Salt Reactor Experiment" (MSRE) pilot plant built/run at its Oak Ridge National Laboratory (ORNL) over a half-century ago.
https://www.patreon.com/posts/molten-salt-msrr-44081272?utm_medium=post_notification_email&utm_source=post_link&utm_campaign=patron_engagement

In April 2021, China's leaders committed to build an underground bunker "laboratory" 500 meters below the surface of the GOBI desert to see if its high-level reprocessing waste can be safely disposed of therein China builds bunker to test whether nuclear waste can be dumped underground | South China Morning Post (scmp.com). It will be the world's largest such laboratory, take seven years to build, operate for 50 years and cost taxpayers ~2.7 billion yuan (US $400 million, only ~3% of what US taxpayers ended up paying for DOE's aborted "study"

[577] China's first molten salt test reactor has just been completed and is scheduled to go "hot" during 2022.

of Nevada's Yucca Mountain. If China's research proves that/their site to be suitable (it will – it's not really all that difficult to find such sites in countries with big deserts in them), a long-term underground repository for its high-level radioactive waste will be built nearby by 2050.

10.5 The Russian Juggernaut ?

Russia's economy is heavily focused upon energy (it's a "petrostate" among other things) and has been lengthening its strategic penetration by encouraging/enabling the EU's reliance upon today's unreliable "renewable" sources which have rendered its nations more heavily dependent upon Russia's "cheap" piped-in gas. Meanwhile it continues to develop nuclear technologies to sell if/when the West's decision makers realize the probable consequences of trying to power themselves with political correctness.

The United States hasn't been the world's predominant reactor builder for over two decades – that's another "technical" honor currently held by Russia. In 2018, of the 72 nuclear reactors planned or under construction outside Russia's borders, under 3 percent were being built by U.S. companies and over 50 percent by Russia's "Rosatom State Nuclear Energy Corporation".

Russia's first sustainable fuel cycle-type (breeder) reactor, the "BR-1", was designed in 1949 and commissioned at Obninsk in 1955 –four years after the world's first breeder reactor - the USA's "EBR I" - was first fired up at Idaho's National Reactor Testing Station (it's now "INL") . After that, two more Russian reactors, the   BR-5 and BOR-60, were commissioned & tested, both there and at the Research Institute of Atomic Reactors (RIAR) in Dimitrovgrad. They paved the way via an intermediate–sized (1000 MWt, 125 MW_e (most of its heat energy was used to desalinate Black Sea water) loop-cooled "BN 350", to Beloyarsk's first, almost full-sized, pool-type LMFBR, the BN-600, which has been generating 600 MW of "clean" electricity since 1980. Based upon its success, construction of the still-bigger BN-800 began in 1984. However, after the incompetent bureaucracy-caused 1986 Chernobyl disaster and subsequent collapse of the USSR, the BN-800's construction was suspended until 2006, after which it was completed and brought up to a minimum-controlled power level for several years' worth of additional testing. In 2014, it was finally connected to the grid reaching full power (800 MWe) by the end of 2016 thereby reclaiming Russia's ownership of the world's most powerful sustainable reactor.

Its VVER-1200 (or NPP-2006 or AES-2006)[6] is an evolution of its VVER-1000 (its most popular pressurized water reactor) offered/built for both domestic and export use refined to optimize fuel efficiency. Specifications include a $1.20 per W overnight construction cost[578], 54 month planned construction time, a 60-year design lifetime at 90% capacity factor and requiring about 35% fewer operational personnel than does the VVER-1000. It will have a gross and net

[578] That about 10% of what's been spent trying to build Plant Vogtle's two new AP-1000 PWRs here in the USA.

thermal efficiency of 37.5% and 34.8% respectively and produce 1,198 MWe of power." VVER - Wikipedia

Its Generation IV BN-1200 breeder reactor is an updated version of its BN-800 LMFBR expected to produce cheap, clean, electricity while exhibiting a breeding ratio of 1.2 to 1.45 depending upon fuel type (oxide or nitride)... Thermal power should be nominal 2900 MW with an electric output of 1220 MW (42% gross, net 39%, heat-to-electricity conversion efficiencies). The World Nuclear Association characterizes it as a commercial reactor BN-1200 reactor - Wikipedia because it's just an updated version of its BN-800 breeder modified to render it more economically attractive and satisfy Generation IV reactor safety criteria. To improve economics, it uses a simpler fueling procedure than that of the BN-600/800 and has a longer, 60, not 40-year, design lifetime. Safety enhancements include elimination of outer primary circuit sodium pipelines and passive emergency heat removal. It's expected to produce electricity for 2.23 US cents/kWh – about 20% as much as I'm currently paying for ~36% wind-generated electricity here in the USA's most wind-powered region (Iowa).

When fueled with mixtures of recycled uranium plus inbred plutonium, it would create from 20 to 45% more fissile (fuel) than it burned which means that a properly implemented nuclear renaissance could cleanly (zero greenhouse gas emissions) satisfy 100% of humanity's power demand (~20 TW) for over a million years without running out of cheap (readily available) fuel.

Overall, Russia's sodium-cooled fast reactors are like those developed/utilized elsewhere. For economic reasons its BN reactors have always utilized ^{235}U-enriched UO_2 fuel but were originally designed to be sustainably fueled with UO_2/PuO_2 mixed oxide (MOX) fuel as were France's and the U.S.A's fast breeders.

Whether any of Russia's other LMFBRs were ever operated as breeders/suppliers of anything other than weapons-grade plutonium was unknown to me up until 20SEP2022, but there's no reason to expect that they couldn't have been operated in that fashion if it had made economic sense to do so at that time[579].

[579] Demonstrating nuclear power's "sustainability" constitutes a sales pitch unmatched by any other country's offerings which is likely the reason that Russia has just announced that its BN 800 is now entirely fueled with recycled/reprocessed fissile Beloyarsk BN-800 fast reactor running on MOX : Uranium & Fuel - World Nuclear News (world-nuclear-news.org). What's going into its fuel wasn't specified but if it's like every other MOX facility that I'm aware of, the Russkies are probably discarding their spent fuels' "minor actinides". Pu only is usually recovered/recycled because it's simpler & makes economic sense, not because it's impossible to recycle all of the transuranics. Here in the WEST the hows of fuel recycling are determined by trans scientific, not technical, factors mostly related to how we feel about "waste". Russia doesn't always play by the same rules & is therefore not so likely to cripple itself with stupid assumptions & over regulation.

This brings me to another of the quirks of human nature responsible for the western world's inability to solve "obvious" technical problems. When we don't like a person, we also reject everything that they may have ever said or stand for. Hitler was right about his country's need for interstate highways & a "people's car" regardless of what else he did or said.

In October 2021 Russia's President Putin told Russian Energy Week [Putin: German nuclear phase out 'does not make any sense' : Energy & Environment - World Nuclear News (world-nuclear-news.org)]. that

- *Russia has set a target of 2060 to reach net-zero carbon dioxide emissions*
- *energy system decisions should be made by technical experts not politicians*
- *It is critically important to take an impartial inventory of the carbon footprint created by different types of energy generation and stick to technological neutrality principles ,*
- *nuclear exports should count as contributing towards global decarbonisation*
- *fossil fuels will play a major role in the global economy until as late as 2045. "According to expert estimates, in the next 25 years, the share of hydrocarbons in the global energy balance may decline from the current 80-85% to 60-65%."*
- *the role of oil and coal will go down whereas the role of natural gas as the cleanest 'transitional' fuel will go up " and Russia plans to capitalize on this by upping its production of liquefied natural gas to "strengthen our positions in this market and occupy about 20% of it owing to low production costs and competitive logistics."*
- *In terms of clean energy, he noted Russia's experience in nuclear, including fast reactors, small reactors, and its goal to close the fuel cycle. "Building on the achievements in this area, we will continue to export nuclear technology and thereby contribute to decarbonising the global energy sector,"*
- *Germany and Belgium's complete phase out of nuclear power "does not make any sense",*

The fact that Mr. Putin is a mudak (asshole) doesn't necessarily mean that he's wrong about nuclear energy or other "technical" issues. Russia has repeatedly demonstrated that it's possible to build big, safe, clean, nuclear power plants of any type that makes sense to its customers for much less than doing so would cost here in the homeland of privatized oligopolistic, "free enterprise"

To address this book's key-most technical issue the western world apparently needs Russian help or at the very least, to mimic its approach to addressing important technical issues. We need lots of cheap & hopefully more sustainable nuclear energy, not something that's "safer" than something that's already safe. Russia's nuclear industrialists have repeatedly proven that they're able to both build and operate full sized "breeder" (sustainable) power reactors and that its/their future success lies in helping the rest of the world catch up to them. If the USA's topmost decision makers were serious about such things, they'd go hat-in-hand to Russia's nuclear power oligarchs & work out some way to build lots of BN-1200s over here in the land of the "free".

Consequently, our leaders should be making it crystal clear to that country's oligarchs, industrialists, & super patriots that Mr. Putin's leadership is hurting their businesses & their country and he should therefore be "retired" ASAP by whatever means they see fit.

Chapter 11. **Suggestions for improvement**

After I'd retired & had finally gotten enough extra fishing done, I decided to determine for myself whether the world really did need a "nuclear renaissance", the development/promulgation of which had become INL's "new mission". It turned out that world does need to implement (not just "develop" or "study") one in a way that renders its power renewable (inexhaustible/sustainable) as well as reliable, cheap, and clean; i.e., a nuclear renaissance based upon breeder-type ("renewable" fuel cycle) reactors .

That's the rub - the same institutional "symptoms" responsible for the US DOE's radwaste boondoggling (see NAP 1996) were causing it to fail in its "new" and far more important mission as well. The root cause turned out to be the same project mismanagement "symptoms" responsible for DOE's turning the treatment/disposal of Hanford's and INL's "high level wastes" (HLWs), opening a HLW repository, & building its most recently proposed MOX-type fuel factory, into festering $multibillion boondoggles.

My own personal experiences within its laboratories along with what continues to happen after I had retired leads me to suspect that most of its nuclear engineers/scientists are still understandably not "really serious" about much other than continuing to study their own little non-controversial piece "all of the above" until they can comfortably retire too. One of the consequences of this is that after decades of not-so-benign neglect, the entire U.S. commercial nuclear sector, from uranium mining through power generation, is now insolvent. The USA has lost its global position as world leader in nuclear power development/progress because the individuals and agencies collectively responsible for keeping it there adopted "comfortable" paradigms that defeated attempts to restore that leadership. Rapid innovation is the reason why after millennia of stagnation, the last three centuries have featured sudden, dramatic technological advances and therefore in human living standards, from steam engines to search engines, from vaccines to vaping.

Rapid advances are also localized and temporary phenomena. At any one time, there is usually just one part of the world where innovation flourishes attracting talent from everywhere else: China since 1980, US from 1945 to 1980, California from 1960-2002, the U.S. East Coast in 1920, Britain in 1800, Holland in 1650, Renaissance Italy in 1500, Abbasid Arabia in 800, Rome in 200 BC, ancient Greece in 500 B.C., & Egypt two thousand years earlier. However, history tells us that when a "business" model" for a big technical breakthrough becomes firmly established, stagnation and bureaucracy inevitably take over & significant progress stops - another example of Gould's "punctuated equilibrium" thesis. Consequently, the USA has since ceded its once-lofty position to Russia, China, South Korea and other "developing" (not stagnating) countries possessing state-owned nuclear enterprises willing to do "controversial" but sensible things.

For instance, China's Haiyang nuclear power plant in Shandong province is now providing district heat to the surrounding area rather than simply throwing away the ~two thirds of its water-cooled reactor's heat energy wasted by its steam plant's condensers . Beginning in September 2020, Shandong Nuclear Power Company (SDNPC) - a subsidiary of State Power Investment Corporation (SPIC) and the owner of Haiyang plant - cooperated with local thermal company Fengyuan Thermal Power to conduct a trial operation of the entire heating pipe network. At the end of October, a trial using steam from Haiyang's two AP1000 reactors was carried out. On 12 November, the entire heating network began low-temperature trial operation. This was completed on 15 November and the system is now in commercial operation.

It extracts non-radioactive steam from the secondary circuit of the two Haiyang units, which is then fed through a multi-stage heat exchanger. This heat is then fed to an off-site heat exchange station belonging to Fengyuan Thermal Power, from where heated water flows through municipal heating pipes to its consumers.

China's latest redemonstration of such an old and obvious nuclear energy application [580]is expected to head off the burning of 23,200 tonnes of coal annually thereby cutting soot emissions by 222 tonnes, sulfur dioxide by 382 tonnes, nitrogen oxide by 362 tonnes, and carbon dioxide by 60,000 tonnes.

Russia, several East European countries, Switzerland, and Sweden have all implemented nuclear district heating schemes, and such useful heat has also been sent to industrial sites, not wasted. To date the USA has insisted upon siting its reactors so far from residential and business areas that doing something as reasonable as is that almost impossible[581].

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[580] Russia has been doing the same thing for several decades.

[581] About forty years ago I did some analytical consulting work at one of DOE's geothermal power demonstrations in So East Bum...k Idaho. That power plant never did produce much electricity (its biggest problem was that its pipes and heat exchangers quickly plugged up with a very tough hydrothermal mineral scale) but its "spent fuel" (still-warm, salt & silica-saturated, runoff water) was run downhill through a string of greenhouses which kept everything within them nice and steamy. The veggies and flowers grown in them really thrived in that region's

Because the USA never did decide to implement any sort of real nuclear renaissance, the University of Illinois is purportedly planning to heat its Urbana campus with an underground "micro" nuclear reactor featuring a fuel "cartridge" that's supposed to last for 20 years. They are working with Ultra Safe Nuclear Corporation (USNC) to partially replace a coal-fired plant, seeking DOE funding and preparing a NRC license application
MMR Energy System (usnc.com) . Its proposed 15 MWt reactor core would consist of hexagonal graphite blocks containing stacks of Ultra Safe's FCM™ (TRISO-type) fuel pellets. Its MMR™ core features a low power density and high heat capacity resulting in very slow and predictable temperature changes. It's also so small, simple, and ultra-durable that there's no way that it could melt down or "explode" regardless of how stupidly its operators might behave.

Dartmouth had already rebuilt its circulating hot-water district heating system in anticipation of a planned wood chip burning plant, but that proposal was dropped because its smarter students pointed out its probable environmental impacts. Dartmouth continues to burn 3.5 million gallons of No. 6 fuel oil annually while its deciders seek a better energy source. The USNC reactor concept would 15 megawatts of heat which approximates Dartmouth's heating demand.

We'll see what happens, but I wouldn't bet even your farm that either of those campuses is micro reactor-powered a decade from now.

Socialist economies have massively different priorities and are impervious to the capitalist drive for short term profits. The first and essential priority of any socialist economy is the betterment of living conditions for all of its citizens including its oligarchs. In practice, this means elimination of poverty and the provision of adequate food, clothing, shelter, education, health care, transportation, for everyone

History suggests that deregulated capitalistic economies are unable to plan or achieve national goals except during officially recognized wartimes at which time their governments take control of their economies. The best that a self-interest driven capitalist can do is to plan and then implement an individual enterprise such as convincing his country's decision makers to mandate the use of whatever product or service he is selling. In a purely capitalistic economy that's all that an individual company's decision makers are rewarded for doing.

Even in a democracy like Germany which was well on its way to conversion to full nuclear-generated electricity, "green" activists and clever renewable energy entrepreneurs collectively succeeded in having its nuclear power plants replaced (almost) with thousands of windmills and millions of solar panels backed up with new soft coal and gas fired peaker plants. That's

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otherwise desert-like climate. There was also some talk about trying to sell carp raised in its cooled-off water. That didn't work out either (Idahoans covet trout and salmon, not carp).

seriously raised its citizens cost of living and also increased its dependency upon Russia's natural gas, Sweden's nuclear and hydro power) and France's nuclear .power. In a planned or "socialist" economy, its people deliberate upon what their country should accomplish with its material and intellectual resources and then choose leaders that will get it done. Sweden, Norway, Cuba, and China provide good examples. Immediately after the revolution that kicked out its capitalistic dictator, resource-poor Cuba (almost no coal, oil, gas, bauxite, iron ore, etc., etc., and continuously subjected to crippling US mandated trade embargoes) decided to eliminate childhood illiteracy and then with the help of those children quickly did so with its adult population as well (its kids became their parents' teachers). Cuba also prioritized the creation of a first-class health care system, not for just its own citizens but anyone else in the world that could/would accept such cheap "outsider" help.

Circa 1980 the Chinese Communist Party decided to eliminate poverty and therefore adopted realistic policies that have empowered its entrepreneurial go-getters to lift 800 million of their neighbors from the lowest internationally recognized poverty category. China also plans to increase nuclear electricity production six-fold by 2050 and achieve carbon neutrality by 2060. By the end of this century, it will likely be able to implement this book's cornucopian future for its citizens (and maybe even ours if we can still afford to buy their reactors).

If the USA's leaders are serious about addressing this book's technical/social issues they must change the policies that determine the behavior of its people and industries. A part of that must be changing its approach to regulation. Its current approach reflects a mid-twentieth-century belief in government's ability to solve complex problems based upon the assumptions that industries would not voluntarily act to reduce air and water pollution unless forced to and that its own managers would be technically competent enough to demand that industries do what's right, not just "differently".

When the federal government finally did respond to its citizens' environmental concerns because a much-polluted river flowing through one of its most heavily industrialized cities had repeatedly caught on fire, its new Environmental Protection Agency's policy makers drew from an established set of strategies that heavily relied upon technically clueless, bureaucratic, top-down intervention through an elaborate system of rules based upon the assumption that only coercion would lead to the necessary behavioral changes. Formal, adversarial relationships were built into the system to ensure that government would be insulated from industry influence. Given the state of mind in both government and industry in most of the Western world's industrial democracies at that time[582], it wasn't a bad model for a first stage of environmental problem solving.

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[582] That state of mind still obtains in many US jurisdictions & is responsible for its inability to properly deal with challenges like those posed by the COVID-19 virus and Texas's most recent cold snap.

However, it was based upon a series of questionable assumptions about what motivates human behavior and how to change it, not upon an understanding of business perspectives or the internal dynamics of business firms.

The most basic assumption was that the interests of society in environmental protection and those of industry in realizing profits were at odds. That assumption isn't always right because industry's behavior depends upon the government's policies. If those policies are as constructive as China's have been for the last four decades, almost everyone in its society benefits – if they are as stupid as some of the USA's have been most of that time we'll end up with more riots, food lines, mass killings, and eventually the election of another wannabe "Il Duce" to restore "order".

Digging ourselves out of the mess created by that mindset will require changes in the policies incentivizing regulatory behavior.

For instance, most of the people working at the NRC were originally strongly pro-nuclear because that's the reason they had decided to work in that field in the first place. However, like DOE's employees they became captive to their employer's institutional logic and its congressionally mandated incentive structures.

Their employer does not have a mandate to increase nuclear power or goals tied to its growth. Its employees get no credit for approving new plants but do "own" any problems that might come up if they are built. Consequently, for them, there's no upside, only downsides to moving things along efficiently. Furthermore, the NRC does not benefit when power plants come online because its budget is not proportional to nuclear capacity or energy produced. Instead, the nuclear companies themselves pay the NRC for the time it spends reviewing applications. This creates a perverse incentive for their agency : the more overhead and project delays it causes, the more revenue it gets.

The result is that the NRC's "new" reactor approval process now takes several years and costs hundreds of millions of dollars. Why should that surprise anyone?

The US spends more than $200 billion annually to enforce its environmental laws. The EPA in a close but often strained cooperation with its counterparts in the states regulating their people, businesses, and other agencies (e.g., DOE) doing anything falling within its/their bailiwick. Some 15,000 pages of federal regulations translate legislation into detailed instructions and an elaborate system of reporting, inspections, and penalties tries to make everyone follow the rules.

Regulated firms must therefore maintain a cadre of well-trained, well paid, professional legal and technical experts to ensure compliance[583].

Meeting the requirements of federal environmental protection regulations has cost US citizens roughly $5 trillion since the early 1970s.The scope, cost, and stringency of environmental regulations have been the subject of almost constant political controversy and has therefore contributed to the hyperpolarization that's been crippling every level of its government(s) and the USA's overall economy .

Those new policies should build upon the foundations of its old regulatory system but recognize the changes that have since occurred. They should become based upon performance rather than on narrow interpretations of compliance with assumed . They must allow regulated firms, especially the better performers, more flexibility in determining how to achieve goals and complement the way that the private sector makes business-relevant decisions rather than just impose additional legalistic obligations.

There are basically just four different sorts of policies.

- "command and control," such as mandating the use of use a portion of electricity from renewable sources
- financial incentives, including taxes, subsidies, and loans
- monetary awards for cutting pollution or improving efficiency and technology
- nonmonetary awards, such as public recognition (that's how the USA's military system works). .

Those policies must be consistent with Porter & Van der Linde's assertion that properly formulated environmental policies would spur the development of innovations that could reduce both pollution and costs while stimulating growth, development, and profits (Porter 1995, Fiorino2006).

People like misters Bezos, Musk, & Gates got rich because they could recognize the opportunities that their country's policies and "technical problems" offered & take advantage of, not just 'study" them. Bill Gate's Terrapower nuclear startup seems to be making more genuine progress in nuclear reactor/power development than are any of the Western world's governments.

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[583] During the 20th century's last decade, "compliance" became the primary goal/service provided by and expected of the people employed by DOE's lab Management and Operation (M&O) contractors.

For example, during the last few decades the USA's policies, rules, and business regulations have incentivized the owners of many of its cement, steel, and nuclear power plants to shut them down thereby putting millions of people out of work, causing the towns/cities where they lived to wither leaving their country more dependent upon outsiders for its citizens' needs. Its citizens could repair its therefore "decaying infrastructure" - roads, bridges, streets, driveways, sidewalks, building & home foundations, etc. - if making things with cement and concrete were to become a heck of a lot cheaper than it is now. That in turn would naturally happen if a constructive set of new policies/rules/subsidies encouraged regional decision makers and local entrepreneurs to replace landfills and garbage incinerators with cement plants. Doing so would also provide lots of worthwhile, constructive[584], work/jobs while competently addressing ancillary issues such as the "plastic waste" problem that we hear so much about these days (see Appendix XV).

Note that I don't feel that the governments should build or run those cement plants themselves – their job is to establish policies that incentivize/enable its citizens to do constructive things for themselves. I should also remind you that when the USA really was "great", its topmost income tax rate was over 90% which policy served to equalize its citizens' wealth, standards of living, and opportunities. In a country as enamored with both private enterprise and "freedom" as is the USA, properly thought-out/implemented tax policies represent its most powerful tool for incentivizing its decision makers and entrepreneurs to make the necessary changes. That should begin with espousing James Hansen's approach to taxing anything that will dump more "carbon" (methane and/or CO_2) into the atmosphere.

"I *will do anything that is basically covered by the law to reduce Berkshire's*[585] *tax rate. For example, on wind energy, we get a tax credit if we build a lot of wind farms. That's the only reason to build them. They don't make sense without the tax credit*."

Warren Buffett: CEO Berkshire Hathaway

(the key word here is "anything")

[584] At the heart of the USA's malaise is the fact that everyone now seems to want to think, act, and work like a lawyer. As Will Shakespeare said, "*the first thing we do is kill all the lawyers*".

[585] Berkshire Hathaway is the parent organization of MidAmerican Energy 's 1.6 million billed customers. Believe what its billionaire founder, Mr. Buffet has to say – he doesn't need to lie. That company has also cornered the corn belt's natural gas markets meaning that its citizens often pay far more to heat their homes than they should. However, Berkshire Hathaway's boss, Warren Buffet has made the same commitment to give back to his country & world that Bill Gates has. Bill and his now ex-wife have done almost all of their philanthropy through the Gates Foundation to which Buffet's gifts since 2006 have totaled about $45 billion considering the appreciation of his company's stock after they were given.

Finally, nobody's work time should be "worth" 1000 times more than anyone else's. The US military's top-to-bottom (O10 to E1) pay ratio is about 8:1 – that's clearly sufficient to incentivize individuals to do their best to rise in their work site's social pyramid but small enough to let the people at its base live reasonably well.

A recent Cornell University meta-analysis of the effects of nearly 2,700 environmental laws and regulations in effect in thirty different Chinese provinces between 2002 and 2013 concluded that Porter was right: incentive-based market policies benefited regulated firms in both the traditional and "green" energy sectors by spurring technical innovation and improvements in production processes. Financial incentives -- loans for increasing renewable energy consumption --improved industrial output in the petroleum and nuclear energy industries, and monetary awards for reducing pollution boosted new energy sector profits.

On the other hand, policies based upon command and control, non-monetary awards, and mandated environmental standards & technologies stifled both industrial output and profits.

Let's next go through some of the changes that the almost totally politicized US institution primarily responsible for developing a sustainable nuclear fuel cycle (DOE) must undergo.

The highlights of Ford et al's paper summarizing the outcome of the structured interviews conducted with 30 of the USA's nuclear energy veterans were as follows:

- The U.S. Department of Energy has been unsuccessful in enabling advanced fission.
- Its Office of Nuclear Energy (NE) exhibits little long-term programmatic focus.
- It is burdened by legacy infrastructure and commitments to a light water reactor-based nuclear industry.

Overall, their responses suggest the demise of US nuclear power if the agency entrusted with "growing" it doesn't eschew policies that threaten American energy security, narrow/eliminate policy options, and erode the USA's influence in setting international non-proliferation, safety, and security standards.

Russia – a nation that has successfully "weaponized" its bountiful fossil energy supplies – recently[586] dominated nuclear markets as well. It is advancing its economic/foreign policy influence around the world via $133 billion in orders for 50 new reactors in 19 different countries. China, a strategic competitor that utilizes economics as a tool of statecraft, is currently constructing four reactors abroad, with prospects for 16 more in multiple countries in addition to

[586] Putin's recent attempts to reassemble the Soviet Union has killed his county's chances of becoming as "important" as it was during the Cold War. However, its technological infrastructure is still intact and could Make Russia Great Again (MRGA.

the 45 reactors already built within its own borders and the 12 new ones currently under construction.

Putin's recent attempt to reassemble the Soviet Union has killed his county's chances of becoming as "important" as it was during the Cold War. However, its technological infrastructure is still intact and could Make Russia Great Again (MRGA?).

Meanwhile, the United States remains entirely absent from the global new-build nuclear reactor market with no new foreign orders. It is missing out on a market that the U.S. Department of Commerce (DOC) estimates to be worth $500-740 billion over the next decade. U.S. industry faces competition from nation state-owned enterprises directed by their respective national strategic economic and foreign policy goals. The companies comprising the U.S. nuclear reactor industry do not compete in a truly free global market –their competition is from foreign State actors which means that ours shouldn't be left exclusively to their own individual efforts to survive. Their/our government must begin to help and guide, not just "regulate" (harass) them. Its goal should become empowering them to compete in that market with a nuclear fuel cycle capable of powering everyone forever, not just filling in gaps left by attempting to do that with windmills, solar panels, biofuels, and batteries *partially* backed up by a few "advanced" micro/mini/small burner-type reactors.

I agree with the US Secretary of Energy's (2jun2020) declaration that the US Federal government must take the lead - create a state-owned corporation with a single clearly defined mission. However, that mission should be to devise a practical way to implement a genuinely sustainable (breeder-based) nuclear fuel cycle, period - not to help any lobbying group, company, or person realize their ambitions.

DOE's NE division is already a state-owned "corporation". However, like much of our government, it is totally politicized, partially "privatized", often incompetently led, & serving multiple masters many of whom believe that it is neither necessary nor their duty to address "controversial" technical issues.

I don't know what to do about this situation. Its problems are almost entirely trans-scientific ("wicked") and I'm no good at politics[587].

[587] If I had my druthers, I'd be reborn with the same innate political talents evinced by the gentle knight starring in Monty Python's "The Meaning of Life's" witch-hunt scene: after he got through adjudicating that case, the accused is still murdered by her neighbors but everyone including her now felt OK about it.

However, I'll continue to try to remind folks that there are lots of ways to get to where we need to go all of which depend upon someone coming up with arguments that will convince our leaders to pull their heads out of their bosses' nethermost regions[588].

Admiral Rickover was pretty good at doing that – it's too bad that he's dead.

11.1 Stop bean-counting

The way that DOE has gone about labeling, performing and assigning costs to its activities often served as "the kiss of death" to perfectly reasonable – often the most reasonable - ways of addressing its technical issues. For example, because almost everyone chooses to characterize its interminable Hanford tank waste management boondoggle as a "vitrification" project, to many people that relatively simple, cheap, and venerable treatment technology (glassmaking) must be almost impossibly expensive/difficult[589]. That's baloney; "real glass" that's much more durable than is the benchmark that DOE set for its contractors' HLW vitrified waste forms is too cheap to recycle in much of the USA and a glass melter's off gas "waste" is also easy/cheap to clean up[590]. Similarly, DOE's assertion circa 2000 AD that it would be billing its then-official HLW repository's prospective DOE customer, INEEL, at a volumetric rate >$800,000/m^3 appeared to render the disposal of anything that's been labeled "high" prohibitively difficult/expensive as well[591].

What ***should*** it cost to dig out a one cubic meter hole in an easily accessed, government-owned, soft-rock (welded tuff) mountain ridge with a second-hand, 25 feet diameter, tunnel boring machine & chuck something into it?

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[588] That's what my "technical nerd's cookbook" project has also turned into. Over 10% of the people within the USA's fantastically food-productive "corn belt" are "food insecure" for the same sort of "wicked" reasons that killed its nuclear industry.

[589] For instance, circa 2002 the "overhead" cost assigned to any time that an INEEL scientist or engineer charged to a specific project was typically four times his/her hourly salary+benefits compensation rate. In my case, that cost US taxpayers $300 per hour (over $800,000 per year) which was relatively cheap because by then, I hadn't been receiving my pay grade's "average" percentage-wise pay raises for over a decade (divulging such information was verboten and I didn't really care about it all that much – I was then & remain "rich" enough to not worry about it).

[590] For example, a wet electrostatic precipitator (WESP) can remove virtually 100% of particles/mists along with most of the gasses boiling up and out of a glass melter and recycle them back to its feed system. A downstream condenser followed by HEPA filters will capture everything else.

[591] The highest volumetric cost I have yet heard being charged by one of the USA's privatized radwaste disposal companies is $1000/ft^3. That figure is about 3% of that which DOE was planning to charge US taxpayers for disposing of the high-level waste forms that INL's road mappers planned to bury at its YM repository-study site.

The fact that DOE's radwaste management wizards have also managed to demonize calcination and incineration[592] continues to provide tough-to-refute talking points for anyone looking for waste management-related antinuclear arguments.

11.2 *Really* "reorganize" the USA's NE R&D programs

"*To solve 21st-century problems, innovators need the freedom to experiment without the burden of overregulation and the abuse of intellectual property rights by vested interests*."

Matt Ridley

Energy has been the entire world's biggest "real" business[593] for well over a hundred years and devising viable substitutes for the destructive ways that we have been generating it could make America great again. Consequently, DOE/NRC should no longer be entrusted with the management of the USA's nuclear engineering/scientific development efforts because that undertaking is too important to entrust to organizations that can't decide what their missions are ("all of the above"?) or how to go about accomplishing them[594]. DOE's NE division should not just be reorganized again because much of what it does doesn't have much to do with developing a sustainable nuclear fuel cycle and its topmost leadership has consistently proven itself unwilling to either change or lead[595].

Two recent reports (https://www.energy.gov/sites/prod/files/2020/04/f74/Restoring%20America%27s%20Competitive%20Nuclear%20Advantage_1.pdf and http://globalnexusinitiative.org/wp-content/uploads/2019/05/PGS_ThoughtLeadershipReport_052419_FINAL_Pages.pdf) certainly represent good news in that it's apparent that there might be some serious paradigm shifting

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[592] See APPENDIX IX

[593] "Real" as opposed to service industries such as marketing several–times marked-up Chinese-made goods and US farm-raised crops, banking, insurance, regulation, litigation, and advertising.

[594] e.g., "all of the above" is a slogan not a plan. The purpose of a nuclear reactor is to generate power, not to be "small", "modular", "idiot proof", "manage waste", fill tiny niches, or complement more politically correct (wind, solar, biofuels, etc.) renewable energy sources - see APPENDIX XXXX .

[595] The survivors of DOE Complex reorganizations have invariably promised to "go and sin no more" (JOHN 5:14-15 14). Unfortunately, its reorganizations generally just shuffle management personnel sideways to equivalent pay-slots where they are apt to be equally or more incompetent. Some of them end up filling positions supposedly reserved for that lab site's "Fellow" and "Consulting" engineers & scientists. In any case, they remain "important" and are therefore recruited by outside contractors to serve as advisors during upcoming contract negotiations.

going on in the USA's approach to NE R&D. However, only time will tell if it morphs into something that could address our world's technical issues. We humans need to build 20-30 TW's worth of practical breeder-type reactors along with efficient fuel cleanup/reprocessing systems ASAP, not just a few micro/mini/small reactors regardless of how "advanced" they might be or ideally suited for cost-is-no-object niche applications.

The intent of those documents' authors is fine but doesn't address the fundamental problems responsible for US nuclear insolvency.

- absence of a national commitment to addressing future environmental, social, and economic issues (e.g., no carbon tax)
- failure of its privatized electricity market structure to properly incentivize its suppliers to do those things
- failure to either champion or develop a sustainable/renewable nuclear fuel cycle

Because the US federal government's energy experts apparently assume that the purpose of advanced reactors is to fill little niches in a world powered by non-nuclear renewables it's likely that its reactor R&D programs won't restore its leadership in nuclear power.

Unlike Mr. Trump's deliberate efforts to create a government-wide kakistocracy[596], DOE's appointed top dogs usually do not deliberately set out to run their bailiwick in that fashion. DOE NE's entrenched management culture accomplishes that spontaneously and its leaders are confident that they can outwait any non-cooperative, technically clueless, political appointee boss because they have repeatedly done so in the past. In "The Innovation Illusion" (2016), Fredrik Erixon and Bjorn Weigel argue that Western economies have "*developed a near obsession with precautions that simply cannot be married to a culture of experimentation*." They have made innovation in nuclear design all but impossible by devising an immensely costly byzantine regulatory system.

Innovation requires freedom to think, experiment and try new things, which in turn requires sensible regulation that is inexpensive, permissive, encouraging, and quick to render decisions. Most of DOE's nuclear-related R&D would be best characterized as "spuddling" (*making a lot*

[596] One of Mr.'s Trump's chief goals was to replace his government's technical scientists with "political" scientists". Consequently, his USDA Secretary, Sonny Perdue, dismissed global warming as "weather patterns" and saw to it that his agency's official reports downplayed anything having to do with anthropogenic pollution. For instance, Lewis Ziska, a plant physiologist at its Agricultural Research Service (ARS) had worked on a study that concluded that rising CO2 levels could imperil the major food source of ~ 600 million people by lowering the nutritional value of rice. He and several other of that agency's senior scientists have since quit because they were not allowed to include such "controversial" conclusions in their reports. The same thing had already been happening at DOE's nuclear labs for over two decades.

*of fuss about trivial things, as if they were important***)**. That's not OK if the people doing it are public servants paid with tax dollars and capable of doing useful work.

The NRC's "barriers to science" are even more destructive because it outranks DOE politics-wise and therefore sets the agenda. Bloomberg's (7/2/2022) precis of the e latest ANS briefing, **Outdated regulations slowing advanced reactor progress** states…

"*An antiquated regulatory system coupled with regulators' lack of understanding of advanced nuclear technology is a barrier to the deployment of next-generation reactors, and advocates say that won't improve until at least 2025, when the Nuclear Regulatory Commission is expected to publish a new licensing framework for advanced reactors.* Amy Roma of law firm Hogan Lovells said the NRC is *"largely divorced of actually understanding -- in depth -- the technology"* and called the current rules *"a square peg in a round hole for these advanced reactor designs."*

Every assumption/rule/law currently engendering today's habitual foot-dragging on efforts to address the future's most important technical issues must be critically examined and appropriately modified. One such assumption is that nuclear power isn't "renewable". It could, should, and must become so and achieving that should be DOE's primary mission, not continuing to help his/her/its "industrial partners" develop/sell whatever they feel to be more "realistic" over the short haul[597]. If our leaders want to solve mankind's long term energy conundrum, they must become willing to take their employees' blinders off and empower them to do the experimentation required to first devise and then implement a genuinely sustainable nuclear fuel cycle.

"*You must do the thing you think you cannot do.*" –

[597] For instance, Dr. Rita Baranwall's (Trump's DOE's last NE 1) chief arguing point to the US Congress for a resumption of fuel recycling (reprocessing) was that doing so would enable US-based nuclear reactor manufacturers to promise prospective foreign customers that they wouldn't have to treat/dispose of the spent fuel that their new US-designed/built power reactor(s) would generate – the US could/would take it all back and somehow deal with it. I'm sure that she would much rather have been able to cite a better reason (i.e., that fuel cleanup/recycling is one of the two keys to rendering nuclear power genuinely sustainable/renewable) but in today's world you pretty much must say/do what your real "customer" (Congresspersons & their contributors) want to hear. Dr. Baranwall has since moved on to EPRI and been replaced by a freshly-minted PhD.

Nuclear weapons proliferation is a political, not technical problem because any sort of reactor must have fissile within it which, in principle could somehow be "diverted" and misused[598]. Again, we voluntarily accept the risks of traveling in automobiles and airplanes even though such risks are both real and much greater than are those posed by any sort of realistically managed nuclear fuel cycle. Likewise, nuclear waste management's technical issues are "pretend issues" that would be easy/cheap to deal with if our leaders really wanted to deal with them.

11.3 Reevaluate priorities

As of August 2021, DOE's lead NE R&D lab's experts are apparently still intent upon devising/promoting little burner/converter-type reactors suitable for solving little problems, not big, sustainable reactors that could « save the world ».

Here's a recent press release.

> *"Potential deployment of this subset of small modular reactors of 1-20 MWe capacity, which includes light water, molten salt, gas-cooled, metal-cooled fast and heat pipe reactors, in 63 nations was evaluated for the 2030-2050 timeframe. By 2030, initial deployments of these systems could potentially expand the nuclear contribution in North America and Western Europe, areas that would otherwise show low future nuclear growth."*

It may be fun to study gnats but when there's an elephant stomping your home into rubble it's time to quit fooling around looking for another niche for your favorite bug.

"Small" and "modular" are about the only "advanced" reactor characteristics that DOE's leadership has consistently emphasized during the last 15 years. That is why its business partners are designing and trying to sell fuel inefficient mini-LWRs (e.g., NUSCALEs) or HTGRs instead of reactors capable of "saving the world". "Modular" and "small" are fine attributes if seeking them doesn't distract scientists and engineers from doing what they should be doing. A downside of "small" is that there's about as much overhead cost associated with running a small power reactor as there is a big one. Another is that its neutron leakage is almost certainly higher/GW, meaning that they cannot breed replacement fissile as well (less fuel efficient). If the world is to be powered with fission-type reactors, they must generate at least as much new fissile as they consume (isobreed). "Modular" is desirable any way it's looked it and several of today's

[598] Terrorists are more apt do relatively simple things like crash hijacked airplanes into buildings which in fact has killed/injured far more people than have all of the world's nuclear accidents put together. Like bombs, those planes themselves were neither "evil" nor stupid - it's up to governments to prevent their misuse.

molten salt reactor concepts could be modular because their cores –their part that would wear out relatively quickly - could be small enough to be transported by trains or trucks.

”Small's” chief downside is that it is not large – our world is confronting large, not small, problems.

Next, any clean energy source's value should be based upon the degree that it could serve mankind's long-term needs, not upon how much power "capacity" it would occasionally provide[599]. If adding such capacity to an energy supplier's portfolio does not enable replacement of its fossil fuel powered generators - not just some of their fuel(s) - its "value" should be considered low, not especially high due to special subsidies, fine sounding labels, or warm green fuzziness.

A hefty carbon tax should be levied upon any fossil fuel that is to become GHG[600]. James Hansen has suggested that most[601] such money should be returned to taxpayers/customers via the IRS rather than given to special interest driven/funded politicians to spend as they wish. I agree that that would probably be the fairest and most effective way to affect the necessary changes.

A US GHG reduction policy should create a level playing field in which all real and proposed energy production technologies can compete in an open marketplace conditioned by legislated CO_2 emissions goals. A "carbon" tax for all carbonaceous fuels with no long-term subsidies or other preferential policy treatments would be the most effective way to achieve it.

The NRC should oversee the operation and licensing of existing reactors, not dictate how the experimentation required to develop something new must be done. Its current rules, regulations, lack/level of technical expertise, hyper conservative mindset, and financing mode[602] constitute one of the industry's most formidable "barriers to science". For example, one of the chief drivers/excuses for DOE's grossly inefficient separations-based reprocessing waste management boondoggling is a several decade old NRC opinion (not a law) which stated that "high level

[599] For instance, a 300 MW solar farm situated in Iowa would generate a year-round average of about 50 MW ranging between zero (every night) and 300 MW (occasionally for a few hours during the summer).

[600] This means that natural gas utilized in a power plant or hydrogen-making facility that is close coupled to a carbon capture & sequestration system wouldn't be so-taxed. That makes good sense from a political, environmental, and economic point of view.

[601] A few percent of that tax money should fund NE-R&D dedicated to devising a simultaneously practical and sustainable nuclear fuel cycle. See APPENDIX XXXVIII for a worked-out example.

[602] Among the contextual benefits that China, Korea, and Japan reactor builders enjoy relative to ours is that their regulators are paid by the government, not the vendor or developer.

waste" (HLW) to which a "maximal effort" had been made to remove certain "high" components[603], no longer had to be considered HLW.

Any governmental rule/opinion dictating policies should specify definite toxin/radionuclide concentration limits, not adjectives like "high", "low", or "maximal"**.**

Whatever organization ends up in charge of developing/implementing a sustainable US nuclear renaissance (I recommend the creation of a new military branch[604]) should eschew the personnel management philosophy currently reflected throughout the USA's "Nuclear Complex "because it destroys esprit de corps, inhibits creativity, and fosters cynicism.

For instance, at INEL/INEEL/INL although everyone "coming on board" at a specific time was "guaranteed" a set of work-related rules and benefits, every succeeding M&O contract change encouraged the contractor inheriting the management of both that site and its employees to chip away at those guarantees and keep the money for itself. The excuse proffered by that site's management whenever anyone screwed up enough courage to point that out was, "*that's the way that things are going everywhere else in good 'ol USA – if you don't like it, you are more than welcome to quit because there's lots of fresh young college grads out there clamoring for any sort of 'good' job these da*ys".

That's no way to convince the best and brightest of any institution's employees to do their best to help it address its technical issues.

Another consequence of DOE's cynicism-fostering work culture is that many of its employees eventually lose whatever enthusiasm they originally may have had for nuclear power itself. If researchers and their managers are consistently forced to act in ways that would render a sustainable nuclear renaissance impossible (e.g., design reactors that would maximize the waste of a breeder-type reactor's startup fissile), he/she/it eventually becomes incompetent to address the future's energy conundrum regardless of what his/her/its credentials or title happens to be.

During the years that I worked there most of INL's Chem Plant's employees were considered cogs within a machine that implemented procedures. That worked well until its primary mission changed from reprocessing small lots of miscellaneous spent reactor fuels to devising "*uniquely*

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603 Especially "high" or "evil" constituents of radwastes include ^{90}Sr, ^{137}Cs, TRU (especially Pu) and in some cases, ^{99}Tc,^{3}H, and ^{129}I.

604 The USA's two most successful nuclear engineering projects were managed by uniformed (not retired) military officers (Groves and Rickover) neither of whom expected to get rich doing it or were confused about who they were working for or what their mission was. One caveat I would add though is that it should become verboten (result in permanent loss of all benefits, honors, pensions, stipes, stars, etc.) for any such person to "retire" and go to work for a contractor having anything to do with that mission either directly or as a lobbyist.

cost-effective ways of managing high level radwastes" consistent with inconsistent political drivers and too-distant project completion deadlines[605]. Research can't be proceduralized because it requires creative as well as collaborative talents along with the freedom to follow up on leads revealed by experimentation. If an institution's leadership really wants to address new technical problems, employees motivated to both learn and grow would be much more valuable than those who only strive to be good team players.

Private industry's leaders recognize that fact - our government's don't.

A good-sized chunk of money should be devoted to building a test reactor like that proposed by the folks managing the EU's EVOL (MSFR) program eight years ago (Lucotte 2013). It (Figure 89) is a relatively but not trivially small reactor (about one cubic meter core volume producing up to about 100 MW thermal output – enough to power a small city during its testing) which could be used to test/develop almost any kind of "fast" molten salt breeder/isobreeder & its attendant fuel cleanup/reprocessing/waste treatment system.

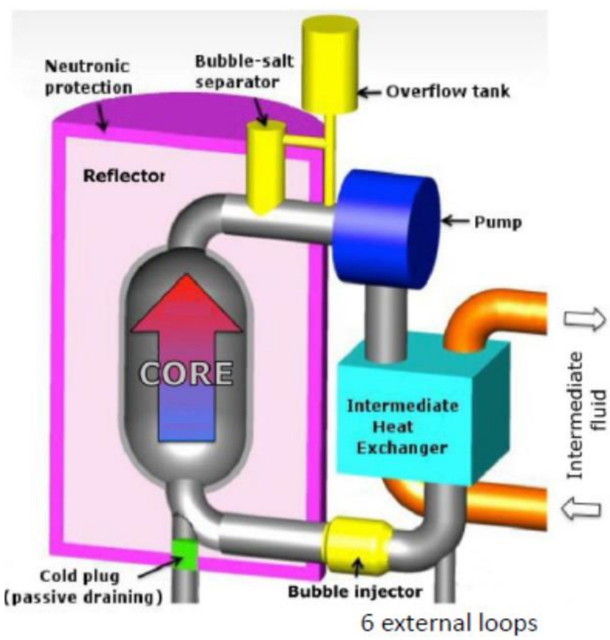

Figure 89 Generic FS MSR test reactor (core volume roughly 1 m^3, heat generation up to 100 MW, its "reflector" volume/tank could either contain a molten bismuth (or tin/lead) neutron reflector or a fertile isotope-containing molten blanket salt.

605 If a tax supported institution like INL/INEEL given 17 years (from 1995 to 2012), to do a job that should/could be done within 2 years would actually do it within two years, Congress might decide that there's no reason to continue funding its "research". Horrors! That's the reason why INL's leaders chose to have its clean up contractor try to implement a "first of a kind" technology that didn't then and still doesn't as of March 2023, work.

The goal of studies performed with it should be to devise something that is simultaneously sustainable (CR>=1), maintainable, and affordable, not just make more work for technical experts doing more of whatever they and their managers are already comfortable with[606]. DOE's topmost NE R&D experts are still refusing to consider building a test reactor capable of enabling any such effort. For example, starting in 2015 INL began putting together a list of options for a brand-new test reactor optimally capable of addressing DOE's sundry R&D goals. That document was finished two years later (Petti et al 2017) – it listed criteria & characteristics of four different possible alternatives none of which was any sort of fluid-fueled (molten salt) reactor but didn't yet reveal the "winner". Two years later, that program's then-director did so – it was to be the "Versatile Test Reactor" or VTR - at a conference in San Diego (Pasamehmetoglu 2019). As anyone familiar with DOE NE's decision making might expect, the VTR is to be just another sodium-cooled, fast reactor[607] – the same concept that INL/ANL has been "studying" since circa 1949 & Russians have been full scale, real-world, "demonstrating" since 1973. DOE's VTR is apparently to be functionally identical to its Hanford site's 43-year-old, 400 MWt, "Fast Flux Test Facility" (FFTF) which has been "*maintained in a cold standby condition"* (mothballed) there since 1993[608]. Like its more powerful predecessors, the VTR is designed to test solid fuel rod assemblies and is therefore poorly suited for doing anything having to do with MSR development.

It appeared that the Biden Administration's decision makers initially agreed with me because they zeroed-out VTR funding in June 2021[609]. The reason for doing so isn't clear but probably

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[606] For instance, a great deal of work has recently been done at ORNL to "assess the feasibility of replacing the conventional uranium oxide (UO_2) fuel of the existing fleet of light water reactors (LWRs)with accident-tolerant fully ceramic microencapsulated (FCM) fuel" (Powers 2013). The fuel in question consists of the NGNP's project's TRISO kernels in which their UO_2 has been converted to uranium nitride (actually $UC_{0.25}Si_{0.75}$) and then embedded in silicon carbide instead of pyrolytic graphite. Such fuel would be difficult to make, virtually impossible to reprocess, and the reactor itself would be little or no more fuel (uranium) efficient than are today's LWRs.

[607] This refers to a collaboration between GE Hitachi Nuclear Energy (GEH) and TerraPower supported by Energy Northwest in response to the INL's M&O contractor's 2019 Expression of Interest (EOI) seeking an industry partner to design and construct the VTR. The reactor itself was to be GE's much studied S Prism concept differing mainly in that it would be unable to breed (no fertile fuel assemblies) and air-cooled - no useful power generated (in other words, useless). After a final design has been completed, the decision to build was expected to be made in 2022. May 2020's best-guess of when it might be built is 2026. https://en.wikipedia.org/wiki/Versatile_Test_Reactor. (post script - President's Biden's decision makers have cancelled that project.)

[608] VTR's FAQ (frequently asked questions) webpage didn't mention the FFTR in its experts' answers to, "*Can this testing be done somewhere else*? and, "*Why can't we use existing U.S. test reactors*? https://inl.gov/trending-topic/versatile-test-reactor/frequently-asked-questions/ In practice, DOE simply ignores any "tough" questions and/or advice asked/offered by its nominal stakeholders (US citizens) because it doesn't report to them.

[609] However, it's apparently been revived again. In the USA's "nuclear lab complex", bad proposals that would enrich especially important stakeholders never really die. Michael (Mike) K. Simpson is serving his twelfth term in

has something to do with the fact that the Terrapower/Hitachi/Bechtel consortium's *Natrium* reactor could serve the same purposes while producing useful/salable power, not just additional LMFBR-relevant information for DOE's road mappers.

I recommend that the FFTR be de-mothballed to facilitate whatever research still must be done to "qualify" a US-built LMFBR and a reactor like that proposed by EU researchers a decade ago (Figure 89) dedicated to MSR development be built instead. *APPENDIX XIII goes through a specific example of the sorts of questions that a little test re*actor like it could answer.

When one or more of the concepts so investigated meets those criteria , moving it/them to full commercial scale will require additional paradigm shifting because current incentives for private investments in large scale demonstrations are too weak (the "valley of death") and the US federal government's track record in managing large scale demonstrations itself is terrible (the "technology pork barrel"). Both recent literature (Nemet 2018) and the results of over 500 case studies indicate that policy makers should emphasize/support: prioritizing learning, iteratively upscaling, tolerating minor setbacks, engaging the private sector, knowledge dissemination, and encourage demand pull by removing bureaucratic barriers and giving new concepts full credit for their strengths/virtues relative to other sustainable/renewable energy sources.

A big problem with MSR development is that most of the USA's NE "technical" powers-that-be (invariably nuclear engineers) don't seem to realize that the best way to implement a sustainable nuclear renaissance would likely be with a "chemist's reactor" and therefore don't pay enough attention to chemical/reprocessing/recycling issues. Their reactor concepts tend to be "engineered" before the necessary experimentation is done[610]. That plus the fact that insufficient attention is paid to rendering conceptual reactors easy/cheap to maintain is the reason that "unobtanium" has become part & parcel of the USA's "advanced reactor" R&D.

Most of DOE's radwaste management gurus are similarly blindered . That's the reason that the people implementing that part of DOE's mission didn't recognize that using a paper-based, kitty litter-like, adsorbent to sop up decay heat-generating, nitrate-containing, wet radwastes might

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the House of Representatives for Idaho's Second Congressional District (that's where the INL is located) . He serves on the House Appropriations Committee and is the Ranking Member for the Subcommittee on Energy and Water Development. .

[610] Thomas Edison understood better than anyone else that trial and error is the key to turning an invention into a useful innovation. His employees purportedly performed ~50,000 experiments in developing the nickel-iron storage battery. He famously said that developing a new technology is "1 % *inspiration and 99% perspiration*" Jeff Bezos recently made the same point: "*Being wrong might hurt you a bit but being slow will kill you. If you can increase the number of experiments you try from a hundred to a thousand, you dramatically increase the number of innovations you produce*." It turns out that continuous tinkering to develop and refine a better product is much more important than is protecting what you've already created.

lead to the "issues" that shut down DOE's $19 billion Waste Isolation Pilot Plant (WIPP) thereby backing-up its cleanup activities everywhere else for over three years (WIPP 2019).

I also feel that the US federal government should again become willing to compete with (lead) "free enterprise" in the electrical power business, especially nuclear-type power. There is nothing radical about this because the "new deal" dams that enabled the USA to become "The Arsenal of Democracy" during WW II, were government designed, built, owned, and managed. Nuclear power generation must be done especially "right"[611] meaning that it should be provided by a mission-dedicated[612] institution run like a US Coast guard managed by someone like Admiral Rickover , not by a typical US businessperson or DOE bureaucrat.

I'll digress here for a minute to explain why I feel that a governmental institution like the one that Rickover ran should be running that show.

My experience with the military began when I got drafted out of graduate school during the Vietnam war. I subsequently spent twenty-one months[613] first learning how to do something that's worthwhile (~4 months-worth of Fort Ord Army Hospital on-the-job training quickly turned me into a clinical-type lab tech), then doing it while being rewarded (rapidly promoted) for doing it well. Like another of my childhood heros, Robert Heinlein, I respect the military because its policies and actions are more honest, logical, and efficient than are those of most of the USA's businesses & institutions.

As far as I'm concerned, another good thing about the military's business model is that its system doesn't let its topmost dogs hog all the "sugar".

For example, https://www.cnbc.com/2019/08/16/ceos-see-pay-grow... teaches that the average US big-business CEO is paid ~280 times as much as his company's average employee and that in some cases that disparity is much greater.

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[611] In 1971 Alvin Weinberg first used the term "Faustian bargain" to describe nuclear energy: "*We nuclear people have made a Faustian bargain with society. On the one hand we offer—in the catalytic nuclear burner (i.e., the breeder)—an inexhaustible source of energy. Even in the short range, when we use ordinary reactors, we offer energy that is cheaper than energy from fossil fuel. Moreover, this source of energy when properly handled is almost nonpolluting. Whereas fossil-fuel burners emit oxides of carbon, nitrogen, and sulfur... there is no intrinsic reason why nuclear systems must emit any pollutant except heat and traces of radioactivity. But the price that we demand of society for this magical source is both a vigilance from and longevity of our social institutions that we are quite unaccustomed to*." Expressing such sentiments in a public forum is the real reason that Nixon's AEC downsized him.

[612] to fission-based nuclear, not "all of the above"-type energy

[613] I got a three month "early out" to go back to Montana State University so that I could take an important class that "*would never be offered again*"(ha-ha).

According to WIKIPEDIA , the US military's top:bottom employee (General/Private)[614] official salary/pay ratio is ~8:1 [Uniformed services pay grades of the United States - Wikipedia](). That figure likely overstates the disparity because junior ranks receive proportionately greater additional "Basic Allowances" for housing, subsistence (food), and doing the special things that the military's leadership deem especially important & too dangerous to do themselves , e.g., parachuting out of perfectly good airplanes to fight Muslim insurgents in dystopian slum-cities.

Another good thing about working for the military is that unlike most civilian businesses, it still guarantees its employees substantial and reliable (inflation adjusted) retirement pensions.

Another thing that should happen is that the US Congress must undo its 2005 repeal of the Public Utilities Holding Company Act of 1935. Sixteen years ago, the relentless lobbying of hyper ambitious energy entrepreneurs including ***ENRON's*** Kenneth Lay finally convinced congress to deregulate energy regulation - not just its production and distribution - which is what eventually led to Texas's and California's current "rolling" blackouts and force majeure-rationalized ("Acts of God") total blackouts. The passage of PUHCA served to break up monopolistic electric utility holding companies and represented the climax of a thirty-year nationwide fight between public vs private development of electricity in the United States. It limited holding company operations to a single state, thus subjecting them to effective state regulation. It also broke up any holding companies with over two tiers, forcing divestitures so that each became a single integrated system serving a limited geographic area. Another purpose of the PUHCA was to keep utility holding companies engaged in regulated businesses from also engaging in unregulated businesses.

Other societal requirements including an efficient, affordable, and fair postal service (why should we pay our postal service far more to deliver an envelope than a junk mail sender pays it to bombard us with far bigger fliers & catalogs?), public roads, schools, social security, medical/dental care, and affordable energy were part of a global phenomenon with most of Europe and parts of the United States in support of so-mixed economies – not the privatization of almost everything or service that a modern civilization's citizens must have[615]. If western

[614] O8 = Major General (highest rank with a definite "salary"), E1=buck private (lowest rank)

[615] The USA has the world's longest and most expensive medical-education system and also among the fewest physicians per capita. The ~$400,000 beginning-to-end student cost of obtaining permission to practice medicine has led to a huge scarcity of the relatively low-paid primary-care doctors, GPs, and pediatricians many of whom then must operate in a scarcity framework with insufficient support/resources. That same scarcity-based business framework explains the USA's dysfunction in providing everyone with food, housing, electricity, cheap insulation, and worthwhile employment. The driver behind it is that societal scarcity is more profitable for the providers of a privatized service or good than is societal abundance – if there's not enough of something to go around, your "customers" will pay a lot more for whatever you do provide. In the case of medical services, having a few "unimportant" people suffer & die miserably and toothless incentivizes the rest of us to pay whatever their market

governments insist on relying upon private industry to build nuclear capacity, fossil fuel prices must be allowed to go up enough to make doing so profitable. If the same governments also lack the moral fortitude to impose substantial fossil carbon taxes, lots of other prices will have to go up (inflation) thereby increasing their citizens cost-of- living . In that respect people who've come to tolerate such governance will be getting what they deserve.

Again, it's just too darned bad that circa 1960 Admiral Rickover wasn't reassigned to devise a practical, affordable, & sustainable civilian nuclear fuel cycle.

Had that happened, it's likely that mankind would be dumping far less CO_2 into the atmosphere, there wouldn't be anthropogenic "climate change", gigantic lignite (Figure 18) and mountaintop removal-type coal mines, mountaintop-defacing gigantic wind farms, or bat/bird/desert tortoise-killing solar towers, and the USA's policy setters would never have encouraged the outsourcing of the USA's "heavy" (but no longer "dirty") industrial jobs to Asian nations that didn't have their own "Environmental Protection Agency".

The "rest of the world's" (Russia, Japan, Korea, and China) relatively low reactor build costs are a consequence of politically supported national nuclear programs and the consistent, rational implementation of best practices." Continuity through on-going construction allows everyone to systematically realize learning, maintains supply chain readiness, enables the same consortium and laborers to work from project to project, and allows for economies of scale for components and materials. Success requires long-term cooperation of key stakeholders and relentless focus on driving efficiency and savings across all key cost drivers. Some of these cost reductions were experienced in the UK, US, France, and Sweden during the height of their "new build" programs several decades ago and could be realized again if their leadership were determined to make it happen.

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will bear. In fully privatized power markets like ERCOT, allowing providers to charge 30 times more per kWh or "therm" during emergencies incentivizes its providers to have lots of emergencies. America should adopt an abundance agenda https://www.theatlantic.com/ideas/archive/2022/01/scarcity-crisis-college-housing-health-care/621221/ that eliminates scarcity in its housing, infrastructure, labor force, power/energy, and, health/dental care systems. The still ongoing COVID 19 pandemic should have made it clear that we need medical abundance - more high-quality therapies, more clinics, better insurance, and better access to medicine (we should not have to pay for permission to purchase any non-opioid drug.). It also means that it should become easier/cheaper for our people to become medical/dental/clinical laboratory/nursing professionals. As it is now those professions are all closed shops with rules, regulations, and extensive entry barriers that prevent capable people from entering those fields. THE MEDICAL MONOPOLY: PROTECTING CONSUMERS OR LIMITING COMPETITION? (chiro.org) Although protection of the public is usually cited as the reason for imposing entry barriers, history indicates that professional interest is the overriding concern in both the enactment and preservation of those laws. This reflects economist Paul Feldstein's perspective that health associations act like business firms in that they try to maximize the interests of their existing membership.

Here's a wrap-up:

MSR corrosion issues can and will be solved only when someone screws up enough courage/resolve to build/run a little test reactor like the one described in Figure 89. Another 50 years' worth of computerized modeling, "cold" testing, pontificating, & hand wringing won't accomplish much more than did the last decade's worth of flailing about making it *LOOK* like work was being done but staying as far away from actual solutions as humanly possible -it's been the equivalent of splashing in a pool and calling it "swimming laps". [616]

Several of that industry's other underlying assumptions must also change.

1) Its new fleet of MSRs should be readily maintainable - there's no compelling reason to assume that a MSR's core walls must last 20 times longer than does a PWR's fuel assembly's cladding (typ. 2 or 3 years). We don't discard our cars when their tires wear out.

2) The future's reactors must generate "renewable" energy meaning that their fuel should be recycled/cleaned up on site - preferably continuously upon small slip streams because doing so is apt to be both safer and more fuel efficient than doing it elsewise. That translates to close-coupling reactors with reprocessing/waste treatment plants neither of which would have to be prohibitively big/expensive if intelligently designed and properly operated. If something like this is too tough for the nuclear industry's current workforce to accomplish, its members should be replaced with people willing to learn how to do things differently (besides, the USA's entrepreneurial geniuses need even more laid-off PhDs to drive their uber cabs and delivery vans until someone comes up with cheap-enough self-driven vehicles).

4) Deliberate FP transmutation for the purpose of waste management is not worth doing because it compromises overall system performance (wastes neutrons) and doesn't significantly simplify/cheapen either waste "treatment" (vitrification) or disposal. Something along the lines of the isobreeding MSFR concept that I described a few years ago (Siemer 2015) would "naturally" burn up most of its FP anyway because that reactor's mean in-reactor salt residence time (~8 years) is so long that the bulk of its fission products would decay therein & thereby be generating additional useful power (after 8 years the radioactivity of a reactor fission products are ~1E-10 of what they were when first created).

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[616] This sentence summarizes John Kutsch's opinion of DOE's NE R&D program. John is the Executive Director of the Thorium Energy Alliance.- the outfit that's largely responsible for getting me reinterested in nuclear power after I'd retired from INL

5) In tomorrow's zero-GHG-emission world, electricity rates should be 90% based on capacity (or peak demand) and 10% based on energy. Whenever there happens to be surplus non-fossil generation, the marginal value of that energy is close to zero, if not negative. What a society's consumers really need is sufficient capacity to meet their demand whenever it occurs. Surplus non-fossil energy during low demand periods should be used to make fuels, desalinate water, and charge automotive batteries. Retail electricity prices should address that reality.
6) When non-fossil electricity is marketed solely upon energy to be delivered during immediate short intervals there is no incentive for suppliers to ensure long-term reliability. In fact, many of the USA's grid managers are now assuming that deliberate rolling blackouts ("load management") identified with acronyms like DM (demand management), DR ("Demand Response"), and PRD (Price Responsive Demand) is the best way to address grid stability when today's favorite renewables aren't producing . In legal terms that's when the convenient (for them) "force majeure" concept would apply. During February 2021's Texas force majeure some of the ERCOT energy suppliers that had counted upon on receiving such relief, got it and are now being sued for doing what its bidding rules had incentivized them to do (make easy money).
7) There are lots of ways to build renewable reactors. Over the long haul fast or epithermal MSRs seem to offer the most promise. Thorium-based fast or epithermal MSRs would generate far less TRU (plutonium and minor actinides (MA) than would DOE's proven but not implemented sodium-cooled fast reactor concepts. What little TRU their fuel cleanup/recycling system would recover wouldn't be any tougher to vitrify and then bury than anything else in its radwaste.

Meanwhile, since our federal government's NE R&D experts don't seem to be much interested in devising anything new capable of "saving the world", our political leadership should commit to building Russia's already proven BN-800 (or BN 1200) breeder reactors as rapidly as possible (see APPENDIX XLIV) . Since the USA apparently has 34 tonnes of 'extra' bomb grade plutonium and that reactor only requires about 3 tonnes of startup fissile, we should be able to have eleven of them u and running within a decade[617]. Since they generate 30-45% more fissile than they burn, from then on, that little fleet would rapidly/exponentially grow to a size (~2000 GW_e) capable of powering the entire county by 2100 AD.

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[617] This assumes that we would also become willing to adopt the "Far East's" (South Korean, Chinese, etc.) approach to reactor building.

Finally let's end this sorry chapter with an upbeat cartoon featuring someone who seems to be an unusually clever US nuclear engineer – if we were to implement his proposal with Alvin Weinberg's or Admiral Rickover's mortal remains, we'd have plenty of "nuclear" power.

Figure 90 Dilbert's sustainable reactor

POSTSCRIPT

The toughest thing about writing a book like this is that every time I think "I'm finished", someone comes up with something so good/clever that you've got to add it (see some of this book's APPENDICES). For instance, over a year ago(2/8/2020) a note (below) from Charles Forsberg (Forsberg 2019) was in my "in box" along with a beautiful set of Powerpoint slides describing how best to go about addressing some of the problems I've discussed (e.g., making transportation fuels by hydrogenating CO_2 and/or biomass via "Cellulosic Biorefineries"). He's invoked some of this book's same suggestions rendered even more possible/sensible via another of the advantages of a MSR-based nuclear renaissance: it would enable relatively cheap multiGWh-scale heat energy storage via rock piles heated by trickling molten salts through them (LWRs run too "cold" for that anything like that to be sufficiently efficient - see Forsberg 2020.)

Since then, a continuous barrage of freely available information about the causes, effects, and consequences of the COVID-19 pandemic has inspired lots of other changes including a half dozen additional footnotes, more homework problems, and several more APPENDICES.

That along with an especially cleverly done You Tube video I stumbled across posted by one of the younger people (Eric Meyer 2018) who've taken up this book's causes are making it harder for me to remain pessimistic about the "West's" chances of devising solutions to the issues I've discussed. It's also rendered it impossible for me to really "finish" this project.

Oh well, maybe there'll be a 3rd book.

Conclusions

"*The scientific consensus on what we need to do to reduce the risks of long-term catastrophic climate change is clear: slash greenhouse gas emissions as fast as possible. But that's not going to happen anytime soon. No major Western economy is yet meeting the modest emission reduction targets set by the 2016 Paris agreement, a deal the Trump Administration pulled out of last year. And emissions levels in developing countries will only rise in the coming years. China's middle class has grown from 29 million people in 1999 to some 400 million today, and India is expected to add 500 million to its middle class over the next decade. Those people want the same carbon-intensive luxuries that Americans have enjoyed for years: air conditioning, family car, a meat-heavy diet. We can hardly demand they curb their appetites when we refuse to do the same, but so long as no one makes any meaningful sacrifices, our planet will continue to burn.*"

Theunis Bates, managing editor, "The Week"

Climate change is upending old rules and disrupting predictable weather patterns: Heat waves, wildfires, and tropical storms and hurricanes—the trifecta of extreme weather events—now arrive earlier than expected, occur with greater frequency and intensity, and stretch well past their historical timelines. Just today (96Sep2022) CNN's reporters announced that 50 million American citizens are now under heat alerts & that some of the California's central valley veggie/nut farmers are apt to quit even trying to raise their crops. It's also quite likely that millions and maybe billions of people will have to abandon their homelands due to rising sea levels because Antarctica's "doomsday" glacier (Thwaits – it's bigger than the state of Florida) is 'now "hanging on by a thread" and apt to entirely break off thereby almost immediately raising ocean levels by another three feet[618].

Because 1) our numbers continue to grow in spite of the fact that the habitable parts of our world are already overcrowded (Figure 91), 2) there's now worldwide "supply chain" issues and multiple weather disasters the worst of which is (and always has been) extended droughts in

[618] Again, the best book I've read about what's apt to happen to us is Professor Turney's "Ice, Mud and Blood" - buy yourself a copy while it's still cheap.

food-raising regions, and 3) the fact that both Russia and China are apparently itching to go to war over silly territorial disputes , it looks like humanity is on course towards a disaster that'll make WWII look puny.

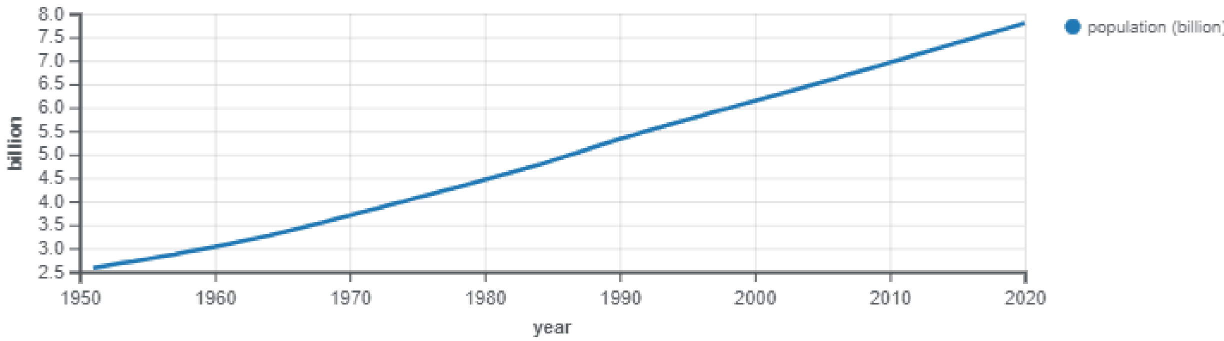

Figure 91 Human population continues to grow

To someone who's really old or really pessimistic or really believes that GOD intends to kill us all off soon, it'd be easy to just give up & continue to "eat, drink, and be merry" doing whatever feels good [619] until everything collapses. However, I still feel that there's hope for us because more of humanity's best and brightest have come to realize that we must change how we go about doing "technical" things.

At the "2021 Leaders' Summit on Climate" conference, President Biden announced that the United States will target reducing greenhouse gas emissions by 50–52 percent by 2030, with the goal of achieving net-zero emissions by 2050 at the latest. To much of the rest of the world's people, we North Americans are a hypocritical lot contributing several times our fair share of humanity's atmospheric pollution allowance while refusing to take the actions required to reverse the effects of climate change and lift the rest of the world's people out of poverty and "food insecurity".

When we refer to climate change as a crisis and existential risk, we often act as if we don't believe it to be true. If we did, we would approach the tradeoffs involved in addressing its issues. If we took that rhetoric seriously there would be much greater support for a sustainable nuclear renaissance. This is not to ignore the risks and other reasons to be skeptical about how a US

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[619] For instance, I'm currently also researching & writing a "corn belt technical nerd's cookbook" because it's fun and something I can both do and perhaps "influence" by myself.

nuclear renaissance might be implemented. The question to ask is whether it is easier to address nuclear power's challenges than to try to achieve net-zero without it.

All available evidence suggests that it is.

Here are some more uncomfortable facts.

- No major country has made the transition out of poverty without using cheap fossil fuels. If our world is to be "saved" this means that countries capable of doing so must come up with something capable of satisfying all, not just a few of the demands that those fuels have satisfied.
- The world's biggest gas/oil companies are all nationalized (Saudi Arabia, Russia, etc.). What the western world's privatized energy businesses do is irrelevant if they refuse to change their business models.
- We here in the west are under the illusion that we are still the biggest players in that game which isn't true unless we quickly develop an economic strategy that gets the world off fossil fuels.
- A properly implemented nuclear renaissance – not just building a few more-of-the-same but "smaller" reactors for niche applications- represents the best way to do that.
- Unfortunately, after six decades of "research" costing several tens of billions of dollars, the promise of breeder reactors remains largely unfulfilled and efforts to commercialize them have been steadily cut back in most of the "free" (western) world[620]. In Germany, the United Kingdom, and the United States, breeder reactor development programs have been abandoned.
- In the last few weeks of 2021, when it had become was clear that the Russian invasion of Ukraine had put the USA's reactor fuel supply in jeopardy, nuclear energy advocates lobbied hard to attach provisions to various pieces of "must-pass" legislation—such as the National Defense Appropriations Act (NDAA), the Ukraine Supplemental Appropriations Act, the Infrastructure Investment and Jobs Act, and the CHIPS and Science Act—to have the government get the ball rolling on new domestic uranium fuel production capacity. Four times they thought they had succeeded, that Congress was going to allocate enough money to start the United States on the road to a secure supply of reactor fuel, including the higher-enriched fuel needed for advanced reactors[621]. By

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[620] "free" in in quotes because no one in the Western world is free to work with anything that their government's experts deem a "special" material.

[621] Here's an "exciting" *Nuclear Newswire* (American Nuclear Society) 7September 2023 press release.   *Centrus Energy is ahead of schedule on its plan to produce high-assay low-enriched uranium at the American Centrifuge Plant in Ohio, with production set to begin next month after final system tests are completed. The company has a contract with the Energy Department that calls for production of 20 kilograms of HALEU by year-end and annual production of 900 kilograms.*

> now (September 2023) that effort has fallen victim to political gamesmanship. The uncertainty in funding allocation and the lack of a clear resolution pose challenges to the stability of the current fleet and the development of advanced nuclear reactors in the United States.

In August 2021 the United Nations issued a ~4,000-page climate-change report documenting the earth's catastrophic warming and warning us of worse to come. Temperatures soared around the world as if to illustrate that point: Europe and most of Canada experienced their hottest temperatures ever and nearly two-thirds of Americans, most Europeans, and all the Mideast's inhabitants live in places under excessive heat advisories. Fire officials everywhere in the USA's western states and around much of the Mediterranean Sea are worrying that persistent high temperatures will add additional blazes to those already burning.

In September 2022 US journalist Katherine Blunt published her book *"California Burning": The Fall of Pacific Gas and Electric and What it Means for America's Power Grid*". She was thrown into covering PG&E's story in 2018 as the Camp Fire erupted three days after she started. Since then, she has investigated PG&E's complete history to understand all of that tragic and devastating fire's contributing factors. It's a complicated story with serious consequences and her book is an insightful examination of not only the fire, but America's power history. It also identifies implications for other utilities across the nation including the formation of monopoly companies supplying power to California in the early 1900s, the lack of maintenance on its nearly 100-year-old equipment which had catalyzed that fire, the people and infrastructure involved in California's electric power system, PG&E's bankruptcy and restructuring program, its much renegotiated settlements for fire victims, public perceptions of PG&E, reactions to her book, the pressures utilities face to keep expenses low, and PG&E's nuclear asset Diablo Canyon. PG&E has declared that the book will be required reading for employees as they work to bury ten thousand miles of distribution lines to mitigate future fire risks.

This year's world-wide extreme heat spells are a tangible reminder of what its inhabitants are up against. That report's conclusion is grim. "*Where its scientists once warned of disasters in the distant future, they now strive to understand what has already happened—and what is already too late to save*,"

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900 kg/annum *sounds* impressive but represents only ~5% of the fissile required to start a full sized LMFBR.

Three of that report's takeaways would be …

- Extreme heat represents the human-rights issue that will define this century (in a too-hot world, the "heat gap" will be a defining manifestation of inequality")
- This part of the year needs a different name (Heat Season?) to differentiate it from normal summers so that more people realize what's been going on.
- It's long past time for our leaders us to "get serious" about repowering our civilization in a way that's simultaneously "clean", reliable, and affordable.

Every country has its own political and technical strategy. Up until the dissolution of the USSR, the goal of Russia's "cold war" with the USA was to convince the rest of the world that its version of socialism is "better than capitalism'". It lost that war because the consequences of its policies/decisions/actions had proven that contention wrong. However, since then the results achieved by Deng Xiaoping's "Socialism with Chinese Characteristics" combined with the issues serving as the subject of this book have demonstrated that the USA-'s version of democracy isn't the best" way for it to "become great again" either.

James Hansen's recommendation seems to be the mostly privatized Western World's cheapest option: impose a large "carbon" (GHG) tax that increases with time. Since money talks, that policy would incentivize everyone to do whatever they can to solve those problems and therefore would be relatively efficient and painless. Centralized planned command and control strategies like those imposed by the Soviet Union and Mao's Red China (or like California's politicians seem addicted to) are no more likely to work for that new mission than they did for those failed-state economies. On the technical side, our government's new policies should encourage/reward replacing all three parts of the world's energy business sector: electricity, gaseous fuels, and liquid fuels.

The world's largest economies including China, Japan, Britain, and France are definitely returning to the nuclear energy fold and the pro-nuclear movement is growing in even hostile nations like Belgium, Germany, and Australia.. Although surveys generally indicate that its electorate is against it, Japan has finally (17Oct21 decided to return to the nuclear fold by restarting 30 of its nuclear reactors Japan's carbon goal is based on restarting 30 nuclear reactors | The Japan Times

There's also a growing realization within the USA that its nuclear power "options" must be resurrected, Abandoning Nuclear Power Would Be Europe's Biggest Climate Mistake - Bloomberg, Column: If Biden is serious about the climate crisis, he should put nuclear power on the table - Los Angeles Times (latimes.com). It is becoming increasingly clear to liberals and conservatives alike that *only* nuclear can achieve global prosperity and environmental sustainability. The reason for this is that a decade's worth of over-investment in unreliable renewables and underinvestment in nuclear, hydroelectricity, and natural gas, has resulted in today’s energy shortages, skyrocketing electricity prices, and a return to coal around the world. Fossil fuels’ share of global energy hasn’t significantly changed since 1980 because solar and wind power depend upon, not replace, fossil fueled power plants. Over the long haul only hydroelectric and nuclear power plants can replace fossil fuels.

The USA’s younger generations (born after 1979) are currently experiencing economic anxieties like those that haunted their great-grandparents during the Great Depression (the 1930s). The root causes of their distress are basically the same human foibles responsible for that depression, WWII, and 2008-2009’s “Great Recession”. These younger people are also well-educated enough to understand that they’re apt to be bearing the burden of trying to address the environmental consequences of their parent’s fossil fuel addiction (Hansen et al 2017).

It's long past time to get rid of the lower Snake River's salmon-killing dams and long past time for Idaho's (INL) and Washington's (Hanford) national laboratories to design, test, build, and then operate the sorts of big, sustainable-fuel-cycle, nuclear reactors needed to replace those dams' power. DOE's nuclear site managers must be forced to quit their radwaste boondoggling & NE R&D foot-dragging & get on with doing meaningful work - the AEC was able to do that back in the 1950s & 60s and a differently managed DOE could do it now.

Because molten salt reactors should be uniquely well suited to addressing these problems, research seeking to realize their potential should receive top priority at its national laboratories - we already know everything that needs to be known about pool or loop type LMFBRs, TRISO, NGNP, “steam reforming”, Hanford waste “pretreatment”, radwaste glass recipes, etc. & should instead be doing research that matters. DOE’s decision makers "follow the money" & it's up to our topmost political leaders to tell them what to do and change enough rules to render success possible. “

Neither they nor we can afford to continue to allow the tax-supported institutions and experts charged with the responsibility of solving our nation’s technical problems to “grow their businesses” by consistently choosing to discharge their responsibilities in grossly inefficient and self-serving ways. DOE’s reprocessing wastes could be properly disposed of quickly and cheaply, which feat would demonstrate that a nuclear renaissance’s “waste issues“ do not constitute just another excuse for not implementing one. The USA’s failures in most things “nuclear” other than providing its military with thousands of bombs and providing generating *some* cheap, clean, & reliable electricity for its citizens, aren’t “disasters” because none of its people have been or apt to be injured by its reactors. However, its nuclear project failures and boondoggles continue to generate easily documented and hard-to-refute arguments for why a US “*nuclear renaissance would be both environmentally impactful and prohibitively expensive*” and thereby serve to prevent us from doing what must be done to begin moving in the right direction again. Those failures reflect negatively upon the institutions responsible for doing that work.

Unfortunately, most of the world's political leaders choose to address causes that are less controversial and deemed more immediate [622]than is the development of a sustainable solution to what many of them apparently still consider only "future" problems.

Frankly, it's hard for me to remain optimistic about the USA's future. After all, we now live in a country in which one of our recently "retired" President's most heavily lithified cronies (Mr. Stone) thought that it'd be a good idea to post a "GOFUNDME" request featuring a set of crosshairs imposed upon a Federal District Judge's picture to raise money for *his* defense in *her* court[623]. It would be nice to believe that such things couldn't possibly happen, but they do[624].

However, every four years or so we have an opportunity to see that a few currently active politicians (mostly Democrats) & a few billionaires in addition to Bill Gates[625] are smart, caring, & trying to do the right thing despite their "human nature"[626]. I've been feeling somewhat better about the USA's chances of "leading the nuclear renaissance" ever since Mr. Gates' Terrapower nuclear startup teamed up with Bechtel & GE Hitachi. Mr. Gates is smart enough to understand that sustainability is paramount and that reactor concept ("Natrium") is both breeding-capable and scalable.

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[622] For example, New York Governor Coumo's both realized(?) and attempted relations with female underlings.

[623] He did indeed go to jail but was then soon pardoned just before that POTUS was "retired".

[624] Based upon what I had seen on CSPAN during the Trump administration, I've concluded that Mel Brooks was right when he declared in his "*History of the World, Part 1*" masterpiece that… "*It's good to be the king*" when you have ~250 Congressional "p..s bucket-persons" at your beck & call.)

[625] Mr. Gates isn't the only US billionaire who feels that way. Tesla CEO Elon Musk and his current(?) life-partner, the Canadian singer Grimes have been using their star power to advocate against the closure of nuclear power plants, echoing a growing pressure on California's decision makers to reconsider their plans to shut its last such plant. As Grimes explained in her video (https://twitter.com/isabelleboemeke/status/1467897553681276931?s=19) calling for California to reverse its decision to shut the Diablo Canyon nuclear plant, "*This is crisis mode, and we should be using all the tools that we have." She went on: "If we push the closure back by a decade, it will help the state decarbonize faster and make the transition to clean energy faster and cheaper.*"

[626] However, the western world's growing income and wealth inequality has also given us "billionaires in space" which certainly isn't being all that they could be. One way to hold the super wealthy accountable and invest in humanity's collective future - not just its tycoons' egos - would be to pass Senator Elizabeth Warren's Ultra-Millionaire Wealth Tax, which would apply to fortunes >$50 million. It would raise $3 trillion over ten years and therefore cover ~80% of her party's proposed $3.5 trillion budget reconciliation package. To sooth their egos, those who have demonstrated Mrs. Musk's and Gate's project management skills could be empowered to do the job that Rickover should have been given circa 1965 – build us a sustainable nuclear renaissance.

Moreover, I'm hoping that our new POTUS and his Secretary of Energy realize that their country has over 12 GWe of clean nuclear power sitting around ready for refurbishment, completion, and/or restart -. Belefonte, Duane Arnold, Oyster Creek, Indian Point, Pilgrim, even San Onofre and VC Summer could all be quickly be rendered useful. https://tinyurl.com/44uv49z3

Both of those leaders should also be able to understand that providing those power plants ~12 GW of reliable electrical energy with any combination of wind/solar/batteries and /new transmission lines would take much longer to accomplish and prove to be both far more expensive and environmentally impactful. Failure to understand such things constitutes a threat to the USA's environment and economic & national security. It shouldn't be as tough to do these days because nuclear power's tides have risen due to a global energy supply crunch that's lifting coal and gas prices to record levels which inflation is being supercharged by COVID 19's "supply chain issues" and Russia's invasion of Ukraine. Appendix XLI suggests a way for our leaders to turn those tragedies into something that might "save the world".

Both the USA's electrical utilities and the Biden administration intend to decarbonize power (electricity) generation by 2050 and Biden's 2030 goal is to halve GHG emissions compared to 2005.[627] Those emissions were down about 15 percent in 2020, compared to 2005 (a COVID 19 effect) but have since bounced back again. Unfortunately, there is no federal road map (plan). There are lots of initiatives and analyses, but there's little indication that Mr. Biden's administration knows how to fit those parts together. This is not to say that all of its clean energy standards and carbon promises are empty. We already know of ways to make energy without emissions—mostly nuclear, hydro, wind, and solar—and we could probably figure out how to capture and dispose of fossil fuel GHG emissions or even recycle them if we somehow also generate cheap-enough hydrogen to do it with. We also understand another critical element, transmission, whether conventional high voltage AC or the somewhat more efficient DC and know how to build it. But what we don't know, and don't seem to be on the way of discovering, is how to knit everything together into a functional system.

There are plenty of plan fragments. The Biden administration has announced a solar goal and a hydrogen goal. Its "Infrastructure Investment and Jobs Act" includes numerous subsidies, incentives, and tax provisions to bolster clean energy. It's a goody bag, assembled by existing individual industries and industrial wannabes in a manner consistent with Washington's lobbying structures - a solar lobby, a wind lobby, a petroleum lobby, a biofuel lobby, a battery lobby and a "small modular" nuclear lobby. There's no big picture plan capable of addressing America's obligation as the world's biggest contributor to atmospheric carbon pollution, to develop a solution and demonstrate it to the rest of the world.

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[627] This and the next eight paragraphs were inspired by an opinion piece written by Matthew Wald.

Today's policy mix today is like a cocktail party's hors d'oeuvres, "food" that shouldn't be confused with a balanced diet.

In contrast, President Eisenhour's interstate highway system was based on a 1955 publication by the U.S. Bureau of Public Roads, General Location of National System of Interstate Highways, also known as the Yellow Book. Its details changed along the way, but at least there was a broad government plan.

The Apollo program's route to the moon—launching a huge rocket into earth orbit; assembling a capsule, command module, and lander; circling the moon; going down in a lander; having the lander rendezvous with the capsule and command module in lunar orbit; and then coming home—was clearly laid out by an engineer and much of the preceding Mercury and Gemini programs were in preparation for that.

If today's "electric sector" were to replace fossil fuels in transportation, space heating, and their direct use in chemicals and other industries, it would have to be roughly two and a half times larger than it is now. If our population continues to grow and/or economic growth exceeds our efficiency gains and/or more extreme temperatures occur, even more electrical energy and peak power capacity will be required by 2050.

By then we must also phase out sixty percent of today's electricity generating facilities because they burn fossil fuels. Some of the 40 percent of such power currently counted as fossil-free may no longer deemed compatible with a zero-carbon system. For example, the value of burning wood chips, soybean oil, and ethanol to address GHG emissions control is questionable because cutting down forests releases carbon from their underlying soil and making ethanol still requires prodigious amounts of natural gas.

Overall, this suggests that we will need at least an eightfold increase in carbon-free energy generation which if implemented with more wind and solar "farms" would require an even larger "capacity" increase along with several TWh's worth of batteries to ensure system reliability during periods of low wind and sun.

Mr. Biden's Inflation Reduction Act does more to cut fossil fuel use and fight climate change than did any previous legislation by expanding renewable energy, electric cars, heat pumps and more. However, it also contains a counterproductive waste of money, backed by the fossil fuel industry, to subsidize CCS which would allow the continued production of oil and natural gas at a time when we should be ending our dependence on fossil fuels. Again, we shouldn't try to do "all of the above" just to keep especially "important" businesspersons and politicians happy.

100% Clean Electricity by 2035 Study | Energy Analysis | NREL is a document generated to scope out several ways that the USA's could reach the clean energy goals that President Biden has set.

It's a good read but again demonstrates the crippling biases that have been built into the USA's energy related thinking.

Two things jumped out at me.

One was that NREL's experts concluded that we'd have to build 2 TW's worth of clean generating capacity by 2035. The reason that that figure caught my attention is that it's the same number that the AEC's Glenn Seaborg had told President Kennedy in 1962 that the size of the US nuclear fleet could/should be by 2000 AD - thirty-five years before 2035 - see Civilian Nuclear Power. A report to the President, 1962 (Technical Report) | OSTI.GOV). If that had happened, the world wouldn't be facing most of today's energy and environmental problems.

The other was its conclusion that "*Differences in energy contribution among the four core scenarios are largely driven by constraints in transmission and renewable siting*'. Duh - those are exactly the same things that an all-nuke power supply system would render unnecessary - reactors could be built wherever they are needed ,wouldn't take up much space, and wouldn't require energy to shifted to wherever Mother Nature's wind and sunshine wasn't .

The better news is that a sizable number of relatively (to me anyway) brilliant young people (e.g., Beckers 2016), several environmental groups, and some especially distinguished senior scientists have also taken up Goeller and Weinberg'sto be shifted cause (Pro nuclear 2018 & Pandora's promise 2013).

In April 2015, nineteen prominent environmental scholars released "An Ecomodernist Manifesto" representing a declaration of principles for new environmentalism. Its summary says: "*We offer this statement in the belief that both human prosperity and an ecologically vibrant planet are not only possible, but also inseparable. By committing to the real processes, already underway, that have begun to decouple human well-being from environmental destruction, we believe that such a future might be achieved. As such, we embrace an optimistic view toward human capacities and the future.*" (Ecomodernism 2018 see Layout 1 (imgix.net)).

One of those relatively young (to me) scholars, Michael Shellenberger (born 1971) is a scientific environmentalist (thinks quantitatively), journalist, speaker, and author. He has co-edited and written several books, including *Break Through: From the Death of Environmentalism to the Politics of Possibility* (2007), *An Ecomodernist Manifesto* (2015), and *Apocalypse Never: Why Environmental Alarmism Hurts Us All* (2020). For almost two decades, he's been trying to convince his fellow environmentalists to embrace a "science based" approach to activism. Like many of nuclear energy's current champions. he started out as an antinuke but had an epiphany that convinced him that that was inconsistent with acts).

His latest book "*Apocalypse Never*" is based upon two decades of research and three decades of environmental activism. At 400 pages, (100 of them are devoted to endnotes whereas I've devoted roughly the same percentage to both footnotes & APPENDICES), *Apocalypse Never* covers climate change, deforestation, plastic waste, species extinction, industrialization, meat, nuclear energy, and renewables.

Here's a video filmed this year (13Mar2021) in which he's explaining to US senators why the variability of solar and wind power is to blame for many of the recent outages in Texas and California, and why nuclear energy is essential for grid reliability.

https://www.youtube.com/watch?v=WaZGJTkQk1c

During that talk, Mr. Shellenberger mentions that a NAS review of the USA's approach to reregulating its electricity suppliers' systems had generated systems whose "*complexity overwhelms its regulators.*"

There is also a world-wide "revolution" going on among the young "normal" (not technical) people who must live with the consequences of their elders (the survivors of my generation, baby boomers, and Generation Xers) permitting things to become as tough for their descendants as it has (Philippon 2019, Alter 2020). Thousands of idealistic youthful activists like Greta Thunberg are demanding that a Green New Deal happen in time to ensure them a reasonably bright future too.

Even better is the fact that some of the USA's Democratic party's most prominent movers and shakers (e.g., Alexandra Ocasio Cortez and Bernie Sanders) are declaring that a "Green New Deal" must be implemented sooner rather than later and that "radical" changes akin to those occurring during the Roosevelt administrations are long overdue (WP 2019). Furthermore, two Republican ex-governors, John Kasich, & Arnold Schwarzenegger, and Democrat Senator John Kerry have joined up to campaign for a Green New Deal and an end to the USA's increasingly toxic political bickering/paralysis/incompetence (CNN 2020).

The best news I've heard recently is that Republicans and Democrats have voiced their interest in working together to reform the Nuclear Regulatory Commission to enable advanced nuclear reactors because .its "….regulatory timelines do not lend themselves to fighting the climate crisis.", and "we need to review the legal or regulatory conditions, procedures and practices to be sure to efficiently license new and advanced reactors. Safety cannot be an excuse to do nothing.", Especially important is that superstar Democratic congresswomen Rep. Alexandria Ocasio-Cortez (D-N.Y.) told her 9 million followers how she had safely visited Fukushima's triple-meltdown site and she feels that France's nuclear waste recycling (reprocessing) iss a good thing..

Best yet, the Biden administration's top dogs understand that we need nuclear to meet its zero-emission goals and have indicated to lawmakers (Congress) that it supports federal subsidies for the USA's struggling nuclear power plants. Bills co-sponsored by thirteen democratic and two republican lawmakers have been introduced in both houses of Congress. A bipartisan infrastructure bill passed in 2021 tasked DOE it to create a Civil Nuclear Credit Program to distribute $6.2 B in tax credits to nuclear plant owners able to demonstrate that the USA's power marketing system/rules/laws es would otherwise force them to shut down their facilities. [U.S. energy department advances $6 billion nuclear plant program (msn.com)].

That subsidy would be the same production tax credit ($15 /MWh) enjoyed by the owners of wind farms and would become part of the president's $2.3 trillion infrastructure plan.

Fourth, finally and best of all, a few technically clue-full US journalists (e.g., Fareed Zakaria, Robert Bryce, Richard Rhodes, and Theunis Bates)` and philanthropists (e.g., George Soros and Bill Gates) have begun to lecture the rest of us about why we must become more realistic about how we go about trying to implement a Green New Deal.

If the USA's retail electricity price regulators were to become technically enlightened and therefore realign retail electricity pricing policies to reflect the true cost of providing "clean" (~90% GHG free) reliable electricity, retail prices will be charged approximately as listed below[628] .

> ~ 25% for fixed costs independent of energy use or power demand (mostly distribution costs)
>
> ~ 65% for monthly peak power demand (measured in kW, mostly for installed capacity)
>
> ~ 10% for energy usage (measured in kWh, mostly for fuel and/or space lease costs)

The world cannot wean itself from fossil fuels with asynchronous, unreliable, power sources that are neither statistically independent nor adequately backed up by reliable "clean" power source(s). US politicians are afraid to face this issue because even though the people that they are supposed to be representing (US citizens) really do need reliable power (today that means fossil fuel backed-up), their leaders would lose the fossil fuel industry's financial contributions, and the necessary changes might bankrupt the now important/influential owners of its wind and solar power facilities.

I hope that the Biden-Harris administration's topmost energy gurus prove to be sufficiently "technical" and honest to address those issues - Mr. Obama's were not. Unfortunately, many of Mr., Biden's political tribe's leaders seem to believe that just building lots of wind and solar farms would solve everyone's problems which it couldn't unless hugely overbuilt and accompanied with even more impossibly costly new energy transmission and storage systems. Because as the fraction of wind and solar generation of a grid's energy mix increases it progressively becomes less stable attempting to tame the weather by becoming completely

[628] Paul Achionne, personal communication.

dependent on it must be one of the dumbest brainstorms that DOE’s experts have had. The fact that transmission lines cross state borders may give the US federal government the necessary authority, but it is unclear that our new President both understands those issues and capable of communicating them to the public. It will probably take several more major grid failures - not just repeats of Texas’s February 2021“forced majeure” and California’s ongoing rolling blackouts   - to drive that point home.

To quote Robert Bryce, “*The lower your power density, the higher your resource intensity*.” Wind and solar power’s intermittency demands much higher resource (land, construction materials, money, and labor) inputs to match the outputs of fossil and nuclear power sources. One of those inputs is land. And it is land and thus wildlife conservation that many Americans and all environmentalists care most about. Climate and energy outlet Heatmap discovered something surprising in a recent poll: about 80% of American adults think conservation is more important than a rapid renewable energy rollout.

“An overwhelming majority of Americans say that conserving local land and wildlife is more important than building new sources of renewable electricity, even if that slows down the world’s response to climate change,” “The poll finds that even though Americans love renewables in the abstract — with 94% endorsing the benefits of rooftop solar and 88% embracing large-scale solar farms — they are skittish about their potential trade-offs. Some 79% of Americans said that new renewable energy should be rolled out ‘slowly’ rather than ‘quickly’ and that the conservation of land and wild animals should be prioritized above rapid greenhouse-gas reductions.” reports.

Their concerns about wildlife conservation represent one of the great victories of the environmental movement and the reason that many environmentalists are now leading the charge against wind and solar.

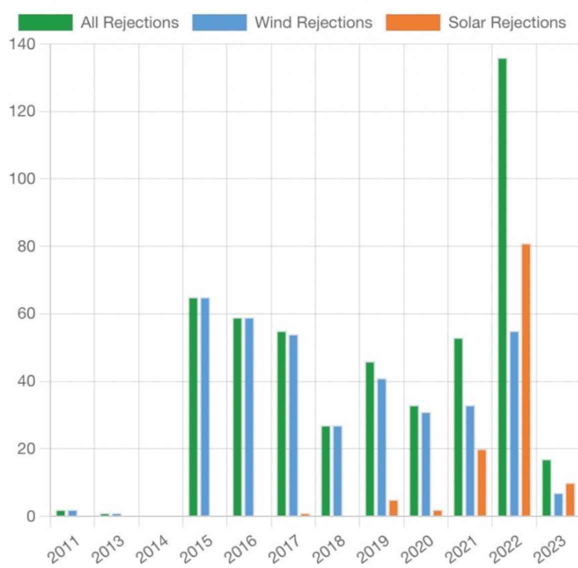

Figure 92 Wind and solar power proposal rejections *Renewables Rejection Database*

In any case, Russia's Mr. Putin and China's Mr. Xi were probably delighted with what has been happening in the West. In time, continued failure to properly address this book's technical issues will cause its/our house-of-cards to collapse. Meanwhile their countries will continue to dominate the world's "new energy" markets.

In terms of which of the country is likely to do most of the work required to implement Weinberg & Goeller's world-wide cornucopian scenario, I'd bet on China because it is especially well positioned to play the dominant in the global nuclear energy regime due to its ongoing domestic reactor R&D and build programs, demonstrated competence in infrastructure building, and sheer size (population 4 x that of the USA). . Within one decade, China is likely to overtake the United States as possessing the world's largest reactor fleet.

China's chief competitors (collaborators?) in the future's "advanced" reactor business are apt to be Russia[629] and South Korea because both have been building/exporting affordable nuclear reactors. Russia currently has a big lead in the breeding-capable (sustainable) reactor field, but it is reasonable to expect that when China's "collectivized" mind has decided how to best go about building them, it will quickly dominate its competition in that arena as it has in most of the others it has entered[630].

China isn't apt to be leading that "save the world" campaign because it has more experience with nuclear power or can operate reactors more efficiently and safely than we do here in the USA. It will lead because its people have become rich[631], it's capable of implementing big projects efficiently, and its political leaders have possessed the will, foresight, and power to reward activities that will serve their county's best interests over the long haul[632]. They've

[629] Putin's insanity may derail this prediction.

[630] India plans to put 21 new nuclear power reactors - including 10 indigenously designed LWRs - with a combined generating capacity of 15,700 MWe into operation by 2031. Its leaders have expressed a great deal of interest in developing a thorium breeder reactor-based, nuclear fuel cycle. However, in my opinion, it is unlikely to overtake France, Russia, South Korea, or China. It will however continue to be a good customer of countries able to build affordable nuclear reactors – especially if they "burn" thorium instead of uranium.

[631] GDP (gross national product) counts the movement of money, not its value. With a more realistic measure of wealth, "purchasing power parity" (PPP), China's economy is already about twice the "size" of the USA's. The USA's is still considered bigger because its people charge each other more for the services representing ~80% of itsr GDP. For example, APPENDIX XIX compares public transportation costs between the USA and foreign countries. Since a nation's GDP is largely based upon how much its people pay for both things and services, China's cheap train service hurts its standing via that measure of national greatness.

[632] At the time that I wrote this footnote (3/15/2020) China's response to the corona virus pandemic was again demonstrating that it has become more able to address vexatious technical issues than is the USA. Rather than cutting interest rates and bailing-out failed businesses, China offered low interest loans to companies willing to switch production to face masks, respirators, ventilators, "space suits", hand sanitizers, hospital beds, etc. China is doing what the US did circa 1941 when President Roosevelt was gearing us up to fight WWII.

accepted the fact that it's their, not their country's private sector's, responsibility to provide a safe, comfortable, and clean world for both their constituents and their descendants – too many of the USA's leaders don't. China's leaders also choose to believe in scientific consensus and that both intra and international cooperation is good for everyone[633] - too many of the USA's consider climate change to be a hoax & that trade barriers & intellectual property hoarding are the best way to deal with competitors, especially foreigners.

" *...only society can address societal problems like climate change. Climate change will not be mitigated if everyone is free to act in their personal self-interest. If we realize there is something bigger than ourselves, we will welcome the idea of doing what's best for the whole of humanity. Think of the required measures as cooperation or as taking responsibility instead of as a hideous assault on liberty. The same principles apply to stopping the spread of contagious diseases.*

Kirsten Sinclair Rosselot, P.E.

However, at this time (14March 2022) what China decides to do next about Russia's attempt to overrun the Ukraine could mark a turning point in both that war and its quiet but steady progress towards achieving world domination in every aspect of the clean energy business.

Both Putin and Xi Jinping have apparently concluded that the Western democracies failure to address their own energy issues had seriously weakened them and that Russia could work alongside China to create a different international system more favorable to them both. However, Russia's decision to invade/destroy Ukraine has put two of China's foreign policy objectives on a collision course. China wants Russia to be its partner in building a new global order, but it also wants to be viewed as a "responsible power" that can someday lead the current one, or at least be at the center of a new system of global governance and connectivity. Consequently, Putin's murderous invasion poses considerable risk for China's leadership. If China decides to back Russia with drones, surface to air missiles, etc. but Putin nevertheless emerges weaker from his war, China could suffer major economic backlash because it relies heavily upon its trading relationships with the EU, Great Britain, Australia, Canada, and USA. It would also reveal that Xi's admonitions to other nations to cooperate in addressing world hunger, poverty, and the consequences of anthropogenic environmental pollution, were just more fine-sounding, political bloviating from another Genghis Kahn wannabe.

Collectively, Homo Sapiens including most of its good team-playing scientists and engineers seems to "think" more like 50 crabs crammed into a gunny sack than do individuals like Bill Gates, James Hansen, Sir Partha Dasgupta, Raj Patel, Rattan Lal, or Albert Einstein. The scariest thing is that during this century human nature could "Trump" rational behavior in

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[633] "*Competition has been shown to be useful up to a certain point and no further, but cooperation, which is the thing we must strive for today, begins where competition leaves off*." — Franklin D. Roosevelt

China[634] as it apparently has here in Trump's USA and Putin's Russia. That is the most compelling[635] argument anyone can make to me about why we humans should take the "Club of Rome's" advice and cut way back on our population and counsel our kids to be satisfied with a much-constrained future because we've refused to pursue the "obvious" solution to their otherwise inevitable energy-related social, environmental, and economic issues.

If we refuse to do the necessary work (thinking for yourself is not easy), or are too worried about "the debt", or feel that we should only feel obligated to attend to our own needs, or perfectly willing to sentence "strangers" (especially "socialists", Muslims, Jews, blacks, browns, gays, unwed mothers, Mexicans, etc.) to destitution and early death, then the least we can do is to admit that that is what we have *chosen* to do – not continue to demonize the technologies and people that could address the issues responsible for most of our miseries.

Because the western world's already-developed & overly bureaucratized countries have allowed themselves to lag so far behind in sustainable reactor development[636], I've rather reluctantly concluded that the best immediate path forward would be rapid build-out of the Russian's BN 1200 breeder reactors along with enough fuel reprocessing/waste treatment plants to start them (see APPENDIX I and XLI) and render their fuel cycle sustainable. It's become too late for us here in the West to continue to wait for our own experts to develop something "new and better" – Russia's breeders are good enough & meet the requirements laid down twenty years ago by the western-world experts charged with deciding what GEN IV reactors should accomplish[637]. Another reason for this conclusion is that Russia is still capable of fueling its and

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[634] After all, just 45 years ago China's people were wearing Mao suits and remain the primary consumers of coal, rhino horns, pangolin scales, bats, bear gall bladders, shark fins, elephant ivory, etc. If China were to go "crazy" again (e.g., like Putin's Russia has) it'd probably be powerful enough this time around to whip everyone else's …es overnight with clouds of rocket-delivered mini nukes. Geoffrey Cain's best seller, "*The Perfect Police State: An Undercover Odyssey into China's Terrifying Surveillance Dystopia of the Future*" tells how China is implementing Silicon Valley's human surveillance technologies to "reeducate" its Muslim minorities. It's scary because some of the people doing it are too "conservative" (authoritarian, clumsy, arbitrary, stupid, obtrusive, brutal, etc.) & *may* therefore be creating a "vicious technological dystopia" akin to that described by George Orwell 72 years ago (" 1984 "). It demonstrates that while 1984 has come and gone, Orwell's dystopian vision of a government willing to do anything to control the narrative is timelier than ever. While I agree with the notion that some of the people in every country including the US do need "reeducation", it's even more important that it be done humanely. We're all human and human nature sometimes really sucks.

[635] but not quite enough to sway me.

[636] In August 2021 the NRC once again demonstrated that its decisions aren't based upon reasonable interpretations of well documented facts. 2021-17475.pdf (govinfo.gov).

[637] This realization is what inspired this book's second-to-last last APPENDIX ("Another Modest Proposal").

other countries' "advanced" reactor concepts (e.g., Terrapower's "Natrium") – the USA no longer can do such things because there's been no way for its entrepreneurs to profit from doing them.

The Western World's real issue is "western standards", not reactor designs or operating details. At this point in time, Rosatom's already-proven BN series LMFBRs represent the most "sustainable" reactor concept that we humans have implemented at "scale". I'm sure that they aren't "perfect" but building lots of them makes a heck of a lot more sense than does waiting around until the West's hyper conservative greybeards decide to change their "standards" or build their own alternative(s).

If the Western World's decision makers continue to insist upon building several times as many "small" reactors to generate the required power, building lots of GE-Hitachi's 311 MWe PRISM LMFBRs makes sense too if their cores are reconfigured to operate as breeders – not "waste burning" SFRs.

If "small" becomes less important to US decision-makers but they still refuse to build anything that their own tribe's members didn't invent, with the help of its Asian manufacturing collaborators, GE Hitachi could build us lots of its full-sized LMFBRs.

At this stage committing to any proven sustainable nuclear plant design would enable the USA's deciders to keep our/their current President's COP 26/27 promises.

Third World countries might be another matter. Smaller, modular, simplified, and cheaper/watt versions of today's LWRs or CANDU burner-type reactors (e.g., GE Hitachi's BWRX-300) are more likely to be scalable faster because they could be built in developed countries and deployed in third world countries that do not yet have the capability to safely build and operate full-sized reactors – especially breeders - by themselves. When those reactors have "worn out", they could be replaced with breeders fed with actinides recovered from their nations' spent fuel accumulations. By that time "big" nations should have already rendered their own energy systems clean, green, and sustainable.

Another option for those countries would be to build lots of medium-sized CANDU reactors like Ontario's Pickering site's units 1-4. Dr. Jerry Cuttler tells me that they were built for a total of about one half billion Canadian dollars.

Those reactors represent a bit over 2 GWe's worth of power generating capacity - let's say 2.2 GW_e altogether – and were apparently finished circa 1973. Mr. GOOGLE tells me the dollar inflation factor since then is about 6.1 meaning that Dr. Cuttler's 0.5 $ billion/GWe figure translates to about 3 billion Canadian dollars today

In today's US dollars that'd be 1/1.27*3/2.2 or $1.07B/GWe for new CANDU-type nuclear power.

If Canada's current industrial & subcontracting wizards could still get them built for anything like that, doing so would make more sense than building GE's simple/cheap BWRX-**300** because CANDUs are more fuel efficient, don't require fuel enrichment, and don't have to be shut down during refueling. The latter means that they operate steady-state; i.e., don't have to be completely shut down for refueling

In my opinion, most of the arguments presented for continuing to dither ("study") until a new way to do the fuel reprocessing/recycling required to render my "renaissance" sustainable is perfected are as phony as INL/Hanford's "waste management" paradigms have proven to be. TBP & kerosene are cheap, dissolving LMFBR-type fuel rods in nitric acid is simple, and everything else required to render that "old fashioned" technology both sustainable & able to clean up after itself[638] has been proven to work for as long as I've been in this business (ask the Russians, if you don't believe me).

I suspect that a molten salt reactor-based nuclear renaissance will eventually prove itself "better", but we've got to start doing something now that's for-sure both doable and genuinely sustainable – APPENDIX .

I've decided to finish this book off with a senior Canadian Professional nuclear Engineer's advice to the folks currently deciding how to go about "saving the world" with nuclear power.

"*Due to recent antics by both the Chinese government and the US government under Trump, it will be a very long time before Canada permits itself to become totally dependent on either Chinese or US politics for critical energy supply. Canadians do not worship the dollar as much as do people in the USA. Hence your forecast about the Chinese completely owning the reactor market is likely incorrect. If the recent pandemic has taught us anything it is that it is folly for Canada to be completely dependent on either China or the USA for anything critical. This view is likely shared in most of the British Commonwealth (former British Empire) countries.*

Neither China nor the USA can be counted on with respect to compliance with treaties. There is a significant market opportunity where supplier independence from China and the USA is more important than price.

Thus, unless there are major political changes the Chinese will not own the SMR market, although they may take a big share of it.

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[638] For instance, TBP & its variants are indeed gradually degraded by such solutions' intense radiation. However, that's irrelevant if we replace the "old" stuff often enough. That's easily/cheaply done & those reagent's subsequent management/disposition is also simple because they are all "burnable" and their ash should supply some of the phosphate required to convert 100% of the reprocessing plant's radwaste to phosphate-glass radwaste forms (Day and Kim 2005, Siemer 2012, Siemer 2014*).

The root of most of our problems is greed and leadership ego. Airbus only exists because Boeing became too greedy. Pfizer is looking at new major competition because it became too greedy. Huawei lost much of its market because it became too greedy. China became greedy and took over Hong Kong contrary to treaty obligations. However, Hong Kong was part of the former British Empire. The mainland Chinese themselves are the big losers. They are losing reactor business in the UK, Canada, Australia and Europe. Trump tried to be a strong man against Canada. His actions had a negative effect on the northern states which contributed to his electoral loss.

The next victim may be Taiwan. If the Chinese take over Taiwan it will immediately lose its world dominance in semiconductor manufacture. Other countries view semiconductors as critical and will subsidize and set up competitive semiconductor competition almost overnight. Politicians in major countries have to learn that short term actions often have long term consequences.

The world contains many medium sized countries that do not want critical dependence on either China or the USA.

A very important area is development of standards. The parties that control and enforce material and component standards will likely dominate the SMR market. Purchasers need assurance of product material quality and need certainty about long term availability of replaceable components. HP used to dominate the laser printer market. It had robust products that were readily serviceable. Then some idiot at HP shifted laser printer production to China. Canada received made in China HP laser printers for which there were no readily available spare parts. The result was that HP quickly lost its gold mine, which was a near monopoly in the commercial laser printer business.

If China wants to play in the commercial-industrial market it is going to have to invest heavily in after sales service. Part of that investment is not shooting itself in the foot politically."

"*Basic issues for the public are:*

1) Reprice electricity so that dependable electricity and interruptible electricity have different prices reflecting their real values. Unless marginal interruptible clean electricity costs less than fossil fuel thermal energy it is impossible to displace fossil fuels with electricity.

2) Appropriately value dependable electricity that has no CO_2 emissions.

3) Concentrate public nuclear developmental dollars on reactors and supporting systems that provide a sustainable fuel cycle as requested by President Kennedy in 1962 (ss https://www.osti.gov/biblio/1212086) .

4) Move nuclear power reactor safety issues to the responsible developmental engineers. The present US nuclear safety regulatory system is a product of fossil fuel industry lobbying to make *nuclear power uneconomic. Face the reality that in the energy industry, s..t happens. The issue is to keep the real impact of nuclear accidents small compared to the real impact of fossil fuel accidents and hydroelectric dam accidents. The concept of ALARA is uneconomic.*

5) Organize and fund all of the above so that it cannot be sabotaged by the fossil fuel industry lobby. This work must be moved out of the political arena. The way to make that happen is to apply a large fossil carbon tax in a such a manner that the fossil fuel industry is forced to heavily invest in new nuclear power capacity.

6) Point out that China and Russia have a 30-year lead on the USA. They have at least fifty large nuclear reactors at various stages of implementation whereas the US has only two. China alone is reasonably expecting to complete eight large reactors per year going forward. China and Russia are busy capturing most of the world energy market while the US argues with itself.

7) The whole concept of relying on renewable energy is a lie. In Canada there is negligible sunlight for half of the year and wind is erratic. Absent dependable power people easily freeze to death in the winter. BC and Quebec have much more energy storage than the USA but even that energy storage is only sufficient for a small fraction of the Canadian population, much less the US population which is nine times larger. Regardless of what happens in the USA, Canada is going to build more nuclear capacity to displace fossil fuels for winter heating. The US better get used to the idea that we will have nuclear power reactors right across the country a short distance from the US -Canada border. For energy sustainability the nuclear fuel will be reprocessed.

8) If the US fails to get its act together the Russians and Chinese will likely become the dominant nuclear equipment and fuel assembly suppliers.

Regards,

Charles Rhodes

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Chapter 12. Homework Problems

MISC. DATA/RELATIONSHIPS (also see GOOGLE, Engineer's toolbox, WIKIPEDIA, etc. and/or this book's Table 1):

one US pound = 454 grams; 1 calorie heat energy raises the temperature of one gram of water one centigrade degree; one centigrade (or kelvin) degree =9/5* one Fahrenheit (F) degree; water freezes at zero degrees Centigrade or 32 degrees F; one BTU = heat required to heat/cool one pound of water one Fahrenheit degree; one calorie=4.184 J; one kilocalorie (kcal)=1000 calories (the "calorie" unit usually quoted for foods etc. are really kilocalories; e.g., , one gram fat = 9 kcal = 37.6 kJ, 1 gram protein or carbohydrate (starch or sugar) ≈ 4 kcal, one gram petroleum (any oil) ≈10 kcal); heat capacity of water =one calorie per centigrade degree per gram; burning one pound of lignite coal generates 6500 BTU worth of heat (it's about one half as "energetic" as is either pure elemental carbon or anthracite coal); one gram mole of fissile uranium (^{235}U) weighs 235 grams and contains an Avogardo's number of atoms; i.e., 6.023E+23; fission of one actinide atom generates ~3.2E-11 J's worth of heat energy;v1 electron volt (eV)=1.6E-19 J, 1 US ton=0.908 metric tonne (1 tonne=10^6 grams = 1000 kg); 1 mile^2=640 acres = 1609^2 m^2; 1000^2m^2=1 km^2=100 ha.

MISCELLANEOUS EXERCISES

1. A few years ago the USA's American Nuclear Society was giving away cards with a little black glass marble embedded in it. The card's words said that 3 such "real" glass waste form marbles could contain 100% of the fission products that a modern Purex reprocessing plant would put in an 100%-nuclear powered first world's person's portion of its fuel cycle's yearly waste forms. If the reactor in question was 32.1% efficient at converting its heat to electricity, the marble had a diameter of 0.55 inch, a density of 2.8 g/cc, and a "real" wasteform glass would be 10% by weight FP, how much useful energy (steady state power) would that person be consuming? (ans ~1000 watts)

2. If peanut butter has 6 kcal/g and "white" bread 4 kcal/g, a slice of bread weighs 20 grams, and the same amount of each constitutes an open-faced (one slice of bread) peanut butter sandwich, how many such sandwiches would it take to feed someone for a year? (Use the same daily calorie-requirement figure I've assumed for the future's Africans) ans = 4562

3. How many grams of protein would he/she be getting per day? (assume that bread is 9.1% protein & peanut butter is 25%)

4. Is my book's estimate of Mankind's total raw energy requirements (~570 EJ/a) still valid? (GOOGLE it - I started writing this thing over two years ago)

5. How many barrel of oil equivalents (BOEs) (Google "BOE") does one peanut butter sandwich represent? How many kWh is that? How many horsepower hours?

6. One peanut sandwich per minute = how many watts? (ans. ≈ 13.9 kW)

7. If $1/x+23/x^2 = 3/x^3$ what's X to two significant figures? hint: set up an EXCEL spread sheet that calculates each side of the equation based upon an input in another box and then ratios the results … keep inputting different x's until that ratio is 1.00 +/- 0.01. (ans =0.13) What would x be if 1/x+23/x2 = 3/x3+283/x4 ?

8. Using this book's "arable" land area figure for the continent of Africa and assuming a soil density of 1.2 g/cm^3, how much atmospheric carbon dioxide would be sequestered if implementing my s recommendations raised the soil organic carbon concentration of its topmost 20 cm from 1 to 6 weight % (ans =58.3 billion tonnes)

9. Assuming that electricity costs 6 cents/kWh and desalination's energy requirement is 3 kWh/m^3, what would the power required to irrigate one US acre with 30 inches of water cost? (show your work, ans =$555)

10. Repeat for 20 inches of water per ha

11. If radwaste put into a tank in 1955 had one Curie per liter of ^{90}Sr in it, what would it have now? (Assume 28 year half-life) ans = 0.20 Ci

12. If ^{90}Sr decay generates a total of 1.09 million electron volts worth of heat, how much power (W) would one gram of it generate? (calculate the number of atoms, then the number decaying per second, then that energy in terms of eV/s & finally convert to J/s) ans. 0.9 watts

13. How many metric tonnes of lignite coal must be burned to heat 1,000,000 (1E+6) gallons of water (1 gal=3785 grams) from 70°F to 120° F? (ans = 29.1)

14. How much fissile uranium (metric tonnes) must be fissioned to do the same thing? (ans = 5.37E-6 tonnes) -

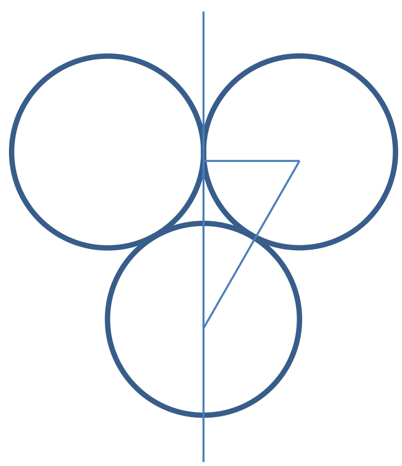
15. If only the ^{235}U in natural U (NU) actually fissions, and it represents 0.7% of natural uranium, how much natural uranium must be used to heat 1E+6 gallons of water (1 gal=3785 grams) from 70°F to 120° F ?

16. If lignite coal costs $25 per metric ton, what's heating that much water with it going to cost?

17. If natural uranium (NU) costs $40 per kg, 5/7 of its fissile ends up in LWR fuel & fuel represents 15% of total LWR power cost, what's heating that pool with electricity generated by a CR =0 (no breeding; i.e., the only thing fissioned is ^{235}U), 35% heat-to-electricity efficient power plant going to cost? (ans ≈ $282)

WIND POWER

A general rule-of-thumb for wind farm spacing is that turbines should be no closer than 7 rotor diameters away from each other. Taking the little figure depicted below into account and assuming that a 2 MW rated windmill's blades sweep a 90-meter circle, let's determine out how many of them could be sited within a square area 100 km on each side



We'll start out by deriving how far apart the rows of wind towers close-packed into that 100 km/side square would be.   (see https://en.wikipedia.org/wiki/Trigonometry)

29. The drawing depicts the area surrounding three such towers. In this case the hypotenuse (longest side) of the triangle would be seven times 90 meters.   What would be the distance between the center of the left most circle and the vertical line drawn upwards through the center of the bottom circle to where the upper two circles touch each other? (ans. = 7*90/2 meters)

30. What does that mean in terms of the angle between the long sides of that triangle? ans: since the short side of that triangle is one half the length of its hypotenuse, it must be COS^{-1} of 0.5 or 30 degrees.

31. What would be the length of the line drawn upwards from the center of the lower circle & and the line drawn between the center of the two upper circles?

30. Since that length represents the distance between the rows of the close-packed circles making up our hypothetical 100^2 km^2square wind farm, how many individual towers could be stuffed into it ? ans ≈ 33489   (this is a bit high – in order to not have the last tower in every other row poke out beyond the 100 km border each of those rows would have to consist of one fewer towers;   i.e. there would only be 100000/(7*90*Cos 30) -1   of them in them - overall it all adds up to 33306 towers

31. If this farm's towers' yearly-averaged capacity factor were 0.333 how many MWh per year could that wind farm generate?   ans. ≈ 198 million

32. Let's assume that the wind farm's average amount of wind-generated energy were exactly enough to meet demand but also that that demand is invariant (a 24/7 demand that couldn't be "load shed"). If the wind blows for 8 hrs per day,   how much back up storage is needed ?   ans.≈ 3.55E+5 MWh

33. If the wind were guaranteed to die out for only 8 hrs. per day, how much storage capacity would we need? ans ≈ 1.78E+5 MWh

34. If the wind were to totally die out for only 4 hours per day, how much storage capacity would we need? ans. = 8.9E+4 MWh

35. What would we need if the wind were to die for a whole week?

36. Assuming the answer to problem #32, if the batteries in question were to cost one half as much as do TESLA's Power walls ($7000/13.5 kWh), what would that storage system cost?

37. If its batteries lasted an average of 20 years (pretty optimistic), what would storage add to that utility's customers' electricity bill/kWh?

38. If the windmills themselves cost $1/watt (nameplate capacity) to build/maintain & last for 20 years, what would the power generated by them cost per kWh)?

39. Assuming shareholders demand 10% profit, what would such power cost a retail customer per kWh?

(the number you come up with likely underestimates a practical renewables-based system's power cost because, without lots of "load shedding, " wind power's unreliability would require investment in additional back up capacity – batteries, etc. and/or power shipped in from elsewhere – China?)

40. How do you go about estimating a 100% wind & solar powered California's storage battery requirements from information like that in **Figure 27**?
That figure assumes that California's decision makers decide to build just enough yearly-capacity-factor-corrected wind and solar plants to meet its annual energy demand. You'll note that renewables easily satisfy demand during the summer (the sun's brightest when air conditioning demand is greatest) but fall well behind during the dead of winter when space heating dominates demand. If you don't have access to a published figure's numerical data, one way to get what you need is "cut & weigh" integration (i.e., print out the figure, cut out relevant areas & weigh them). When I did that, the mass of the piece of paper representing the seasonal deficit at the leftmost part of the figure was 29 milligrams while that of a "calibration" piece representing 12 month, 1000 to 3000 MW, production/demand weighed 517 milligrams.
Question: How many joules worth of electricity does the calibration piece represent? (ans. ≈ 6.31E+16)

41. How much battery capacity (kWh) would be needed to back up CA's wind/solar plants during that time?

42. Assuming that the same Tesla “Powerwall”s referred to in section 2.3 of this book were to be used, what would they cost? ans ≈ 9.1 $trillion

OIL SHALE

According to WIKIPEDIA the world’s shale deposits are supposed to contain 6.05 trillion 42 US gallon barrels (962 billion cubic meters) of shale oil, and ~80% , of it is within the United States

18. If the USA’s shale deposits average 100 meters thick, possess a density of 2.5 g/cc, and contain an average of 40 liters of 0.9 gram/cc “oil” per metric tonne, what’s the land surface area of the USA’s shale oil deposits? (show your work)

19. How many “Utahs” (area~ 89,000mi^2) would that be? ans ≈ 0.33 Utah/

20. If “advanced” technologies could retrieve 50% of such oil, how many tonnes of that shale must be processed to “power the future” (i.e., generate 22.4 TWe) for ten years using 50% thermal-to-electricity efficient oil-fired power plants? ans = 7.49E+11 m^3

21. Assuming that those shale deposits are 100 meters thick, how many km^2 of land must be “disturbed” to power the future (22.4 TW) for ten years? (ans 75,000)

22. If the average depth (to their tops) of those deposits is 500 meters & the density of their overburden is 3.0 g/cc, how many “RMS Titanics” (~47,000 tonne displacement) worth of such rock must be removed each year to get to that resource ? (ans ≈ 478 million Titanics)

URANIUM RESOURCES

data extracted from p 147 of “Beyond oil: the view from Hubbert’s peak”

Estimates of uranium in rocks ranging from rich ores (~18,000 ppm) down to average granites

tonnes	conc. ppm
2.50E+05	18000
2.00E+06	5000
5.00E+07	2000
1.00E+08	550

2.00E+09	200
2.00E+10	60
5.00E+11	20
2.50E+12	6

- put these data into an Excel spread sheet
- translate the tonnes data column to a total tonnes column
- convert both columns to their respective $\log_{10}$ figures
- INSERT a log ppm (X axis) vs log tot U (Y axis) scatter plot
- fit a linear TRENDLINE to it & have EXCEL print out the equation and R^2 value

23. What's the total amount of uranium? Ans=10^12.48 tonnes

24. How many tonnes of NU is there at concentrations >1000 ppm? Ans 8.89E+7 tonnes

25. Assuming that NU is to power 22.4 TWe worth of LWRs (~160 t NU/GWe year) & that >1000 ppm ore is covered with 5 x as much overburden, how much total rock (ore +overburden) must be mined per year to fuel them? ans ≈21 billion tonnes

26. Assuming that the USA has one Utah's (89,000 mi^2) worth of 50 meter-thick, 50 ppm U, 2.5 g.cc "black shale" rock deposits , how long (years) could a "perfect" breeder-based. 50% thermal-to-electricity efficient nuclear fuel cycle provide 22.4 TWs worth of electricity/year burning US shale-derived uranium? (ans ≈ 330,000 years)

27. Assuming a total shale rock actinide accessing/processing cost of 50 dollars per tonne, how much would that actinide fuel cost per kWh? (ans = 8.89E-5 dollar)

28. What would its power cost customers per kWh if the reactor's up-front cost is one \$billion/GW_e, its operating cost/GW_e is 20 \$million per year, and lifetime = 50 years? (ans =0.46 cents/kWh)

SOLAR HEATING RELATED EXERCISES

Home heating is the most reasonable way to take advantage of the sun's free power. In practice it's often difficult to do because most homes are neither built nor sited properly; e.g., their biggest windows typically face the street where ever it might be, not the winter's sunlight[639]. Nevertheless, it's often possible to significantly lower winter heating bills by adding insulation to the right places at the right times.

Let's do some examples.

The insulation value of a material is inversely proportional to its thermal conductivity "k" or lambda-value (lowercase λ): the lower the k-value, the better it is. Expanded polystyrene (EPS) has a k-value of around 0.033 W/mΔT [k or C degrees), phenolic foam insulation's k is around 0.018, wood's ranges from 0.15 to 0.75, and steel's is about 50

Assuming the following:

- an average wintertime outside temp of 0°C and inside home temperature of 20°C
- your home has a 4' by 8' (2.97m^2) "picture window" situated where 50% of "maximum possible" sunlight (1000 watts/m^2) gets through it for an average of 6 hours per day
- 100% of such sunlight is degraded to heat energy within your home

43. How many Joules worth of "useful" solar heat are you getting each day?

44. How many kWh is that? (ans ≈8.9)

45. If that window were to consist of two, clear, uncoated glass panes with air between them possessing an overall "R"-value of 0.35 ΔTm^2/W (R =0.35= ΔT*m^2/W), how much of your home's heat (Joules) would be lost through it per day? (pay attention to R value units & remember that conductive heat loss occurs 24 hrs./day) (ans ≈1.47E+7 J…44% of the window's solar gain)

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[639] > On 7Oct2022 one of CNN's talking heads took a break from politics to present a 3–4-minute blurb about how "Babcock Ranch" a properly engineered ("planned"), 17-thousand-acre, housing development a few miles inland of Ft Meyers, Florida, directly in the path of Hurricane Ian rode it out without damage. That community is mostly solar powered (75 MW total cap including rooftops plus a 400 Ha solar "farm" and that most fragile of "clean" energy systems wasn't damaged either. Its "engineering" preserved wetlands, properly anchored & distributed its electrical system & put its streets two ft lower than the houses to provide channels for water runoff. It's both unusual and "socialistic" because nothing can be built there that doesn't make sense over the long haul.

46. If an inside "shutter" consisting of a 2.97 m^2 slab of 2.54 cm-thick phenolic foam board were to cover that window when the sun wasn't striking it, what would its net daily heat input to your home be per day? (Joules)   ans ≈ 2.99E+07 J (this is a bit tricky because heat loss is now through both window & shutter when it's in place – the combined heat conduction of such "seriesed" things is $(1/W_{1st} +1/W_{2nd}\ldots..)^{-1}$

47 If that window were to be filled in with a section of fairly well-insulated (e.g. with a 15 cm thick layer of EPS) wall and 2.97m^2 of state-of-the art (19% efficient) solar panels, how much net heat energy could those panels supply to your home via baseboard (resistive)-type heating? Don't forget to correct for the new wall's modest but real conductive heat loss. ans = 4.97E+6 J   (that's only about 16.6% of the useful heat gained by the original window/shutter combo)

48. How much heat could your high-tech new wall/solar panel combo supply if the ~$50 baseboard heater were replaced with a $1000 heat pump possessing a "Coefficient of Performance"(COP - look it up) of 3?

49. Let's assume that another house has a total surface area of 200m^2 including 7m^2 of windows like the one I've described above except that none are oriented so that solar heating is apt to be useful. Its wall and roof all have the same 15 cm's worth of EPS insulation employed to make the last problem's modification. Assuming no window shutters or air leaks, what is this house's total heating load? (Watts)   How much less would it be if you were to put one inch (2.54 cm) thick phenolic insulation board shutters in all of its windows?

50. If one-inch-thick phenolic insulation board costs $12/$m^2$ and electricity 12 cents/kWh, how long would it take for those homemade shutters to pay for themselves?   (ans. 91 days)

MSR Nitty Gritty

51. GOOGLE-up the densities of "natural" NaCl and UCl_3 at room temperature (25°C) and use them to estimate the density of a 65 mole% NaCl/35% UCL_3 (i.e., 6.5moles NaCl to every 3.5 moles UCL_3) molten salt at 650°C assuming that that stuff expands 150 ppm volume-wise per degree.   (ans ≈ 3.34 g/cc)

52. Assuming an enrichment of 20%, how many fissile atoms would there be in one cc of that liquid salt? Ans. ≈9.73E+20 atoms ^{235}U/cc)

53. If the reactor containing that molten salt has a "core tank" consisting of a sphere 1.8 meters in diameter, how much of that fissile (tonnes) would be in it?

54 If that tank's walls were one-quarter inch thick 316 stainless steel, what would it weigh?

55. Assuming that "nuclear grade" 316 SS costs $5/pound (~three times what anyone else would pay for the same thing) & that cutting/welding it triples that figure, what should a replacement core tank cost? ans ~$17,000

56. If that reactor were to generate 2 GW's worth of heat & its heat exchangers' size-to-heat-exchanger capacity ratio were the same as the MSFR's (GOOGLE Carlo Fiorina's PhD thesis) how much additional fissile would be required (tonnes)? ans =1.16 tonnes

LMFBR Nitty Gritty

Admiral Hyman G. Rickover briefly experimented with sodium cooled fast-neutron reactors for naval submarine propulsion. This effort began with General Electric's development and operation for the Navy of the land-based S1G prototype at the Knolls Atomic Power Laboratory in West Milton, New York. The S1G, which was HEU-fueled, operated from the spring of 1955 until it was shut down in 1957 after Admiral Rickover abandoned that concept for naval propulsion. Persistent leaks in the Sea wolf submarine's steam plant were an important factor in that decision but even more persuasive were the inherent limitations of sodium-cooled systems. In Rickover's words they were, *"expensive to build, complex to operate, susceptible to prolonged shutdown as a result of even minor malfunctions, and difficult and time-consuming to repair."* (https://en.wikipedia.org/wiki/USS_Seawolf_(SSN-575)

Nevertheless, DOE continued to invest most of its fission reactor-related NE R&D resources on that concept for another four decades up to circa 1994 when Mr. Clinton axed all breeder studies. The following homework exercises deal with a LMFBR that India apparently planned to build. First, here's its description:

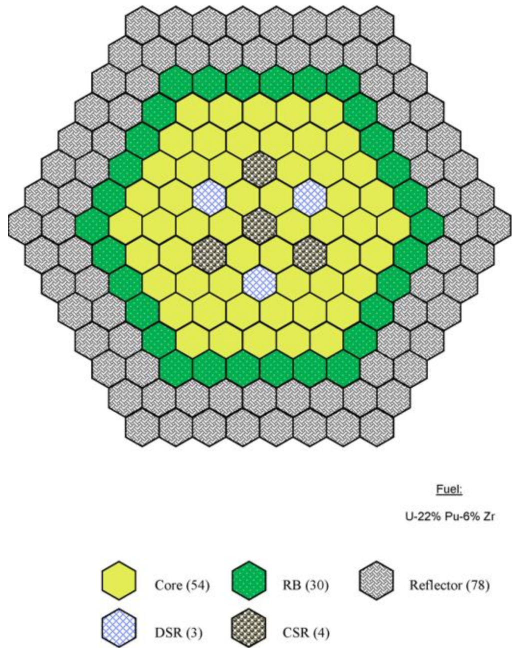

Figure 93 Core configuration of a 320 MWt metal fueled fast reactor (FBR-4) [Physics design of experimental metal fuelled fast reactor cores for full scale demonstration - ScienceDirect](). (Devan et al, Nuclear Engineering and Design 241 (2011) 3058– 3067

To a first approximation it's a right circular cylinder comprised of 169 close packed hexagonal "assembly spaces" each of which may contain either a "driver fuel" assembly (at the core's center), surrounded by a single row of blanket fuel (green colored RB)assemblies, which in turn are surrounded by two rows of neutron reflector assemblies containing lead or stainless-steel rods. Several assembly spaces are reserved to permit the insertion of neutron-poisoned "control" or "safety" rods (DSR or CSR).

Liquid sodium is pumped upwards throughout that core's interstices to - carry off the heat

Each of the fuel & blanket rod assemblies consist of a thin-walled, hexagonal, 13.3 cm flat-to-flat diameter, 304 stainless steel "can" containing 217 wire-wrapped metallic "rods"

Each core/driver fuel rod consists of a 1.6 meter long, thin-walled stainless steel tube containing spacers, liquid sodium (aids heat transfer), and a 6.6 mm outside diameter, one-meter long 72wt % uranium/22wt% plutonium/6wt% zirconium alloy driver fuel "pin" at its center. 30 cm spacers re inserted into the tube above and below the "hot" driver fuel pin to accommodate FP gasses. The larger diameter, more or less pure fertile uranium pins within the blanket rod subassemblies are full length (1.6 meters long) as are the reflector rod sub-assemblies. The~0.01" space between the fuel pin and the tubing's wall contains (liquid) sodium to enhance heat transfer & permit the metallic fuel's "meat" to expand as some of it is fissioned.

57. What's an individual assembly's cross-sectional area, ans. = $13.3^2/(2\cos30)+13.3*(1+1/(2\cos30)) = 123\ cm^2$ (figure out for yourself how this equation/answer was obtained – a sketch will help you visualize it)

58. What's this reactor's core region's total cross-sectional area (cm^2)? Ans = 6647 cm^2

58. What's the entire core region's (driver, blanket, and reflector rod) volume?(ans =1.06 m^3)

59. When the reactor is running at "full power", how many watts does each cc of that reactor volume generate? ans 300 W

60. What's the volume of that region in cc?

61. If the heat capacity of liquid sodium is 32.3 J/(mol K), approx. how much sodium must be pumped through the reactor's entire core per second to keep its (the sodium's) temperature between 400 and 550C? (Hint: what's sodium's atomic weight?) (ans about 1.8 m^3/second)

62. If Zr's density=6.49 g/cc, uranium's density 19.1 g/cc and plutonium's 19.8 g/cc , what's the density of this concept's driver fuel pin alloy? (hint: do the calculation using their partial molar volumes) ans =17.2 g/cc

63 If the fuel rod's cladding is 0.45 mm thick & there's a .025 cm sodium filled gap between it and the Zr/Pu/U fuel pin, what's the mass of each driver fuel Zr/U/Pu fuel pin (grams)? (ans. ~373 g)

64. How many fissile atoms/cc are in that pin (assume ^{239}Pu)? ans = 9.55E+21 atoms/cc

65. How many kg of fissile (assume all Pu = ^{239}Pu) is in the reactor's core? (ans= 0.961 tonnes)?

66. If the driver fuel achieves a burnup of 120 GWd/tonne HM driver fuel rod? ans = 53.1 grams

67. How many grams of FP will be in the reactor's fuel at that point?

68. If that Pu is to come from spent CANDU reactor fuel (~0.35 wt% Pu), how much of it (tonnes) would have to be reprocessed to get it?

69. Assuming the same power generation per unit volume how much Pu would it take to start 1 GWe 45% efficient thermal to electricity LMFBR?

70. If the inside length of each of the driver fuel assembly cans is 128 mm, what fraction of its inside volume is occupied by coolant sodium? ans ~47%

OCEAN ACIDIFICATION EXERCISES

The mass of the Earth's atmosphere is about 5.1480×10^18 kg and its gas mixture's mean molecular weight is about 28.8 grams/mole (~20 mole% O_2 (32 g/mole) & ~79 0% N_2 (28 g/mole) & about 1% total other gases)

71. If mankind were to continue to generate 85% of ~580 EJ/a by burning pure carbon (very much like anthracite coal, ~ 33 MJ/kg heating value) for the next 30 years how much $_{CO2}$ would be generated? (ans = 1.64E+15 kg)

72. At 44 g/mole how many moles of $_{CO2}$ would that be?

73. Roughly how many gram-moles of gas does the Earth's atmosphere contain?

74. At today's ~410 ppm by volume (number of CO_2/total number gas molecules) atmospheric CO_2 conc., how many moles of CO_2 is already in it?

75. How much lower will burning that "coal" push the pH of the oceans' surface waters (calculate pH of its water for both $_{CO2}$ partial pressures   see APPENDIX XX)

WIND POWER HYDROGEN

In 2011 NREL published its "Hydrogen Production Cost Analysis" based upon an assumption that it would be made with via wind-power-derived water electrolysis at 42 different wind farm sites across the nation. . https://www.nrel.gov/hydrogen/production-cost-analysis.html (look it up)

That website has lots of useful/interesting data about those sites' power generating potential.

It appears that the USA's good wind farm sites are " based upon their mean annual wind power potential ranging from 3 to 5".

76. What power range (W/m^2) is supposed to be encompassed by those wind "classes" (ans 300 to 600 $Watts/m^2$)

If …

- the wind turbine is at sea level and the temperature is zero Centigrade (32 F); i.e., at Standard Temperature & Pressure ("STP")
- air has an average molecular weight of ~28.8 g/mole
- 1 gram mole of an ideal (and almost any other) gas at sea level (1 BAR (standard atmospheric pressure) & 0°C occupies 22.4 liters
- It's blowing/moving at 7.5 meters/second (16.8mph) when it impacts a surface
- & the kinetic energy of a moving object (e.g. air) impacting & being total stopped by such a surface is $½*mV^2$ (if m =kg & V= m/s, energy = Joules)

77. What's the maximum *theoretical* energy that could be extracted from that wind by 1 m^2 of a windmill's "wind swept area"? Remember that the mass of air striking something per second is proportional to its velocity, V). ans 271 watts

(The following very well-written report's power vs wind speed formula gives about the same result - the small difference is due to differing average gas mass/mole (or volume) figures and temperature, 15 rather than 0 degrees Centigrade. Standard temperature and pressure (STP) air is close to but not an "ideal" gas. http://www.ijsrp.org/research_paper_feb2012/ijsrp-feb-2012-06.pdf

78. Most wind turbines reach their rated power at a wind speed of about 13 m/s (29 mph). If one rated at 1.5 MW with 116 ft. long propeller blades (a popular GE

model) puts out its rated power with that much wind, how efficient is it? (eff ='s 1.5 MW/what it should generate if 100% eff) ans ~28.3%

79. Look up "Betz limit" – does it account for this particular wind turbine's inefficiency? ans="no"

80. The NREL's "target" price for wind power generated H_2 was \$3.7 per kg 2007 dollars: if it takes 50 kWh's worthy of electricity to electrolyze 1 kg of H_2, how much must have NREL's wind power have cost per kWh?

81. What does that translate to in today's dollars? (assume today's ~2.3% annual inflation rate 'tween 2007 & 2020) ans = \$4.97/kg H_2

82. What would the cost of the gasoline described in the numerical example at the end of section 3.3.3 have to be to match NREL's 2020-adjusted wind power H_2 cost? (hint: see the example that I worked-out for "nuclear hydrogen")

CONCENTRATED SOLAR POWER

Concentrated-solar power plants utilize many mirrors equipped with sophisticated tracking systems (dual axis heliostats) to focus a large area of sunlight onto a small area "absorber" (or "receiver"), usually the top of a tower situated in the middle of the mirror array. Because it's a thermal power station, CSP has a lot in common with those using coal, gas, biomass, or geothermal heat. They *can* incorporate thermal energy storage, stored either in the form of sensible or latent heat (for example, via a hot molten salt), enabling them to continue to generate electricity whenever it is needed, day or night. Unlike photovoltaic (PV) solar power, CSP is a potentially dispatchable form of solar power. Because CSP was originally considered to be a competitor to photovoltaics, DOE's Ivanpah facility was built without a molten salt thermal energy storage tank. Its subsequent "Solar Two" facility did include several hours' worth of heat storage. However, by 2015 the cost of photovoltaic plants had fallen to the point that its energy was selling for 1⁄3 that of extant CSP contracts because utilities & regulators had begun to understand that dispatchable power is worth more than intermittent power. Consequently, energy entrepreneurs began to build/bid CSP plants featuring up to 17 hours' worth of dispatchable electrical energy when the clouds roll in or the sun goes down. As such, CSP is seen as competing with natural gas and PV-plus-storage battery generation.

DOE's Crescent Dunes facility is a representative example. It was started in 2011 & finished in 2013 for a total cost of $975 million including a $737 DOE loan guarantee. Its 10,347, 115.7 m^2 mirrors are arrayed in a huge circle surrounding a central 230 m dia. circular area containing its 200 meter-high "tower of power" which apparently required about 100,000 m^3 of concrete to build, boiler, turbogenerator, & "solar salt" storage tank.

82. What's the total area of its solar energy collection mirrors?

83. What fraction of the entire facility's footprint (area) is occupied by its mirrors? (GOOGLE EARTH "Crescent Dunes" & use its "ruler" to measure the diameter of its mirror array)

a. Since that region's "Direct Normal Incidence" (DNI) solar irradiance is 7.8 $kWh/m^2/d$ how much solar energy (Joules) should its tower's receiver collect per year? (assume perfect mirrors , tracking, and heat absorption)
b. The capacity of its molten salt energy storage system is nominally 1.1 GW_e -hour– what does that translate to in terms of hours of dispatchable110 MW_e electricity?
c. If it were to actually generate its nameplate-rated steady 110 MWe, what would its percentage solar energy-to-electricity conversion efficiency be? ans 2.8%
d. Assuming that rating how much power would facility generate per m^2 of ground covered?
e. The capacity of its molten salt energy storage system is nominally 1.1 GWe -hour– what does that translate to in terms of hours of dispatchable 110 MWe electricity?

84. (the big one) assuming 1) that that entire facility's area were to be converted to a big corn field, 2) an enterprising farmer somehow managed to raise 200 bu of corn/acre on it, 3) each bushel (~24.5 kg) of that corn was converted to 2.8 gallons of pure ethanol (SpG =0.7892 , ΔH=29670 J/g) which is burned in a 35% heat-to-electricity efficient turbogenerator, what would the steady state biofueled electrical power generation of that field per m^2? (ans 0.136 W/m^2)

85. Finally, what percentage of that site's solar energy input would corn raising convert to biofuel-generated electricity? ans, 0.0419 of one percent.

FUEL CELL-RELATED PROBLEMS

Ammonia fuel cells have been used/studied for over 5 decades .The reason for this is that GHG-free ("clean") ammonia represents a reasonable substitute for fossil fuels, especially if used in fuel cells rather than internal combustion engines.

The following data are excerpted from a paper describing an up to date at that time (2003) alkaline fuel cell run with H_2 generated by thermally cracking ammonia via an on-board "cracker" (Hacker 2003).

> **average full load cell voltage =4: average full load working amperage =107 amps; individual cell dimensions 9.8 by 25 by 31 cm; weight complete with 6.6 M KOH electrolyte = 6 kg, H_2 consumption at full load = 270 liters/hour STP (i.e., gas at 0 C & one atmosphere)**

Let's assume that the car in question needs an average of 15 hp (GOOGLE what a horsepower(hp) is in Watts) to do the job & that its fuel cells would be charging a "perfect" 5 5kWh Lithium-ion battery (100% of the energy going into it will come back out) that would actually be powering the car's also-100% efficient motor.

86. On the average how many watts worth of power does that car require?

87. How heavy would that car's fuel cell assembly have to be (pounds) ? ans 345

88. How many gram- moles of cracked ammonia-type hydrogen would that assembly be "burning" per hour? ("combustion" heat is relevant because in effect that's what fuel cells accomplish)

89. If the combustion heat of H_2 is 286 kJ/gram mole, how efficient would that fuel cell assembly be? ans ~44%

90. Assuming a liquid ammonia density of 0.609 g/cc and the car would be moving 60 mph, what would its mpg (miles per gallon) be? ans ≈ 39.3 mpg

DIY computer modeling

If you already have DIY programming ability type in APPENDIX 5's "starting fissile" program

If you don't, watch this video (below), take notes, and do what it tells you https://www.youtube.com/watch?v=CDtSb4pNQLw (“How to Download GW Basic Free For Windows 10 8 1 7 XP Tutorial” (about 10 min)

after downloading/installing both DOSBOX & the video’s version of BASIC (mine is an older but functionally identical version, qbasic not gwbasic) then type in APPENDIX 5’s “starting fissile” program

91. if you start with 1000 tonnes of startup fissile (the first thing it asks you to INPUT), RUN it for 40 years (until 2060 AD if starting in 2020) with a reactor requiring just 1 tonne of startup fissile and start adding fresh fissile extracted from 40,000 tonnes of natural U each year after the first 20, how many 1 GWe reactors are you going to end up with? ans 17,745

92. If these reactors’ CR=1, not 1.1, all else unchanged, how many reactors would we have by 2060? ans 1477

94. If they have CRs of 1.1, all else the same but require 5, not 1, tonnes of startup fissile, how many 1 GW reactors do we have by 2060 AD?

(feel free to change the program any way you wish to answer your own questions)

PS Here’s the little note I wrote to remind myself how to run my BASIC stuff

(I’d put everything into drive C, not G, & used qBASIC rather than GWBASIC)

DOSBOX Primer

To “mount” the folder where basic files reside as the “c” drive in DOSBOX, do the following:

After DOSBOX’s z:\ prompt, type: mount c c:\basic

Now at the z:\ prompt, type: c:\qbasic

To run basic programs on it, type qbasic after the “c:\>” prompt

TO GET OUT, TYPE “EXIT” AFTER THE PROMPT

note: To copy anything in BASIC & put it into a WORD (or anything else) doc

Copy whatever it is to a screen shot by hitting “ALT prt sc”

Get out of DOSBOX then hit “CTRL V” to paste it into your “Whatever.doc”.

BATTERY Nitty Gritty

The battery pack of Mr. Musk’s first-generation Tesla S super car consisted of about seven thousand industry-standard 18650 Li ion batteries wired up together. A state of the art 3.4 Ah

18650 battery is 65 mm long, 18.3 mm in diameter, weighs about 46 grams, and costs $3.75 in "large lots" (>1000).

96. Assuming that each individual 18650 battery provides 3.5 volts during discharge, how many of them it would take to make a 85kWh Tesla battery pack. ans. 7143

97. Assuming that its interconnecting wires etc., constitute 40% of that battery pack's weight, what would it weigh (pounds)?

98. Assuming zero costs for labor and other materials, what would it cost? ans. $26,786

99. Assuming that 100% of its lithium (atomic weight 6.9 grams/mole) charges/discharges each cycle, how much lithium (kg) is in that battery pack? (Hints: power (W) = volts times amps; one amp = one coulomb/second; one gram mole of anything contains 6.023E+23 particles (in this case, that's Li atoms); and 96500 coulombs (one Faraday) ='s one gram mole's (one equivalent's) worth of electrons) ans 6.25 kg

WINDJAMMERS vs CONTAINER SHIPS

Misc. data (GOOGLED)

- Modern container ship capacity is measured in twenty-foot equivalent units (TEU).
- one TEU corresponds to about 7.5 tonnes displacement
- one knot =1.15 mph
- windjammer top speeds averaged about 15 knots, modern container ships about 23 knots (these are "as the crow flies" speeds - in reality windjammers almost always had to go considerably further to get to the same destination due to wind direction changes and were therefore much slower)
- container ship fuel consumption/day vs TEU @ 23 knots

TEU	t/day fuel
0	0
4500	120
9500	230

Source: https://transportgeography.org/?page_id=5955

100. How many tonnes of bunker fuel would a 20,000 TEU container ship consume per day?

(put the data into a EXCEL spread sheet, insert scatter plot, fit a 2nd order polynomial trendline,& use its equation to determine fuel/day for 20,000 TEU) ans ~378 t/day

101. How much fuel would that ship consume going from Hong Kong to Oakland (11097 km)? ans = 3778 tonnes

102. If bunker fuel is n*$CH_{2.05}$(where n ~10-20) how much CO_2 will that ship emit/trip? Ans 11,832 tonnes

103. If its crew size is the same as that of a 5000 tonne windjammer and that "tall ship" averaged 15, not 23, knots speed-wise, what would relative windjammer:container ship *labor* costs of shipping a tonne of anything be? ans. 46 x higher

SHIPPING'S ENVIRONMENTAL ISSUES

The world's total containership shipping last year was about 800 million TEU. If each of those trips were the same distance as my Hong Kong-to-Oakland example and done with same sized/speed container ships, how much total bunker fuel was burned? ans. 151 million tonnes

104. Assuming that…

- The oceans' "surface" water is 200 meters deep…
- and contains 200 micromoles/liter of carbonate ion ($CO_3^{=}$ - the predominant basic buffering ion that keeps the oceans pH buffered at ~ 8
- The radius of the earth is 4000 miles & 70% of its surface is ocean,
- That bunker fuel contained 2.7 wt% S which all ended up in the form of s sulfuric acid (H_2SO_4) in the oceans' surface water,

How many gram moles worth of that acid (nominally the H+ cation) were generated by that bunker fuel. (each sulfuric acid molecule contributes 2 H^+ ions)

105. What fraction (percent) of that surface water's carbonate buffering ions are being neutralized (converted to bicarbonate) each year by those ships' sulfur emissions? (0.00175%)

(calculate the volume of that water in km^3, convert it to liters, calculate the total amount of carbonate, and then ratio that to the acid generated by the world's shipping's bunker fuel-burning.

106. If all of the CO_2 generated by burning that fuel ends up in the same water & each molecule of it neutralizes one (not 2 as does SOx) carbonate ion, what's the total percentage of that water's carbonate so-neutralized each year? ans 0.076% per year

WIND TO AMMONIA EXERCISES

Australia's wind power entrepreneurs have been trying to come up with ways to convert their excess (curtailed) product into something that could be sold to its Asian neighbors who would use it as a relatively compact & easily transported synfuel. One way to go about it that's receiving a great deal of attention would be to electrolyze water & convert the resulting hydrogen to liquid ammonia.

According to [https://www.ammoniaenergy.org/articles/green-ammonia-dominates-hydrogen-demonstrations-in-australia/?mc_cid=1c552f91eb&mc_eid=b9bd2abe82] 13 different outfits have already installed electrolyzers rated at a total of 700 MW max to make hydrogen.

HOMEWORK

Assuming that

- it takes 14.2 MWh's worth of electricity to make a tonne of ammonia (other estimates go as low as 10 MWh/tonne)
- its heat of combustion (fuel value) is 22.5 GJ/tonne
- typical petroleum has a density of 0.83 g/cc & a heat of combustion of 46 kJ/gram
- one barrel of oil = 42 US gallons & 3.785 liters = one gallon
- the USA uses about 13 million barrels of oil per day to fuel cars, trucks, chainsaws, etc.
- Australia's wind turbines' nameplate capacity is 2 MW/each & have an average CF of 0.35
- US farmers now pay about $550/tonne for liquefied ammonia
- the USA currently devotes about 39 million ha of farmland to corn-raising & typical ammonia fertilizer application rates are about 250 kg/ha

107. How many barrels of oil equivalent's worth of ammonia could Australia's new windfarm electrolyzers make per day if 100% of their output were devoted to synfuel-type ammonia manufacture?

108. If the USA were to replace its fuel-type petroleum with similar windmills & synfuel ammonia plants, how many windmills would have to be devoted to serving that noble cause? ans. =2.96 million

109. If building 1 MW's worth of windmill capacity costs $1.5 M and electrolysis-based ammonia plants cost $600/kW (input) and both have a working life of 20 years, what would a BOE's worth of their synfuel product cost to make? ans. $204 (during the mid-coronavirus epidemic , crude oil's cost temporarily dropped to ~$1/bbl because hundreds of huge tanker-ships carrying it couldn't dock/unload unless someone stepped up with an offer to buy it – a tiny offer because supply suddenly greatly exceeded demand & the petroleum industry's business model punishes anyone that builds lots of storage capacity.

110. How much would a tonne of its “green” ammonia cost (same assumptions)?

111. Assuming 80% energy in/H2 combustion energy out electrolyzer efficiency, what’s the overall input energy / synfuel energy efficiency of ammonia synfuel if burned for heat or used in 100% efficient fuel cells (%)?

112. If it were to fuel 30% efficient internal combustion engines instead, what fraction of the electrical energy going into the system manifests itself as useful mechanical energy? (about 13%)

113. If a newly elected "Green” US government were to mandate that the country’s corn fertilizing ammonia had to made that way too, how many additional windmills would someone have to pay for?

HYDRIDE STORAGE/FUEL CELL POWERED CAR EXERCISES

… simplest storage tank consists of two concentric tubes, with the solid-state hydrogen carrier in the inner tube and thermal exchange fluid in the outer one. As an example, a hydrogen storage tank based on LaNi4.8Al0.2 to be integrated with a Low Temperature-PEM (a hydrogen fuel cell) has been realized . The selected hydrogen carrier has a maximum gravimetric density of about 1.4 wt.% H2. Water was used as the thermal fluid and the working conditions were close to 1 atm of H_2 *and 60 °C. The system can operate for 6 h at an average power of 0.76 kW and delivers a total energy of 4.8 kWh, consuming about 3120 Nl of* H_2**.*

*Von Colbe JB, et al(>19 coauthors) 2019, Application of hydrides in hydrogen storage and compression: Achievements, outlook and perspectives, International Journal of Hydrogen Energy, Volume 44, Issue 15, 22 March 2019, Pages 7780-7808

Assuming that…

- Nl =gas volume at standard temperature & pressure
- one gram mole of any gas occupies ~22.4 liters at STP
- State of the art electrolyzers are 80% efficient (product H_2’s combustion energy/energy fed to the electrolyzer)
- The tank containing the hydride adsorbent and fuel cell weigh twice as much as does the absorbent

115. What would an 85 kWh (Tesla S capacity) hydride storage/PEM “battery” combo weigh?

116. Is a so-equipped car apt to be as fast/powerful as a conventional Tesla S? Why or why not?

117. How efficient (energy out/energy in) is the overall system (electrolysis +hydride storage "battery" +fuel cell) ?

ANOTHER "BATTERY BREAKTHROUGH" EXERCISE SET

(Catbert - Dilbert's "evil" HR manager - helped me write this one)

Here's today's (4/29/2020) most exciting green energy research breakthrough

Wang, Min & Joshi, Unnati & Pikul, James. (2020). Powering Electronics by Scavenging Energy from External Metals. ACS Energy Letters. XXXX. 10.1021/acsenergylett.9b02661.

"*ABSTRACT: This article demonstrates a new approach for powering robots and electronics by electrochemically scavenging energy from metal surfaces. This approach overcomes energy storage scaling laws by allowing robots and electronics to extract energy from large volumes of energy dense material without having to carry the material on-board. We show that a range of hydrogel electrolyte compositions can be combined with air cathodes to extract 159, 87, and 179 mAh/cm² capacities from aluminum, zinc, and steel surfaces at up to 130, 81, and 25 mW/cm² power densities, which exceed the power density of the best energy harvesters by 10x. When moving across a metal surface, metal scavenging exceeds the energy densities of lithium ion and metal-air batteries by 13x and 2x. Metal scavenging is especially beneficial for small robots and electronics, whose size and performance are severely limited by the low energies provided by micro energy storage technologies."*

Questions: Assuming that this breakthrough's concept were to be built into a "battery stack" to power a TESLA-type car having a range of 300 miles at 60 mph with Mr Musk's conventional 85 kW/h battery

1. Assuming aluminum how big (total area in cm^2) would the total area of this stack's electrode/electrolyte combo thingy have to be to run that car down the road at 60 mph?

2. What's each of that battery stack's individual cell voltage? ans 4.08 V

3. If that car's electrical system requires 307 DC volts to operate properly, how many of these "cells" must be seriesed together to make up that stack? - ans 75

4. Assuming that the stack is square shaped how big would it be/side (cm) ? ans 22.5 cm

5. How much aluminum (kg) would this thing consume per 300 mile "fill up"? (hint, there's 96500 coulombs/mole of electrons & each aluminum atom (atomic weight 27 g/mole) provides 3 electrons while the stack is converting it to Al_2O_3 and finally …

6. If the rest of the battery stack's components weigh 2x that of their fresh aluminum-foil "fuel" how many pounds would it weigh when fully charged with fresh foil? When fully discharged? (its "spent" foil still within it)

APPENDICES

APPENDIX I. Reprocessing

Like trucks and chainsaws, nuclear reactors must consume fuel to do useful work. When fossil fuels (typically gasoline, diesel oil, or propane) are burned to power an engine, they are consumed both immediately and almost completely. When that fuel is gone, energy production totally stops. Nuclear reactors are usually incapable of achieving such near-complete burn-up because as their fuel (predominantly ^{235}U along with some in-bred ^{239}Pu) is burned via nuclear fission, a variety of other elements – fission products (FP) – are created and become intimately associated with the remaining fissile. Because they absorb some of the neutrons that energize fission, such FP accumulations slowly poison the system and will eventually stop the reactor. Some fission products may also damage the structural integrity of solid-type fuel assemblies via alloying with them or corrosion. Even though a good deal of fissile material may remain in such fuels, it can't be burned until it has been separated from neutron-absorbing fission products and its physically compromised cladding via some form of "reprocessing".

Conventional reprocessing

Defense/research reactor fuels Let's look at the history of the nuclear fuel reprocessing facility about which most of this book's examples were taken.

The USA's Atomic Energy Act of 1946 established the civilian Atomic Energy Commission (AEC) to direct atomic energy "*toward improving the public welfare, increasing the standard of living, strengthening free competition among private enterprises so far as practicable, and cementing world peace.*" That Act required the AEC to conduct research in nuclear energy "through its own facilities…." Consequently, in 1949, following a nation-wide search, the AEC established the NRTS in southeastern Idaho, its first field test facility and only dedicated reactor proving ground. That area was chosen because of its isolation, climate, favorable geology, abundant subsurface water, and social-economic factors including local government support, existing infrastructure, and ready availability of manpower, land, and construction materials. The NRTS originally covered 177,000 acres but eventually expanded to cover 569,000 acres (890 square miles) of Idaho's "high desert" in the northeastern end of its Snake River Plain. The Site's name was changed three times, in 1974 to the Idaho National Engineering Laboratory (INEL), again in 1997 to the Idaho National Engineering and Environmental Laboratory (INEEL), and finally to the Idaho National Laboratory (INL) in 2005. Its original mission was to provide a suitably remote (safe) area where nuclear energy research, development, and testing could be conducted with minimal impact to the public. Initially the AEC planned to construct only five reactors there over a ten-year period. However, rapidly expanding technologies and a nationwide sense of optimism (as opposed to today's pervasive pessimism) that saw no limits to the potential of nuclear energy greatly extended its mission. Eventually, fifty-two, mostly first-of-a-kind, reactors were constructed at the NRTS including Rickover's first pressurized water submarine reactor (PWR) and Untermyer's boiling water reactor (BWR) which came to dominate civilian nuclear power worldwide. The NRTS's experimentation regarding reactor safety, design, and applications influenced virtually every other reactor in the world. The first four facilities circa 1950 included the Experimental Breeder Reactor I (EBR-I), the Naval Reactor Facility (NRF), the MaterialsTest Reactor (MTR), and the Idaho Chemical (re)Processing Plant (ICPP).

Succeeding expansion included several additional centers each reflecting a new direction in nuclear research or filling necessary operational functions. .From the beginning, political tides and changing world events periodically shifted priorities. Although those influences varied, they fell into two categories: national defense and peaceful applications.

Throughout history, almost all government facilities everywhere have bent to the needs of national defense at one time or another. Conceived as it was in the aftermath of World War II, the initial throes of the Korean War, and the heightening tensions which defined the Cold War, the NRTS exhibited both extremes. For example, its Naval Reactors Facility, devoted itself entirely to projects related to national defense, the most prominent of which was development of the PWRs powering most of the U.S. Navy's submarines and aircraft carriers. Other NRTS facilities contributed to that cause less directly. For example, the ICPP's construction schedules were given a boost when shortages of uranium and plutonium threatened to compromise weapons production at other AEC labs. Consequently, the first batch of uranium recovered/recycled by it came from the Hanford Site's plutonium production reactors

However, not many of its subsequent fuel reprocessing runs had to do with weapons production or even national defense. President Eisenhower's "Atoms for Peace" program encouraged the development of peaceful uses for nuclear energy (electricity generation, medical applications, food irradiation/preservation, etc.) and much of the subsequent work done at the NRTS was directed toward furthering those efforts. One of the most pressing questions at that time was how the materials and components (e.g., fuel assemblies, fuel cladding, and reactor construction materials) in civilian power reactors would perform under intense irradiation. That why the Material Test reactor (MTR), a high flux, water thermalized neutron reactor, was designed to determine how well the materials being considered for use in those reactors would withstand several years of exposure . This testing was accomplished by bombarding materials ("coupons') with thermalized neutrons. Since the MTR was a "hot" but small relative to utility scale reactor, enough fission products built up within its tiny aluminum-clad highly enriched (bomb grade) uranium fuel assemblies to bring everything to a halt every 17 days or so. It's so-depleted fuel assemblies then had to be removed and replaced with fresh ones. Under 30% of the valuable ^{235}U originally in such "spent" fuel was burned per cycle which means that it had to be recovered/recycled. The NRTS's reprocessing facility, Idaho Chemical Processing Plant (ICPP aka "Chem Plant") was designed to be the MTR's support facility and fulfilled that mission for nearly four decades, recovering millions of dollars-worth of fissile (^{235}U) that was fabricated into new fuel elements for both it and DOE's other test reactors.

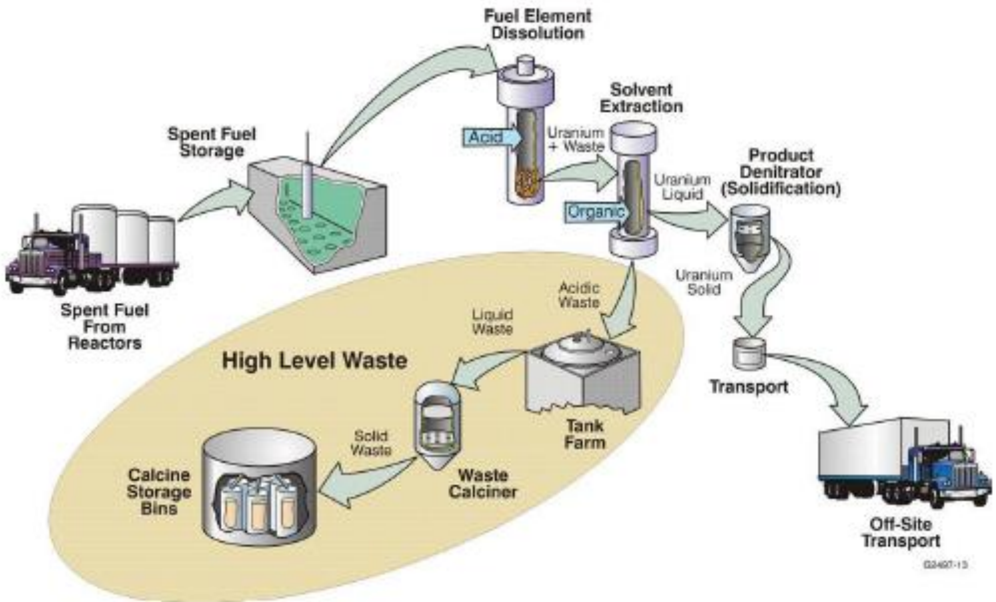

Figure 94: INL's Chem Plant (Staiger 2011)

The NRTS's Chem Plant was far more versatile than were those of the federal government's "production" (of bomb grade plutonium and tritium) facilities, primarily Savannah River and Hanford. It could recover the uranium within fuel assemblies clad with virtually any sort of material – aluminum, stainless steel, zirconium, graphite, or ceramic composites.

It also did a better job of managing its reprocessing wastes:rather than simply neutralize the acid in them and "temporarily" store the resulting mix of oxy/hydroxyl sludges plus salt-saturated liquids in tanks, about 90% of it was calcined and the resulting stable/innocuous sand-like dry powder stored in stainless steel/concrete "binsets".

Throughout the years, the Chem Plant recovered both uranium and certain valuable fission products from nearly one hundred different research and power reactors throughout the nation. By the end of the 1970's most of the DOE's test reactors had been shut down ("decommissioned") so it was reconfigured/repurposed to enable it, in principle at least, to recover the highly enriched uranium remaining in spent Naval reactor fuel assemblies.

That's where things went awry. Although nominally zirconium-clad, the Navy's LWR fuel assemblies were apparently overplated (alloyed?) with the secret element I've alluded to in a prior footnote that likely rendered their dissolution more difficult than was assumed by the refurbished facility's designers (See APPENDICES XVI & XVIII). That plus the actions taken to address its increasingly hyperconservative safety concerns (see APPENDIX XVI) rendered its productivity so poor that the Navy's decision makers eventually decided to cut their losses and just continue to "temporarily" store its spent reactor fuel instead).

The technical screwups leading to that decision included…

- The design of that facility's three individual dissolvers didn't render it impossible for an accumulation of undissolved HEU fuel particles within them to randomly assemble themselves in a "critical" configuration (the uranium in question is/was highly enriched (weapons grade); & the dissolvers weren't geometrically safe). That "what if" also dictated the addition of a neutron poison to the dissolvent (HF). Because its engineers decided to use cadmium nitrate for that purpose, the plate-out of metallic cadmium upon fuel assemblies inhibited/slowed their dissolution[1].

- Also, in order to lower initial build costs, the product solutions generated by all three dissolvers were to be sequentially fed to a single "accountability" tank which meant that the batch-wise fuel dissolution process performed in each had to be precisely synched 120 degrees out of phase timewise with the other two dissolvers

- Fuel assembly dissolution rates were unexpectedly low and erratic (probably at least partially due both to the mysterious element within (on?) them about which no one could speak and, perhaps, a different fuel configuration - plates instead of tubes?)

Those technical issues combined with the fact that any sort of "criticality incident" would immediately shut the entire facility down for at least a few months (maybe permanently) meant that it had to be operated in an extremely "conservative" manner; i.e., every few dissolutions had to be followed with an aggressive "heel out" (the addition of more dissolvent followed by another dissolution period followed by another round of "product" solution characterization) to reassure everyone that everything had indeed been dissolved before another fuel assembly could be processed.

This plus the fact that the process modifications required to achieve satisfactory productivity caused the dissolvers to corrode more rapidly than expected meant that DOE/INEL then decided to ask the Navy for another half $billion or so to replace them. That proposal was rejected. (APPENDIX XVI is an "insider" description of what happened.)

The State of Idaho objected to that facility's shutdown, demanding that the DOE develop a plan for managing both the Navy's spent fuel and the site's already-generated reprocessing wastes,

[1] Plate-out happens because cadmium is a much more noble metal (harder to oxidize) than zirconium and the dissolvent itself isn't strongly oxidizing.

both liquid and solid, plus various other sorts of waste scattered elsewhere within it. A lawsuit to prevent any further receipt or storage of spent fuel until such a study had been completed accompanied that demand. In 1995 this conflict resulted in an agreement (the "Batt Agreement") between DOE, the State of Idaho, and the U. S. Navy outlining the future of fuel storage and waste management at the INEL. DOE promised to "clean up" everything at the Chem Plant including the roughly one million gallons of still-liquid reprocessing wastes within several of its then >40-year-old tanks. In 1998, DOE identified the Chem Plant's Main Processing Building (CPP-601) for removal, along with its Fuel Storage Building (CPP-603), and several support structures. In 2005, DOE deemed most of the remaining ICPP structures including its waste calcination facility (NWCF) obsolete and the deactivation, decommissioning, and demolition (DD&D) of its buildings and other structures began, including everything associated with fuel reprocessing.

This left the folks who had worked there without much to do other than watch DOE's new subcontractors tear down buildings, bulldoze everything into pits and pour gravel and/or concrete over them. The exceptions were the folks given an opportunity to try to get INL's now-infamous "steam reformer" (IWTU) up and running. As of October 2021, they've spent 16 years and over a billion dollars trying to do so and haven't succeeded yet.

Anyway, the INL's Chem Plant was built to do what virtually every other fuel processing plant does; i.e.,

1. Receive and store spent solid fuel assemblies until they've "cooled off" enough to safely work with – typically at least one and more often, ~five years

2. Dissolve that fuel assembly in a way that eventually generates an acidic aqueous solution containing several molar nitrate ions. However, unlike most civilian fuel reprocessing facilities, the Chem Plant dissolved the fuel's cladding along with its "meat" thereby generating solutions containing whatever the cladding consisted of along with the uranium, plutonium, minor actinides, and fission products.

3. Extract the uranium and plutonium from that solution via countercurrent liquid-liquid extraction with ~30% tri-butyl phosphate in a kerosene-like organic solvent. (uranium/plutonium are extracted as zero-charge, nitrate-based, "ion pairs", e.g., $UO_2^{+2}(NO_3^-)_2$. This is a key step of the "PUREX" process)

4. Transfer the U/Pu in that solvent to a second aqueous phase by contacting it with water containing very little nitrate (e.g., 0.1 M HNO_3) which breaks up the ion pair thereby rendering the U/Pu insoluble in the organic phase.

5. Boil off most of the water in that solution to concentrate it, add aluminum nitrate to bring the nitrate concentration back up again, add some hydroxylamine and/or ferrous sulfamate to reduce/convert quadrivalent Pu to unextractible trivalent Pu, and then extract the uranium from

it, again as an ion pair, via countercurrent liquid-liquid extraction with/into “hexone” (methyl isobutyl ketone). This “2nd cycle” hexone/aluminum nitrate-based process is called the “REDOX process“.

6. That hexone phase was first rinsed with more aluminum nitrate to remove contaminants and then contacted with dilute nitric acid to transfer the uranium back into another aqueous solution.

7. To generate an even purer uranium product[2], steps 5 and 6 were generally repeated (this was the Chem Plant’s “third cycle” extraction)

8. Most of the water in that now very pure uranium nitrate solution was then boiled off after which it was then squirted into a small, fluidized bed “denitrator” which converted it to a compact, easily handled, dry UO_3 powder ready for shipment to a customer (usually a fuel fabrication facility).

The wastes generated by such reprocessing consisted of:

- First cycle raffinate (aka “high level waste”): the aqueous phase coming out of the first cycle PUREX extraction. It contains the majority of the fuel’s fission products and cladding components (e.g., dissolved steel or aluminum or zirconium) along with whatever else was added to either enhance extraction or stabilize the solution (often aluminum and/or calcium nitrate salts).

- Second and third cycle raffinates: these solutions contain lesser levels of fission products, almost all of the plutonium (generally), plus lots of aluminum nitrate.

- Miscellaneous facility clean --p wastes: solutions of sodium (or potassium) carbonate, permanganate, and/or ydroxide were used for cleanup activities throughout the plant primarily because “caustic” readily dissolves the silicic acid gels that gummed up pipes and extraction equipment[3]. Once so-dirtied, they usually ended up in the “sodium bearing waste” tanks along

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[2] Hyper purity was deemed desirable because it’d render subsequent fuel refabrication, shipment and handling easier. Back in those days, our decision makers hadn’t yet decided to assume that terrorists would be diverting the USA’s fissile.

[3] The silicic acid originated from the “purified” ~20 ppm silica local ground water utilized to make its solutions. The chem plant’s water purification process, dual bed ion exchange, didn’t remove silica very well because it is largely present in ground water as non-ionic silicic acid. Currently, silica comprises the bulk of the sludges underlying the liquid in INL’s SBW tanks. If INL ever does get its steam reformer going, the current plan is to leave that sludge there along with a hefty fraction of that waste’s total radionuclides, esp. ^{137}Cs & Pu, because those tanks are to be pumped until “suction is lost”, not until they are empty.

with other small volume miscellaneous waste streams. A good deal of the mercury utilized as a catalyst during the dissolution of aluminum clad fuel elements also ended up in them.

The PUREX process utilized by most of the world's fuel reprocessing plants entails…

- chopping spent fuel rods into short pieces
- rolling/crushing them to break up/remove their brittle uranium (mostly) oxide pellet contents from their zircalloy (usually) tubing "hulls"
- dissolving that ceramic in strong nitric acid[4]
- extracting actinides (mostly U+Pu) from that solution via counter current liquid-liquid extraction with TBP/kerosene
- back extracting them into dilute nitric acid
- separating U from the Pu by adding a reductant (typ. hydroxylamine or ferrous iron) and more strong nitric acid, and extracting again with more TBP/kerosene - the uranium is re-extracted but Pu^{+3} isn't.

Commercial fuel reprocessing Spent-fuel reprocessing was originally launched by countries that planned to eventually deploy breeder reactors. They wanted cleanly-separated plutonium for manufacturing the startup fuel of their first breeders. Standard light-water-reactor spent fuel contains about one percent plutonium. In today's absence of breeder reactors, that separated hot "reactor grade" plutonium has become a disposal problem so some countries decided to recycle it into fuel for the same reactors that had produced it. However, slow-neutron reactors are relatively ineffective in fissioning several of plutonium's isotopes, which therefore build up in recycled fuel and render further reprocessing for that purpose useless for anything other than creating jobs and press releases. On the other hand, if the plutonium and other long-lived transuranics in spent LWR fuel were to be repeatedly recycled to fast-neutron-reactors, they could be almost entirely fissioned thereby rendering the finding of a geological disposal site for waste that would then consists of only relatively short-lived fission products much easier. Since ANL's fast-neutron breeder reactor (IFR) could be converted to a transuranic "waste burner" by removing the fertile natural/depleted uranium blankets surrounding its core and shortening that core so that more neutrons would be wasted, the IFR was deliberately morphed into INL's "Sodium Fast Reactor" concept (Lineberry and Allen 2002).

Because of its limited ability to extend the fuel supply of the USA's burner-type commercial reactors, excessive costs, and proliferation concerns (in principle if not in fact, a reprocessing

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[4] In some cases, commercial reactor fuel is "veloxidized" before it is dissolved. Fuel rods are first physically decladded (chopped/crushed) and the then screened-out ceramic fuel chunks baked-out in an oxygen atmosphere to convert the UO_2 to U_3O_8. That converts the hard/dense, slow dissolving UO_2 chunks to a friable, lower density, powder that's much easier to dissolve. It also volatilizes/drives off some of the "hottest" FP including ^{137}Cs.

facility's recovered reactor grade plutonium might also be used in a nuclear weapon) the United States has made only limited forays into commercial reactor fuel reprocessing. Just one such plant operated for six years before shutting down in 1972 and then permanently closed four years later. Several other commercial efforts never really got off the ground.

Consequently, Congress's Nuclear Waste Policy Act amendments of 1987 gave the Energy Department until Jan. 31, 1998, to begin disposal of the nation's used/spent nuclear fuel and high-level radioactive waste within a deep geologic repository within a mountain ridge adjacent to the Nevada Test Site where most of the USA's smaller ~1100 nuclear "device" test explosions had been performed. It took DOE until 2008 to do enough studies of that particular site[5] to apply for a Nuclear Regulatory Commission license to operate that garbage dump. However, two years later the Obama administration decided to defund that proceeding and instead establish a "Blue Ribbon Panel" to further ponder the USA's "high level" waste issues. Eventually that administration decided to begin a "consent-based" program for siting separate disposal sites for civilian and defense radioactive wastes, which effort didn't get far before Donald Trump assumed the presidency in January 2017. His administration has tried in three consecutive budget proposals to persuade Congress to appropriate new funding to resume Yucca Mountain licensing but has been consistently rebuffed by the Democratically controlled House of Representatives[6].

For the upcoming 2021 federal fiscal year, the administration has switched strategies requesting $27.5 million for an Interim Storage and Nuclear Waste Fund Oversight program. That is intended, in part, to fund implementation of a "robust" program for interim storage of "radioactive waste" (spent fuel) away from its point of generation (on the moon?), along with research and development of technologies for storage, transportation, and disposal.

The best thing I can say about the USA's approach to radioactive waste/spent fuel management to date is that it hasn't yet managed to render the recycling of the actinides therein to a more sensible (sustainable) nuclear fuel cycle totally impossible.

As far as the cost of reprocessing is concerned, here's something to ponder

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[5] That "mountain" turned out to be very complex with lots of cracks and layers of different sorts of rock meaning that many different hypothetical "failure" modes had to be investigated, written about, exhaustively debated, and politicized. Altogether, those activities cost US tax and utility ratepayers about $15 billion dollars. The good thing it did s that it established that a 2nd hand tunnel boring machine could quickly generate cheap, retrievable, underground storage space in the USA's most worthless desert. I suspect that that conclusion could have been reached within six months for about 1% of what was spent.

[6] I can understand both sides of that issue. It is indeed both unwise and unnecessary to stuff more tax dollars down the NRC's rat hole & it also makes sense to store the USA's spent reactor fuel underground at the Nevada Test Site until we've decided to commit to a sustainable nuclear fuel cycle and therefore see it as what it is – enough fuel to power the whole country for several hundred years.

I’ve just discovered (20Mar2021) a report published in 2016 by the Belfer Center for Science and International Affairs Harvard Kennedy School (Bunn et al 2016)

Its Table ES1 gives low & high estimated costs of building/running an 800t HM /a in China for 40years: lowest figure is 27.6 $B, highest was 80$B

Let’s put those numbers into perspective.

If each GWe of nuclear power we generate requires the reprocessing of 20 tonnes HM/a, reprocessing would add from $0.0020 to $0.0058 per kWh to that power’s cost.

Consequently, it’s likely that the Chinese will be reprocessing their spent fuels ASAP - not trying to rationalize “direct disposal” as we do here in the West based upon our collective refusal to commit to developing a sustainable nuclear fuel cycle or to doing anything other than what’s immediately cheapest to whatever supplier is selling its distributors (utilities) their power.

Excellent discussions of just about every aspect of LWR fuel reprocessing can be found in the ”best” (second edition) version of Benedict, Pigford, and Levy’s “Nuclear Chemical Engineering” textbook (Benedict 1981). The best description of today’s reactor fuels I’ve found yet is a set of slides generated by Vanderbilt University‘s Prof. Allen Croft (Croft 2008)

Croft, Allen, 2008, Reactors and Fuels: Short Course: Introduction to Nuclear Chemistry and Fuel Cycle Separations (slide set) http://www.cresp.org/NuclearChemCourse/presentations/06_CROFF_Presentation.pdf

Here’s a worked-out example addressing how much reprocessing a country’s “Nuclear Green New deal” implemented with state-of-the-art sodium-cooled reactors & reprocessing would require.

example of realistic breeder-based national power system's reprocessing capacity				
ref. Romanello et al, 2012, Sustainable Nuclear Fuel Cycles and World Regional Issues, Sustainability 2012, 4, 1214-1238; doi:10.3390/su4061214				
assumes 0.56 GWe fast breeders with 19% enriched oxide-based fuel, CR=1.45, 40% therm to elect. Efficiency, 300 day fuel irradiation, & 12 year doubling time				
since 1 fission =3.2e-11 J, one tonne fission of 238Ac =		3.2E-11*(1E+6 g/t/238 g/mole)*6.023E+23 atoms/mole=	8.10E+16	J
300 days at 0.56 GWe with 40% eff requires	3.63E+16	J thermal energy during irradiation /reactor, ='s	4.48E-01	tonne fission or FP/reactor/burn cycle
150 GWt/d/tonne burnup corresponds to	1.296E+16	J/tonne HM		
therefore that scenario & burnup would need	2.80E+00	tonnes of "heavy metal" fuel reprocessed/.56 GWe/reactor per year		
La Hague's reprocessing plant cap = 1700 t/a	(WIKIPEDIA)			
FRANCE currently powers itself with 58 full-sized non breeders & sells the excess to its EU neighbors				
if "full size"=1 GW not 0.56 GWe, France would need 58*1/.56 or		104	of these mid-sized breeders to power itself & still have some excess to sell	
that corresponds to 104*2.8 tonnes/year or	291.2	tonnes of fuel reprocessed/year which is	17.13%	of its already paid for reproccessing facility's "capacity"
If in order to enhance breeding, fuel burnup is reduced to only 50 GWtday, those reactors would reguire 140/50*17.13 or about 50% of France's reprocessing capability				

Basically, this example demonstrates that if France had decided to power itself with a fleet of these same-sized-as-Russia’s BN600 breeder reactors instead of LWRs, its Le Hague reprocessing facility could have easily kept them all running indefinitely. That in turn would have rendered France truly energy secure “forever” & of course much richer than it is now.

The Future’s Reprocessing

Because there are many different ways to implement a sustainable nuclear renaissance, I'm just going to outline a few scenarios.

To begin with, rumor has it that DOE/INL is again considering the reprocessing of the US Navy's spent reactor fuels to generate the 19.75% ^{235}U enriched fuel (HALEU) fissile required by several of its industrial partners hypothesized, small/micro modular reactor concepts (see APPENDIX XVIII for a discussion of what Naval fuel likely consists of). However, this time around, that process differ in that the fuel's zirconium cladding etc., would be separated from the remaining uranium oxide plus fission products via "chlorine volatility" (reacting metallic Zr with hot HCl generates gaseous $ZrCl_4$) before the latter is dissolved in nitric acid for a subsequent PUREX-type actinide/FP separation. Doing it that way would simplify U recovery/extraction, reduce the amount of waste generated and render its treatment/disposal easier/cheaper.

One way to convert spent LWR fuel to something compatible with a MCFR would be to chop the fuel tubes into short sections, roll/crush them to break up/separate the uranium oxide pellets; powder them; add one mole of $ZrCl_4$ per mole of total actinide; disperse both in 2 moles molten NaCl per mole actinide; and then slowly add zirconium powder while stirring. Thermodynamic calculations indicate that this should produce a fue salt containing trivalent fissile/fertile actinides in the right amount of NaCl for the mixture to exhibit a melting point <550˚C along with solid filterable/removable ZrO_2.

The same sorts of calculations indicate that another way to do it would be to disperse finely ground UO_2 fuel pellets in molten NaCl (>802°C) and then bubble carbon tetrachloride through it. The carbon tetrachloride would convert the actinides to the salt-soluble salts UCl_4 and $PuCl_3$. Since UCl_4 is much more volatile that is $PuCl_3$, most of it could be bubbled out of that molten salt solution by sparging it with an inert gas such as argon (or maybe even nitrogen) which would concentrate the stream's fissile (mostly plutonium): fertile ratio up to whatever level the reactor might require (high for fast reactors, low for moderated reactors).

If the initial "spent" oxide fuel already had more than enough fissile in it to run a fast MSR, the UCl_4 in the $PuCl_3$/UCl_4/NaCl solution produced by reaction with the carbon tetrachloride could be reduced to UCl_3 by stirring in one third as much powdered uranium metal.

Another clever way to make a sufficiently enriched fast reactor startup fuel from the North American continent's accumulations of spent oxide-type CANDU and LWR fuel would be to utilize the scheme mysteriously described in this Japanese patent. JP2003215287A - Reprocessing method for spent nuclear fuel using eutectic phenomenon - Google Patents

That process is begun by dissolving the fuel in nitric acid followed by separation of most of its plutonium and uranium from most of its FP and TRU by co-crystallization/co precipitation of hexavalent U and Pu nitrate salts via adjustment of temperature and nitric acid concentration.

The resulting mixed U/Pu precipitate is redissolved and its hexavalent plutonium (a stronger oxidizing agent than is hexavalent uranium) is selectively reduced to its quadrivalent oxidation state after which that solution is reconcentrated to precipitate/separate out more of the uranium.

How much plutonium is potentially available in that resource? Based upon the USA's LWR and Canada's CANDU spent fuel accumulations in 2007, the number and type of reactors that each possess, and the compositions of their respective spent fuels, I've come up with figures of about 945 tonnes of Pu in the USA's fuel and 261 tonnes in Canada's.

The number of new full-sized breeder reactors that could be started with their recycled plutonium depends upon its isotopic makeup and reactor design. If we assume that 65% of their "reactor grade" Pu is fissile and that it's used in LMFBRs requiring 5 tonnes of startup fissile each, that "magic" number comes to 157 GW_e's worth of new, & this time around, genuinely sustainable power reactors[7]

MOLTEX's WATTS reprocessing scheme represents another promising way to fuel tomorrow's reactors with today's radwastes. CANDU or LWR oxide-based fuel rods would first be declad by blowing hot chlorine gas over them which would convert their metallic zirconium cladding to gaseous $ZrCl_4$. The thus-exposed oxide - mostly UO_2 with ~0.3 (CANDU) to 0.6 wt% PuO_2 plus misc. FPs, also mostly oxides - fuel pellets would then be dumped into a molten chloride salt electrolyte along with some iron filings. The fuel pellets' more readily reduced elements including its actinides would then be electroplated out into a low melting (eutectic) molten uranium-iron metallic electrode. When that's done, that electrode would be flooded with a "clean" $NaCl/FeCl_2$ molten salt. Because metallic plutonium and americium are stronger reducing agents than is uranium, they should be selectively oxidized by that salt stream's ferrous ion which reaction would convert them to molten salt-soluble chloride salts and the ferrous iron to metallic iron thereby separating the former from the bulk of the molten alloy's uranium. Sufficient additional ferrous ion would then oxidize/transfer enough of the uranium to the salt phase to generate a fuel salt sufficiently rich in fissile (>10% of the HM, mostly ^{239}Pu and ^{241}Pu) to fuel MOLTEX's "waste burning" SSR-W.

That's a very clever scheme but like most of the others I've been hearing about, in practice may not prove to be superior to one utilizing a more conventional PUREX-type cleanup/fissile recovery approach. Only real-world experimentation/demonstration will tell.

Moltex's recent press releases suggest that this experimentation is taking place in Canada.

[7] If we then go on to assume that those reactors are built by 2030 and generate 30% more fissile than they burn, that/our continent's 157 GWe's worth of clean, green, & sustainable nuclear power capacity could grow to 2000 GWe by 2077 AD.

Converting the same spent CANDU or LWR fuel to something capable of starting a MSFR or tube-in-shell thorium breeder could probably be accomplished via the same Purex based processes that I've already outlined.

However, a great deal of money has been spent demonstrating that it could probably be accomplished via the electrometallurgical "pyro processing" system devised for the IFR (Till 2013). It invokes electrochemical reduction of such fuel's oxide-form actinides (uranium along with some TRU most of which is plutonium) to their metallic forms after which the uranium and plutonium are separated via another electrochemical dissolution/redeposit ion process utilizing different electrodes. In this writer's opinion that approach is unlikely to be the "best" way to recover any such potentially useful plutonium fissile (the bulk of the so-recovered uranium would be stored for use after the reactor had been started). Pyrometalurgical processing's chief virtues are: 1) it could be performed upon "hotter" (not so much cooled-off) spent fuel than could any process utilizing radiation-labile water/organic extractants; and 2), it doesn't do a sufficiently good job of separating plutonium from uranium (or anything else) to generate something that imaginary terrorists could easily make a bomb "pit" out of -it'd be too "hot" for them to either work with or sneak pass inspectors.

It would be more reasonable to first VOLOXIDIZE [8] and then fluorinate such spent fuel (CANDU or LWR) to volatilize the uranium (Markvart 1999 & Rozon & Lister 2008). Baking in air or oxygen (voloxidation) converts dense, brittle, UO_2 ceramic fuel pellets to a friable U_3O_8 powder that gaseous fluorinating agents can readily penetrate and react with. There are two ways to do fluorination. The first is to "burn" the oxides with fluorine gas (the strongest fluorinating agent) which would convert the uranium, neptunium, several fission products and (probably) some of the plutonium to a mixture of gases which may require further separations. The second is to sequentially affect the separation of gaseous UF_6 from NpF_6 and the volatile fission product fluorides but leave the plutonium in the "ash" by utilizing a weaker fluorinating agent (NF_3) in a series of fluidized bed reactors operated at successively higher temperatures (McNamara 2011). Plutonium could then be recovered by either dissolving it to utilize a PUREX-like separation or via exhaustive fluorination with fluorine gas (McNamara 2011). In the case of spent LWR (not CANDU) fuels, because the bulk of the recovered uranium would contain more ^{235}U than would natural uranium, it then should be re-enriched and thereby roughly double the amount of startup fissile recovered.

[8] Voloxidation also volatilizes/separates several otherwise troublesome fission products.

Very well written summaries of what's known about MSR related fuel salt preparation and cleanup have recently been written by ORNL personnel (McFarlane et al, 2019) and Jan Uhlir (Uhlir 2017).

However, once such fuel has been made and partially "burned" in a MSFR, electrometallurgical pyroprocessing might become a reasonable way of keeping it clean enough to remain useful[9]. See Delpeche 2008 & Lucotte 2013 for descriptions of some of the salt cleanup schemes being evaluated for the MSFR. They utilize the same technologies proposed for ORNL's "classical" one-fluid MSBR.

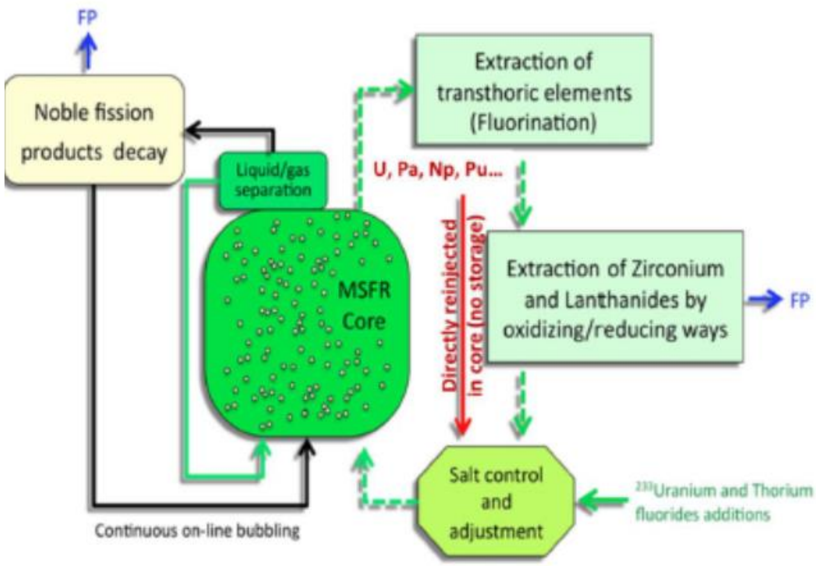

Figure 95 Generic MSFR fuel salt treatment scheme (Lucotte 2013)

Due to their similar physical, chemical, and electrochemical characteristics, the toughest separation in any of these schemes is that of the transuranic elements from rare earth fission product "poisons". That combined with the fact that a breeding-capable, thorium fueled (^{233}U, not transuranic fissile) graphite moderated MSR would also require constant/rapid Pa separation/isolation, is the reason why I feel that developing something along the lines of Leblanc's semi-fast (epithermal), two salt, ^{233}U/Th -based system (Figure 63) should receive top priority. His tube-in-shell concept would require far less startup fissile, and its much simpler (no

[9] Only 60-70% of the FP so formed would remain in any MSR's fuel salt because gasses (e.g., xenon, krypton, and tritium) and elemental metal scum formed from FP "noble metals" at its buffered/controlled redox state (e.g., Ag, Ru, Pd, Pt, Tc, Rh, Re, Sb, etc.) would be continuously sparged/skimmed out of it. Riley et al have recently reviewed molten salt reactor waste and effluent management strategies (Riley 2019).

fertile) fuel salt could be adequately purified by simply fluorinating its ^{233}U fissile out of it (as UF_6 gas) and then distilling/collecting its carrier salt (FLiBe) off the bulk of the FP under partial vacuum (Smith 1969).

In any case, starting a big-enough, sustainable nuclear renaissance's fleet of big breeder/isobreeders will require lots of fissile much of which should be recovered from the world's existing "spent" reactor fuels. Here in the USA, the facility implementing that process should be co-located with its one and only "high level waste" repository hopefully sited within its already contaminated and totally-useless-for-anything-else, Nevada Test Site (Forsberg 2012). Just think of all the jobs that such a noble infrastructure-building, Green New Deal project, would create!

APPENDIX II. MSFR Isobreeder Fuel Salt Reprocessing

The European EVOL project's neutronics modeling indicates that the 1.5 GWe MSFR could run at steady state (CR just over 1.0) with just 6 liters per day of fuel salt reprocessing (cleanup)[10].

Application of the principle of "additive fractional molar volumes" (see APPENDIX IV) suggests that a fuel salt containing roughly 77.5 mole%, LiF and 22.5% of a mixture of $(HM)F_3$ and $(HM)F_4$.(HM = sum of actinide (heavy metal) nuclides), would have a density of ~4.28 g/cc and contain ~47.9 moles/liter lithium plus HN fluoride salts.

Consequently, 6 liters of it would contain ~14 (0.93* 6*0.225*232*47.9/1000) kg of thorium[11] and 1.59 kg (0.775*7*47.9/1000) kg of ^{7}Li

Reprocessing (fuel salt cleanup) would involve sparging the fissile ^{233}U out of the spent salt (as UF_6, another gas) with elemental fluorine (or possibly NF_3) which would oxidize its uranium to gaseous UF_6. That uranium would then be returned along with ~14 kg of fresh thorium and 1.59

[10] The "reprocessing" referred to herein deals with "salt seeking" fission products, primarily the periodic table's alkalis, alkaline earths, and rare earths, not to what's continuously done to remove intrinsically insoluble fission products - a total of ~1 kg/day/GWe mix of gasses and noble metal sludge – from the fuel salt stream.

[11] At steady-state about 93% of the HM in this system's core would be thorium; most of the rest would be quadrivalent uranium, mostly $^{233}U^{+4}$.

kg of fresh ^7Li (both as their fluoride salts) back to the reactor's fuel salt stream by reducing it back to UF_4 with hydrogen gas.

The spent fuel salt from which its fissile is recovered/recycled could simply be discarded – at least temporarily – because there's nothing in it that's really worth the cost of recovery. If it is subsequently deemed worthwhile to recover/recycle ^7Li, that could be accomplished by dissolving that salt in water and then adding ammonia – most of the FP and thorium would precipitate out as insoluble oxides/hydroxides leaving the ^7Li in solution as the much more water-soluble lithium fluoride. Boiling that solution to dryness would recover the ^7Li (as ^7LiF) which could then be refluorinated with elemental fluorine to remove any miscellaneous oxides and regenerate « fresh » ^7LiF. However, since AVLIS isolation of ^7Li from natural lithium shouldn't cost more than about $200 per kilogram (Ault 2012), both ^7Li and thorium recovery/recycle could be put off until most of that « spent » salt's fission products have decayed away.

APPENDIX III. More opinions about TERRAPOWER's reactor concepts

The total amount of natural uranium (NU) that has been mined to fuel the USA's fleet of commercial LWRs generating ~20% of the U.S. electricity adds up to approximately 700 thousand tons. Of those tons, about 80,000 ended up as spent fuel – the enriched uranium fed to the LWRs and then discharged after 3-5 percent of it –mostly its ^{235}U – had fissioned. More than 600,000 tons of that total NU ended up as depleted uranium (DU) "waste". Additional DU was generated by military programs. In principle, liquid metal (cooled) fast breeder reactors (LMFBRs) could burn nearly 100% of such "waste". However, that cannot be achieved via a single irradiation campaign because neutron-induced cladding damage constrains the burnup level achievable with their solid-type fuels to 15% to 20% FIMA (Fissions per Initial heavy Metal Atom), depending upon how fast the core's neutron spectrum is. Consequently, high uranium utilization requires repeated fuel reprocessing/recycling. Traditionally, that includes mechanical cladding removal, chemical separation/removal of most of the fission products from the fuel "meat", addition of depleted or natural uranium (NU) make-up fuel, fabrication of new fuel elements and finally reloading them back into the reactor core for another irradiation/burn cycle. Although technically feasible, there is a significant objection to fuel reprocessing in Western countries due to economic and proliferation concerns. Fast breeder reactors could, in principle, also operate without fuel recycling; that is, using a once-through fuel cycle as do all of the LWRs presently operating in the USA. Although a discharge burnup of 15% to 20% FIMA is 3 to 4 times higher than that of contemporary LWRs, a LMFBR's natural uranium consumption is not significantly different from that of a once-through LWR per cycle because the degree of uranium enrichment required to fuel a fast reactor is more than twice that required to fuel LWRs. Nevertheless, it may be possible to realize a significant increase in the uranium utilization by "reconditioning" fuel that's reached its radiation damage-limited degree of burnup. The functions of such re-conditioning are to remove a fraction of the fission products, primarily the gaseous ones, and replace the fuel cladding prior to fuel re-use in the reactor. The objective of recent fuel reconditioning research is to overcome material performance limits in a way that cannot extract pure plutonium and is, hopefully, not as expensive as conventional fuel reprocessing. After reconditioning the re-fabricated fuel is loaded back into the core for additional burnup and thereby increasing uranium utilization (Greenspan 2012).

According to Dr. Greenspan, Terrapower's initial Traveling Wave (TRW) Liquid metal fast breed and burn reactor (LMFB&BR) and its "Stationary Wave" LMFB&BR successor would operate on a once-through fuel cycle burning most of the Pu and minor actinides bred therein without separating them from the fuel. It's assumed that fuel cladding will last much longer than what's ever been achieved before after which it will be "reconditioned" in a way that doesn't isolate plutonium in a sufficiently pure form to be weapons useful.

To me it seems that this is just semantics: someone's decided to call the "reprocessing" of fuel that's reached its radiation damage and/or FP buildup limits, "reconditioning" instead.

That's too "lawyerly" as far as I'm concerned - rather like substituting "LFTR" for "MSBR" or "steam reforming" for "calcination" for promotional purposes. Employing slippery terms/definitions and deliberately vague documentation is how DOE's waste management experts managed to convince its stakeholders that steam reforming would be the best/cheapest/safest etc. way to convert INL's remaining liquid reprocessing waste to a competent radioactive waste form (see APPENDICES XII & IV).

I don't see anything in TERRAPOWER's MCFR patent applications that I would consider patentable with the possible exception of their displacement-type "control rod". Another thing it/they seem to be claiming is the use of a mixed multivalent fuel salt (roughly equal amounts of tri- and quadrivalent uranium) in order to rationalize some of their low assumed salt melting points[12]. That'd be swell if thermodynamic calculations didn't suggest that any of the periodic table's metallic elements (molybdenum, nickel, platinum, palladium, etc.) or silicon carbide would probably would be oxidized by such stuff (UIV is the culprit), but unfortunately that's not the case[13]. There's a reason why almost everyone who's taken a serious look at the MCFR concept in the past has assumed that essentially all of its uranium must be trivalent thereby generating a more reducing – less corrosive – fuel salt. A mixed multivalent fuel salt might work if someone comes up with a super ceramic material to make or line the reactor's core with, but I haven't heard about it yet.

Again, I feel that a breed and burn MCFR is apt to be superior to any sort of solid-fueled B&B concept for several reasons. However, it's going to take more than what I've seen so far to convince me that TERRAPOWER has come up with the "best" concept yet.

Here's a little BASIC program (below) that demonstrates the downside of Terrapower's breed & burn MCFR.

It assumes that 5 years from now we begin to build the 1 GWe 78 year, 9.4 tonne startup fissile breed & burn MCFR mentioned in section 5.4.2 of this book - 20 of them the first year and 5% more each year thereafter. The first of them are started up with ~2400 tonnes of fissile

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[12] It seems that a better way of arriving at a sufficiently low melting salt mixture would be to substitute $MgCl_2$ for some of the NaCl. Benesˇ & Konings suggest that a 0.607 NaCl, 0.089 $MgCl_2$, & 0.304 UCl_3 (mole fractions) would melt at just 448°C (Benesˇ 2008)

[13] It may be possible to prevent such corrosion by deliberately maintaining an equilibrium level concentration of the relevant corrosion product(s) (e.g, Fe^{+2}) in solution. This is just one of the possibilities that only realistic xperimentation can properly evaluate.

comprised of “surplus” weapons grade ^{239}Pu & ^{235}U and the RGPU in the world’s spent PWR fuel accumulation. After that’s used up, new reactors are started with ^{235}U derived from freshly mined natural uranium. Buildout ends when the total amount of NU required exceeds 18 million tonnes –the highest figure mentioned in any of the nuclear industry’s recent Redbooks.

That growth ends in year 72 (i.e., 2097 AD) when ~13660 breed & burn reactors are up & running.

If the world possesses 11 billion people by then that works out to 1241 watts/person – about 60% of what I’ve assumed would be enough to render everyone as energy-rich as today’s average European.

Solving the world’s energy conundrum will require real breeders.

APPENDIX IV. Example additive molar volume calculation

Let's determine how much plutonium would be in one liter of a room temperature salt mix containing 5 mole %$^{239}PuCl_3$, 28 Mole% ^{238} UCl_3 and 67 mole % NaCl. The principle involved is that to a good first approximation, partial molar volumes of a molten salt mix are additive; i.e., mole/cc mix = Σfraction mole/cc components

We begin looking up or guessing the densities (g/cc) of the salts going into our mix (I've made some educated guesses for this example – the pure heavy isotope salts will be just a bit denser than the natural ones (mix of isotopes) listed in WIKIPEDIA).

The fourth column lists molar volumes of the pure salts e.g for $^{23}Na^{37}Cl$ =(37+23)/2.17 g/cc

salt	g/mole	g/cc	cc/mole
$Pu^{37}CL_3$	350	5.71	61.3 (350/5.71)
$U^{37}Cl_3$	349	5.5	63.5
$Na^{37}Cl$	60	2.17	27.6

cc/mole salt = 0.05*63.5+0.28*61.3+0.67*27.6=	38.8	cc/mole
g/cc salt =0.05*5.71+0.28*5.5+0.67*2.17=	3.28	g/cc
one liter contains 1000 cc/38.86 cc/mole or	25.7	ΣSalts/liter
weight Pu per liter = 0.05*25.7*239 =	307.1	g/liter
weight Σ HM/l = 307.1+0.28*25.7*238 =	2020	g /liter

Due to thermal expansion both of these concentration figures would be 10-15% lower at the reactor's ~700°C normal operating temperature.

This is probably a good place to remind readers that these ball-park calculations are good enough to serve useful purposes. The reason for this is that unlike the situation with a solid-fueled reactor concept, safe startup of a MSR would be easy/simple because its fissile could be added gradually – its esigners would not havet to pre-specify everything to a gnat's whisker.

Another downside of most of the proposed 100% renewables schemes is that they assume that continent-wide grids would serve as batteries for whatever regions happened to be dark and/or socked in under stationary (no wind) cloudbanks. For efficiency's sake, such grids would utilize extremely high voltage DC long distance power transmission, not today's AC based power transmission, which would therefore require almost total replacement of today's system at both ends. This is not reasonable because such huge grids would be prohibitively expensive to build and the conditions that they are supposed to mitigate often obtain over very large areas. Another issue is that any such system would render that nation (or nations) even more too vulnerable to cyber-attack. (Governing 2020) A power/energy system consisting of sustainable nuclear power plants scattered throughout the country would be superior in every respect. Each reactor or reactor cluster would serve a "microgrid" consisting primarily of the same facilities that we already have today. Doing so would not only be cheaper and more reliable, it would also be far more difficult for terrorists to disable.

Another downside of most of the proposed 100% renewables schemes is that they assume that a continent-wide grid would serve as batteries for whatever regions happened to be dark and/or socked in under stationary (no wind) cloudbanks. For efficiency's sake, such grids would utilize extremely high voltage DC long distance power transmission, not today's AC based power transmission, which change would therefore require almost total replacement of today's system at both ends. This is not reasonable because such huge grids would be prohibitively difficult/expensive to build and the conditions that they are supposed to mitigate often obtain over very large areas (one of the real-world issues revealed by Germany's Energiewendie). Another issue is that any such system would render that nation (or nations) even more vulnerable to cyber-attack. (Governing 2020). A power/energy system comprised of sustainable nuclear power plants scattered throughout would be superior in every respect. Each reactor or reactor cluster would serve a "microgrid" consisting of the same facilities that already exist. Doing so would cheaper and more reliable and render it far more difficult for evil doers to "cyberattack" the whole country . It would render it much easier to restore/"blackstart" each sub region after they are shut down by another of Mother Nature's increasingly unpredictable tantrums.

APPENDIX V. QBASIC STARTUP FISSILE PROGRAM

REM « Assumes 400 LWRs for first 5 years, then a 15 year build-out with initial startup fissile »

REM « After that, all NU goes to building new 1 GWe breeders »

REM « breeder CR can be anything from 1 to 1.3 ; initial startup fissile (typ. 1900 t, max 2380), NUM = years run time (typ 81) & NU t/a after 20 years to NUM »

INPUT « breeder CR is « , CR

INPUT « tonnes available startup fissile is «, START

INPUT « numbers of years run is », NUM

INPUT « Tonnes fissile per start is « , TON

RTOT=400 :REM « initial 400 1 GWe LWRs, etc.»

FOR X=1 to5 : NU=NU+64000 : REM « 64000 is tons NU /a required by 400 state-of-the- art LWRs -what we're mining now)»

NEXT

FOR Y=6 to20 : NU=NU+64000 : RTOT=RTOT+START/TON/(20-6)

NEXT

INPUT « Tonnes NU mined per year for starting more breeders is », MINEDNU

FOR Z=21 to NUM

RTOT=RTOT+MINEDNU*.007/TON+(RTOT-400)*0.78*(CR-1)/TON : REM « 0.78 is tonnes fissile burned/GWe-year »

NU=NU+MINEDNU

NEXT

PRINT « Total NU after «, NUM , « years is « , NU

PRINT « Number of one GWe reactors then is «, RTOT

APPENDIX VI. A more realistic tube-in-shell thorium breeder reactor startup scenario

Since the world currently contains very little ^{233}U to start breeders with, it would have to be bred in reactors started with either ^{235}U or ^{239}Pu. Here's a concrete example:

Case 1 of Alexander et al's report (Alexander 1959) assumes the same reactor described in my text, running with ^{235}U instead of ^{233}U. Its fuel salt contains 33.8E+19 fissile atoms/cc and its CR is 0.5448 (it's not a breeder when run with ^{235}U but nevertheless makes a good deal of ^{233}U). So, if we assume the same-sized external plumbing ($8m^3$) as my Section 5.4.4's example's, it'd require 1.746 tonnes of ^{235}U to start and would generate 54.48% as much new ^{233}U in its blanket (170 kg) required to start another same-sized breeder. The best way to see what this means is to write up a little basic program like that in APPENDIX V (see below)

INPUT "input the ^{233}U fueled breeder reactor's CR", CR (any number between 1.00 and 1.19)
INPUT "run time in years ", years
Orig = 64000*0.0071/1.746: REM orig is the number of reactors that could be fed/started with the ^{235}U in 64,000 tonnes of NU (about 260 per year)
Increm = 0.5448*orig: REM Increm is the number of new breeders that could be started with the ^{233}U in the "orig" reactors (about 142 per year)
FOR x=1 to years
N=N+increm
N=N*CR (adjusts the number of ^{233}U reactors upwards if CR>1)
NEXT
PRINT "total number 1 GW_e reactors in "years, "is" , N+increm

e.g., for a 50 year run time and a CR=1, we end up with 7349 reactors utilizing the ^{235}U in the same ~64,000 tonnes per year of natural uranium currently consumed by today's ~400 LWRs. If their CR were 1.05, we'd have 31,427 reactors after 50 years. If it were 1.19, we'd have over 30,000 of them in just 34 years.

Over time, breeding is very much like the "magic of compound interest" in that it will eventually make its investors rich. The problem is that most people and the institutions they create can't see beyond the immediate.

"Compound interest is the eighth wonder of the world. He who understands it, earns it. He who doesn't, pays it."

.Albert Einstein

I’ve assumed high-enriched uranium (HEU ≥90% ^{235}U) starting fissile because low enriched uranium (LEU) within the core would destroy its neutronics and thereby render the system unsustainable. Enriching natural uranium from a LWR’s 5%^{235}U LEU to HEU, would raise enrichment costs by about 23% (Benedict 1981, p, 671).

Here’s another way to look at it: If it takes 0.312 tonne ^{233}U to bring the breeder version of this thing up to criticality and a ^{235}U fueled version of it has a CR of 0.5448, it should take 0.5776 (0.312*235/233/0.5448) tonnes of ^{235}U to start one breeder.

For 30000 such breeders that’d take the ^{235}U in 2.443E+6 (0.5776*30000/0.0071) tonnes of NU

That’s pretty close to the same amount of NU (400*160* 34 =2.18E+6) predicted by my BASIC program assuming a CR of 1.19.

It could also be started up with “excess” bomb grade Pu though doing so would somewhat complicate “reprocessing” because, unlike uranium, Pu can’t be easily separated from either its solvent salt (FLiBe) or 25 mole%ThF_4/75%LiF via fluorination.

APPENDIX VII. letter sent to two of DOE's Inspector General's lawyers just after my job had been downsized for the last time

(there was no response or any other action taken by them or anyone else in DOE's/INL's chain of command – I retired in disgust about one year later. I've X'd out most of the names to protect the guilty)

From: Darryl D Siemer [mailto:SIEMDD@inel.gov]

Sent: Thursday, April 07, 2005 10:32 AM

To: XXXXXXXX X XXXX; XXXXX X XXXXXX (the lawyers)

Cc: (*everyone in my chain of command*)

Subject: more HLW-related waste, fraud, & abuse

The latest YM imbroglio has heightened public awareness of the same issue that I've been discussing with you recently; i.e., can folks trust DOE's "science"? Here's some more background on INL's own little EM-science scandal.

At the beginning of this year one of our calcination experts gave me a copy of the fluidized bed steam reforming (FBSR) "book"[1] that THOR's chief technical expert had cobbled together a few months earlier (March '04) for a California-based consultant. The cover note prepared & sent along with that "book" indicated that it was being cc'd to DOE-ID's HLW/SBW treatment czar, XXXX XXXX (& only to him).

THOR's "book" made for fascinating reading (to me anyway) because it was the first time that a "proprietary" document describing what had really happened during HAZEN Research Inc.'s 2001 "FBSR mineralization" tests had been released; i.e., how its reactor was really configured and what it produced - the fact that most of its product (also) consisted of a bulky, flour-like, dust (fines) - not "grapenuts", and that it (also) quickly rocked-up (agglomerated) when they tried to produce a sodium silicate-type product. It is also fascinating (to me anyway) because it contains the first document I'd seen[2] which discloses information consistent with the "controversial" papers I'd written about INEEL's initial attempts at applying (« demonstrating ») THOR's process to its sodium-bearing waste (SBW)[3,4].

Had I been permitted to see this book when Mr. XXXX (*DOE's local HLW/SBW treatment czar*) first passed it on to BBWI's fluidized bed experts, the job of defending the paper I'd just then written up for the 2004 American Ceramics Society's radwaste symposium would have been much easier. The reason for this is that it seems that no one else (including the reviewers picked for my paper) had apparently seen an unfiltered version of HAZEN's report either - as far as we/they knew, its reactor had produced only a dense, "grapenuts-like", product which several official DOE lab-generated reports had characterized as "better than glass".

Consequently, my paper which suggested that ...

• Mineralization-style FBSR is not an intrinsically "easy" (cheap) process to run

• It invariably produced more dust than "grapenuts"

• It could not turn SBW into sodium silicate, and ...

• Its product is not as "durable" (leach resistant) as previous reports had indicated

… required lots of "defending”. (I did, however, eventually prevail – the paper was published[4].)

The folks who had volunteered to run ACERSOC's radwaste symposium last year (& this year's too) just happen to work at the same DOE lab (SRS) which had provided THOR with the official reports used to "sell" its process[5]. By another coincidence, that same lab had recently become DOE's "lead lab" in managing its own steam reforming R &D program - this in spite of the that fact that SRS possesses neither the expertise nor the equipment required to properly evaluate a fluidized bed-based technology[6].

Curious.

Even curiouser, it seems that as soon as I began to point out some of the inconsistencies between what SRS had published about THOR's process/product & what I had observed during the local test, INEEL's decision makers decided that they could no longer afford to pay me to provide real-time process support (chemical analysis/advice) during subsequent FBSR tests run for their new « customer » (SRS’s material sceintists). They couldn't afford to pay me to continue to do post-run product characterization work either. They subsequently also decided that I wouldn't be retained by the lab-side of the new/improved INL either - that's why I'm now a lab-less "cubicle dweller" here at TSB.

Anyway, last Spring I volunteered to do ”free” post-run characterization of the products of INEEL's CY 2004 FBSR demos & was consequently given samples of everything produced during the rest of those tests. I'm ATTACHING the texts of the notes I sent along with my free analyses/characterizations. Of course, since my results weren't “official”, they were not included in the formal INEEL reports produced after each demo[7]. Another reason why my reports/conclusions didn't show up in INEEL's official reports was that its customer had dictated that all such characterization work be performed at SRS - not here where the stuff was being made. (You'll note that I repeatedly chided our team for not duplicating the conditions outlined in THOR’s description of HAZEN’s test[2]; i.e., implement 100% recycle of fines back to the reactor. One of the things revealed in the before-mentioned “book” is that we had indeed duplicated HAZEN’s experimental system (almost anyway). What we did differently was to report everything that happened when we tried to run it.)

Everything I've seen indicates that FBSR would be inferior to a properly-implemented vitrification system for INL's SBW.

•□□□□□□□□FBSR achieves little or no volume reduction (about 6 x less than vitrification)

•□□□□□□□□it produces more and dirtier (dustier) off gas

•□□□□□□□□the process itself is apt to be problematic – a rocked-up “mineralized” reactor bed couldn't simply be dissolved-out with dilute nitric acid

•□□□□□□□□its product doesn't meet the durability standard that waste forms made from similar radwaste at other DOE sites must satisfy (e.g., Hanford's LLW)

•□□□□□□□□its product doesn't meet CFR 10- 61 disposal/transport criteria (i.e., “no dust”)

•□□□□□□□□its product doesn’t meet the YM WAC

•□□□□□□□□and, of course, "stakeholders" on both ends of the waste pipeline prefer vitrification

These observations shouldn’t be too surprising because an independent “Technical Review” had recommended that DOE not attempt to produce a “repository ready” waste form with THOR's process back circa 2000.

Copies of SRS's FBSR product characterization reports were ATTACHED to the note that I sent to you last Thursday[9]. As that note indicates, it’s apparent that some highly-placed individual (i.e., someone who can decide who receives DOE’s EM R&D funding) decided to champion THOR’s technology several years ago and that SRS decided to go after that money. It's also obvious that INEEL's decision makers agreed to keep the lid on what was going on[10].

It's unfortunate that DOE decided to waste so much time & money on this EM boondoggle. It’s more than just "questionable" ethics - the fact that INEEL was not permitted to continue to seek more efficient ways of vitrifying its waste while DOE was encouraging its contractors to “study” FBSR (the status quo approach to vitrification leaves plenty of room for process improvement[11]) means that INEEL may not succeed in converting its “old” reprocessing waste to a stakeholder-acceptable waste form[12]. Since its unresolved “waste issue” continues to be one of the US nuclear power industry’s greatest handicaps, such failure would undermine INL’s chances of playing a leading role in reviving that industry (which, of course, would generate “new” reprocessing waste).

While it's understandable why individuals whose livelihood depends upon remaining in the good graces of our decision-makers might be reluctant to speak up about issues like these, that’s not the situation with me - I’m old enough to retire & have already been “downsized” out of several jobs here at INL.

Where do I go from here? Idaho's Congressional delegation?

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1. "Steam Reforming Technology for the Denitration and Immobilization of DOE Tank Wastes, Book 1", Brad Mason, dated 19 March 2004, (a compilation of ten documents)

2. THOR's 2003 “Tuscon Conference” paper (J. B. Mason et. al., "Steam Reforming Technology for Denitration and Immobilization of DOE Tank Wastes", WM'03 Conference, Feb. 23-27, 2003, Tuscon, AZ.) is a typical example of prior descriptions of the “HAZEN test” in that many of its conclusions are inconsistent with the information in the actual report (doc. TR-SR01-1, Rev 0, "Hanford LAW Waste THORsm Steam Reforming Denitration and Sodium Conversion Demonstration").

3. D. D. Siemer, M. W. Grutzeck, and B. E. Scheetz, “Cementitious Solidification of Steam Reformed DOE Salt Wastes”, ECI Alternative Nuclear Waste Forms, Girdwood, AL January 18-23, 2004.

4. D. D. Siemer, "Steam Reformation of Sodium Bearing Waste: Pros & Cons", Ceramics Tranactions, Vol. 168, pp. 81-90, 2004.

5. THOR's characterizations of FBSR calcine as "better than glass" are generally referenced to SRS's reports. The one referenced most often is C. M. Jantzen's, “Engineering Study of the Hanford Low Activity Waste (LAW) Steam Reforming Process, “ WSRC-TR-2002-00317, Westinghouse Savannah River Company, Aiken, South Carolina, July 12, 2002.

6. For example, early last year the materials science experts supported by SRS's steam reforming project wrote up a formal description of how they proposed to spend their research money that year. The centerpiece of their proposal was an multiple step scheme to make a "mineralized "steam reformer product with more or less standard laboratory equipment (calcination in a muffle furnace, "hydrothermal" conversion of that calcine, etc.) - not in a fluidized bed reactor. When I pointed out to SRS's "project lead" (Bill Holtzsheiter) that the experimental conditions proposed for that project wouldn't emulate what happens in a fluidized bed reactor (THOR's system) , the plan was modified as described in the project's final report (WSRC-TR-2004-00560 Rev A, "Evaluation of Fluidized Bed Steam Reforming (FRSR) Technology for Sodium Bearing Wastes From Idaho and Hanford Using the Bench-Top Steam Reformer (BSR) (U)"

December XI (sic), 2004.) The modified scheme involved dribbling a slurry of clay, charcoal, "catalyst", and SBW into a big crucible situated in a preheated muffle furnace. The crucible contained aluminum oxide "bed" granules which were initially fluidized with steam. When the feed mix was added to it, the alumina bed quickly agglomerated (fluidization stopped) which resulted in the formation of a "giant turd" waste form (my appellation) - not a fluidized bed's mixture of "grape nuts" and fines.

7. For example: N. R. Soelberg, D. W. Marshall, S. O. Bates, and D. D. Taylor, "Phase-2 THOR Steam Reforming Tests for Sodium-Bearing Waste Treatment, INEEL/EXT-04-01493, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho, January 2004.

8. J. A. Gentilucci, J. E. Miller, R. L. Treat, and W. W. Schultz, "Technical Review of the Applicability of the Studsvik, Inc. THOR Process to INEEL SBW" Rev.1 , (a "Tanks Focus Area" doc. published Sept. 2000)

9."SRS's Steam Reforming Reports - another critical issue", Lotus note to XXXXXX & XXXXX (the lawyers), 31Mar05 (4 ATTACHMENTS)

10. For instance, our leadership decided to not report that the stuff produced by INEEL's first SBW mineralization test didn't exhibit the anticipated degree of "durability" - instead that report (INEEL/EXT-04-01493) indicated that PCT results were "still being evaluated".

11. For instance, the SBW vitrification system outlined in DOE's ICP RFP "shared documents" website (INEEL/EXT-04-01692) assumes that we would have to build another huge DWPF-type melter. That's not true because glass-making technologies have become more efficient since SRS's melter was designed.

12. Why? That book's "proprietary" HAZEN test/report (TR-SR01-1) was actually paid for (& therefore "owned" by) WGI/Bechtel National Inc. I probably don't have to remind my readers that both of those contractors have "proprietary" interest in this Site too.

APPENDIX VIII. Letter sent to INEEL's Director circa 2001 (after "separations" & before "steam reforming" was the Site's "preferred alternative")

"Ethics & EM – a view from the trenches"

Work's been pretty slow out at TRA during the last month. The reactor is down again, another ISM audit is pending (audits always generate paralysis), the ventilation system in my lab hasn't worked for three weeks (INEEL doesn't seem to be able to maintain blowers anymore), & my usual customers (I'm a chemist) are putting off doing things like submitting samples or doing experiments until the new fiscal year's funding situation settles down & the auditors go home. Consequently, I've had lots of time for "training" – most recently, "Ethics". For some reason, being reminded about "waste, fraud, & abuse" always gets me pondering about INEEL's EM programs. Since such thoughts aren't programmatic & I've already burned up too much of my boss's overhead, I've decided to take the day off (PL) to write you this note.

About two months ago I was invited to spend a week in town with about 30 other guys from INEEL and elsewhere (the outsiders included many of the DOE Complex's glass experts) to try to come up with a sure-fire way to implement "direct vitrification" of INEEL's sodium-bearing waste (SBW). We were told that "direct vit" would be the "preferred alternative" in the upcoming "final" INEEL HLW EIS & were presented with a "90% draft" INEEL engineering document that goes into excruciating[14] detail about <u>one</u> way to do it (slurry raw SBW with glass forming agents & sugar in tanks, "characterize" those mixtures, & then feed them directly onto the cold cap of a SRP-type melter @~75 gallons per hour.)

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[14] INEL/INEEL/INL has a hoary tradition of "paper engineering" projects before doing the R&D needed to test key assumptions - that's how it built a $350 M fuel dissolution facility (FDP) that never achieved better than one-third of its originally promised throughput. The document I'm alluding to here specifies the size of every room of the proposed facility to the nearest inch & estimates project costs to 5 significant figures. Don't you think it woud be better to determine (experimentally) if we really need (for example) five feed mix tanks before we go into this degree of detail on paperwork?

We were also told that we were permitted to think about how the system might be used to treat existing calcines as long as those thoughts wouldn't impact on how SBW could be treated ASAP. We were divided up into subgroups that were to concentrate upon one aspect of the proposal.

I was probably assigned to the "waste pretreatment" group because I'd just written/distributed a note about the results of the steam-reforming experiment recently run (by SAIC) to verify contentions made in a STUDSVIK proposal that had been sent to me[15] three years ago.[16]

Just before we went off to our breakout cubicle, I asked the visitors whether or not calcination (aka, "drying", "denitration", "incineration", "steam reforming", etc....) is apt to make the job of convertingINEEL's relatively dilute (solids-wise) nitrate-based liquid into glass easier. They were unanimous, "yes". Consequently, my subgroup (all from INEEL) proceeded to sketch out a scenario that would feed a slurry of SBW, sugar, glass forming agents[17] into a STUDSVIK-type steam reformer & blow the product ash/calcine directly into the melter[18].

When we presented our brainchild to the whole group, it was considered "radical" because what would be going into the melter would have been "characterized" one step before where the folks running the melters at SRS & WVDP do it meaning that no one could prove that it was being fed optimally (in other words its operators wouldn't be able to prove that a dragon or witch hadn't added something that would reduce "safety".

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[15] Because he'd recently managed a successful fluidized-bed SBW sugar-calcination project for one of the contractors bidding on Hanford giant "sodium bearing waste" vitrification project (VECTRA), I'd previously written a note to STUDSVIK's Brad Mason pointing out that INEEL would probably not honor its promise to calcine SBW unless a credible "outside" organization with recently-demonstrated expertise stepped in with "an offer they couldn't refuse" (or ignore). He responded with an offer to bring in Studsvik's own fluidized bed reactor (not utilize INEEL's NWCF reactor) &"steam reform" the stuff for $49 M.

[16] Which I first passed on to INEEL management & then, when nobody paid attention, to the state of Idaho's "INEEL Oversight" program manager.

[17] not "frit"- it's too difficult to keep in suspension – instead, easily suspended/pumped stuff like diatomaceous earth, jeweler's rouge (Fe_2O_3), & lithium tetraborate.

[18] Basically, all we had to assume is that what goes into the calciner comes out the other end - minus "volatiles". The British & French were courageous enough to make that assumption over a decade ago.

This brings me to one of the reasons for this note – the mind-numbing "conservatism"[19] evinced by most of the DOE Complex's decision-makers & technical experts. By this I mean unquestioning acceptance of silly (& often blatantly self-serving) assumptions[20] that render accomplishing anything unnecessarily difficult, grossly expensive, and often impossible but serve as an excuse for further "study". For instance, in this case, the group was ignoring the fact that Cogema & BNFL have been successfully making genuinely "hot" (100's of times more radioactive than DOE's) high-level glasses for over a decade. European melters are fed by close-coupled rotary kiln calciners that simultaneously mix waste with glass forming additives and remove "volatiles" (water, free acid, nitrate, etc.). The reasons why the Brits & French do it this way include; 1) the removal of volatiles improves the productivity of their melters, 2) it simplifies offgas cleanup, & 3) it's intrinsically easier to accurately meter stuff going into a direct coupled calciner/melter system than it is to make calcine separately, "temporarily" store it, retrieve it, mix it with frit, "characterize" the mixture, and then meter it into a melter. In other words those "foreigners" do it that way because that's what both common sense & economics dictate.

Why would doing it that way here too be "radical?"

In the US, the rationale for saying that the stuff going into our melters has to be immediately "characterized" beforehand is that we assume that it's impossible to adequately premix our wastes. At INEEL this boils down to accepting the notion that low viscosity solutions containing very little undissolved solids situated in adjacent tanks couldn't be homogenized by simply pumping them back and forth for a few months (years?) – a patently ridiculous assertion.

If one has the temerity[21] to ask **why** "we can't" mix those liquids (I did), you're told that the **only** way to pump them back and forth would be to do so with steam eductors (jets) which since this would dilute waste with condensed steam & the tanks are already full, "we can't do".

Do you have any idea of how many different ways of pumping liquids have been developed? Couldn't a "lead lab" choose to adopt one that **would** allow it to mix its waste?

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[19]For instance, the melter subgroup's technical guru (an outsider) volunteered that an existing high temperature pilot plant melter at his home base could be derated to approximate the characteristics of DWPF for R&D on our problem - do we really want another DWPF?

[20] For example, for the last ten years, INEEL's HLW gurus justified their program with the contention that a several cubic mile mountain (YM) would be "too small" to contain 4200 m^3 (0.000001 $mile^3$) of calcine unless it's first been "separated".

[21] Asking "why" in this business automatically makes you "not a team player" – which, in turn, negatively impacts your career.

Some of the other opinions recently expressed by INEEL's in-house technical/regulatory/safety experts include:

1) "We can't" efficiently calcine SBW in NWCF [22]
2) "We can't" recover/recycle NOx from NWCF offgas
3) "We can't" recover mercury from NWCF offgas

There's plenty of evidence that those assertions are all dead wrong. More important, DOE-ID's acceptance of "we can'ts" from its contractor's in-house experts has repeatedly resulted in its failure to accomplish things it's promised to do; e.g., 5 years ago, we solemnly promised our then-new Governor (of Idaho) that we'd calcine SBW.

A "lead lab" should keep its promises – if it doesn't, it'll first lose credibility, then missions, &, finally, jobs23.

Another "we can't" has to do with INEEL's refusal to earmark R&D funds for any HLW management scenario inconsistent with the notions that, a) physical size is the most important characteristic of high-level waste, and, b) glass-making is the "best" way to make any so labeled wastes "road ready"24. Consequently, when DOE-ID finally realized (it took eight years!) that "separations" didn't make sense, the only alternative that INEEL had generated enough "official paperwork"25 to fall back upon on was "direct vit".

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[22] The key to efficiently calcining SBW in NWCF (R.I.P.) is precisely what STUDSVIK was proposing to do at Hanford (& which the British/ French already do) – add sugar. One of the reasons INEEL recently lost (abandoned) its ability to calcine waste is that its decision-makers refused to implement sugar calcination (their excuse was "safety issues"). Sugar would have also greatly reduced the amount of NO_x dumped into the atmosphere.

[23] For example, the shutdown of WERF & NWCF not only affected workers at those facilities but also people who provided services for them elsewhere; e.g., I used to do a good deal of WERF's analytical work at TRA. Since we're all still on the INEEL payroll, it's unlikely that abandoning those facilities/technologies/missions gave much relief to US taxpayers.

[24] The rationale for this "we can't" is usually, "*there's not enough money to look at more than one thing at a time*". The fact is that the resources needed to do such research here at INEEL has already been paid for - the equipment, the lab, & my time will cost US taxpayers the same whether they're put to constructive use or wasted. INEEL's bean-counting approach to time/personnel/project management prevents its senior scientific professionals from being more productive because doing work/research that's not been "stovepiped" all the way down from HQ can be construed as "time card fraud". It's much safer for individuals to occupy themselves with "training" during slack times.

[25] "Official" is the key word here. The bibliography of the recent "Draft INEEL HLW EIS" includes only officially sanctioned/produced documentation, mostly DOE's reports. Relevant information from other sources (e.g., the National Academy of Science) apparently doesn't count. Could the reason for this be that much of the unofficial documentation doesn't support the paradigm adopted by the EIS's authors?

DOE-Hanford's latest public relations disaster[26] ought to be a lesson for INEEL. Hanford can't afford DOE-style vitrification & neither can we.

INEEL could become a genuine "lead EM lab" if its leadership permitted it to. One way to make it happen would be to take the blinders off your technical people. There's no valid reason why the research I've done since 1995 (due in large part to the good offices of the Inspector General & an extremely patient wife) couldn't have been officially sanctioned/funded[27]. If it had, a lot more could have been accomplished, the tenor of the reports/publications I'd generated would have been different, and INEEL would have something other than "direct vit" on its plate now.I'd also have a legitimate charge number to fall back on during times like this.

P. S. I've written two more "hobby" papers[28] about how & why INEEL could implement a more productive approach to rendering reprocessing waste road-ready. If you're interested, I'll be happy to send you copies

[26] i.e., BNFL's first being publicly humiliated & then fired for "committing truth" about the probable costs of Hanford's "vitrification" scheme .

[27] Here's a thought. How about giving your PhD's, let's say, 60 hours per month of "Professional Development" time to devote to R&D that *they* consider to be consistent with DOE's professed missions/goals. The number/proportion of "Professional Development" hours should go up every time we abandon another "real" mission/facility, there should be no "carry over" limit on them, & we (the PhD's) ought to be able to trade 'em back & fourth to pay for in-house expertise/services.

[28] Both were presented at this year'***s American Ceramics Society*** radwaste symposium.

APPENDIX IX. Suggestions for improving INL reprocessing waste management

INL's already calcined reprocessing waste

The fuel reprocessing systems developed by the US federal government's cold war nuclear defense plants to recover uranium and/or plutonium generated a far greater volume/mass of radioactive waste per unit mass of fuel processed than do those utilized by modern commercial fuel reprocessing facilities. US reprocessing radwaste is less radioactive because: 1) its defense-type reactor fuel was generally not "burned up'" to nearly the same degree as are commercial fuels, which means that less fission products were produced per unit mass of uranium processed; 2) the entire fuel rod was usually dissolved (cladding as well as the fuel "meat") which further served to dilute the waste's fission products; 3) little attention was paid to minimizing the amounts of solid ash-forming chemicals (e.g., sodium, aluminum, and calcium nitrates, boric acid, cadmium nitrate, etc.) added to facilitate processing. APPENDIX XI discusses radwaste radiolytic heat generation.

Calcination of this sort of waste was often considered[29] because: 1) weight-wise roughly 80% of it (e.g., nitrate, nitrite, organic chelating agents, water, etc.) is intrinsically volatile; 2) calcination would facilitate its storage because calcines generally occupy considerably less space (typically 15-20%) than do the liquids from which they are made; 3) a calcine would not be as readily dispersed as a liquid if the storage vessel were to be accidentally breached; 4) the relatively low temperatures required to calcine waste (~500°C) would minimize co-volatilization of chemical toxins (e.g., Cd) and radionuclides (e.g., ^{99}Tc & ^{137}Cs); and 5) calcination would facilitate subsequent implementation of the ctechnologies (e.g., vitrification) which could create a better ultimate disposal form.

[29]However, NRTS/INEL/INEEL/INL was only DOE site that actually did calcine its wastes.

Figure 96 INL's New Waste Calcination Facility (Dickey1974

Figure 96 is a schematic of the Chem Plant's fluidized-bed calciner. Waste solution was sprayed into a heated, air-fluidized, bed of granular solids where it first dried upon the surfaces of those solids after which its nitrate salts decomposed to form oxides. To begin with, its "starting bed" consisted of limestone granules – at steady state, its bed's particles consisted almost entirely of the waste's ash-forming components. At that steady-state, feed deposition, particle elutriation, attrition, and deliberate removal of larger particles via overflow resulted in a steady-state particle size distribution. Its bed temperature was maintained at about 500°C via in-bed combustion of kerosene atomized by oxygen through wall-mounted spray nozzles. The calcined product consisted of a mixture of flour-like fines and sand-like granules which was blown through pipes to binsets (Fig. 32) several hundred feet away where it remains today. The system's dusty off gas was "wet scrubbed", passed through silica gel asdorbant beds, and finally HEPA-filtered before reaching the atmosphere via a ~300 ft high smoke stack.

The primary weakness of the purely thermal calcination process adopted at NRTS/INEEL was that it could not efficiently deal with wastes in which the molar ratio of alkali metals (primarily sodium and potassium) to polyvalent metal (aluminum, zirconium, iron, calcium, etc.) nitrate salts exceeded ~33%. The reason for this is that sodium nitrate does not thermally decompose at that system's operating temperature (~500□C) but instead melts to form a viscous, glue-like, liquid that agglomerated (defluidized) the reactor's bed. In 2000 (after DOE's "separations" waste treatment paradigm had finally run its course at INEEL), a combination of offgas-related stakeholder issues, INEEL's unwillingness to sugar-calcine its remaining "sodium bearing" liquid waste" (SBW), plus the fact that its calciner was being heated in a way that apparently officially rendered it an unlicensed "incinerator" caused the site's decision makers to abandon calcination for "direct vitrification". Unfortunately, under two years later vitrification was abandoned too because DOE's topmost environmental management decision maker (its "EM 1") decided that it would cost too much to implement at INEEL.

The most sensible thing to eventually do (there's no great rush & we shouldn't pretend that there is) with INL's calcined wastes would be to fill the reinforced concrete, vaults containing its stainless steel calcine « bins » with a blast furnace slag-based cementitious grout containing finely crushed phosphate rock and vermiculite. That combination mixed with enough water to make a stiff but pumpable grout would set up to form a concrete « rock » capable of chemically immobilizing any fission products that might somehow find their way through the walls of those bins thousands of years from now.

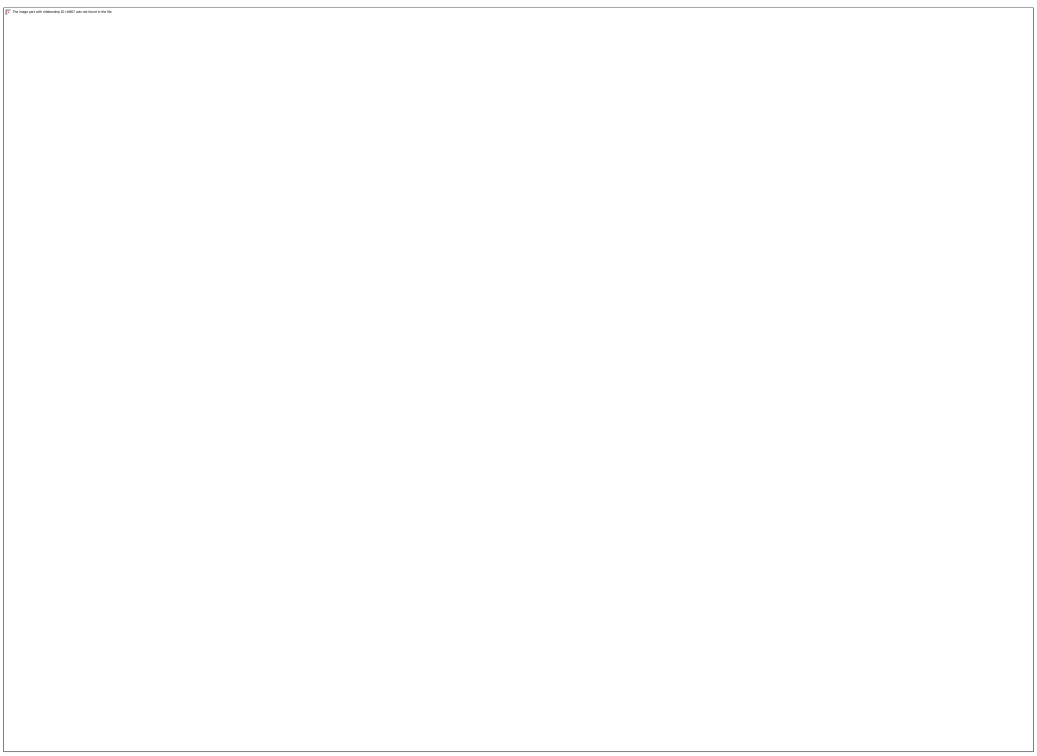

Figure 97 INL's calcine binsets (Staiger 2011, CSSF VII is empty and big enough to contain anything that might be made of its sodium bearing waste (all of them are at least halfway underground)

If that's too simple, cheap, safe, and logical for decision makers to deem acceptable, the same glass melter that could be used to make phosphate glass gems of INL's remaining liquid reprocessing waste (see the following subsection) could vitrify its calcines as well. Phosphate glasses are better-suited than borosilicate glasses for such things because they do a better job of retaining both transuranic elements (mostly Pu) and anionic species (e.g., halides, $^{99}TcO_4^-$, and sulfate).

Better yet, we could slurry up those calcines with the raw SBW and phosphoric acid plus some powdered iron ore and melt the resulting « mud » to make phosphate glass « gems » of 100% of INL's reprocessing wastes. Doing so would reduce the total amount of glass required because those wastes' compositions chemically complement each other[30].

As far as such glass's disposal is concerned, the most reasonable option would be to grout that gem-type aggregate back into the same binsets currently containing INL's unconsolidated calcines. Failing that, we could ship them down to the NTS's Area 5 and bury them at the bottoms of a few more Greater Confinement Disposal boreholes (see APPENDIX X).

Of course, if that doesn't satisfy everyone and we don't mind waiting for a few more decades, I'm sure that one of its contractors will eventually promise DOE that it could slingshot them into the sun.

I recently mentioned two other disposal options for such glass in another QUORA answer. https://www.quora.com/Let-s-say-that-we-used-nuclear-energy-on-a-mass-scale-would-Mars-or-the-moon-be-good-resting-places-for-the-radio-active-waste-left-over (warning: some folks might be offended bymy suggestions.)

Finally, since DOE has officially declared that INL's calcines will be hot isostatic pressed (HIPed) in one way or another before 31Dec2035, a more reasonable* way to go about doing it than is currently envisioned would be to mix them with sufficient dehydroxylated clay and/or class F flyash plus sodium silicate to make a stiff geopolyeric grout that could be pumped into the stainless steel canisters. That grout could then be steam cured (FUETAPed) to form a durable concrete (Moore 1981) which could either serve as the waste form as-is, or eventually totally dried out and HIPed as promised* (Siemer 1995).

***DOE declared that INL's calcines will be HIPed in one way or another (see 75-FR-1 2010) because it's apprently convinced the EPA that it's equivalent to its "Best Demonstrated Available Technology" (BDAT) meaning « vitrification »). HIPing is usually done by mixing dry powders (in this case, calcined waste) with the additives (mostly silica) required to form a durable product and transfering that mixture to a stainless steel canister. That**

[30] A requirement for good quality, low/easy melting glass manufacture is that the relative amounts of glass network formers (silica and/or P_2O_5), alkali (sodium, potassium, cesium…) plus alkaline earth (calcium, etc) elements , and polyvalent metals (aluminum, ferric iron, zirconium, etc.) fall within certain ranges. Sodium bearing waste's non radioactive ash-forming components (Al^{+3}, Fe^{+3} & Na^+) would have to be added to any phosphate glass made from just INL's calcines.

canister is evacuated (air sucked out), sealed, and placed into an hot isostaic press (HIP) which is pressurized with 1-20 thousand psi argon and heated to ~900 to 1200°C for an hour or so. If everying is done right, the product is a dense, hard, chemically durable (leach resistant) « rock » sealed within a thick-walled stainless steel canister (Atkinson 2000). In practice, hipping proved to be difficult to accomplish remotely due to powder disaggregation which caused the finished product to be much less durable (to see what happens for yourself, mix ground pepper with rice or tapioca, put it onto a platter, tilt one side of the platterup & shake/tap it to slide the mixture downwards). If everything is done right (i.e., the waste well-mixed with proper additives when it is HIPed - a committment that DOE has refused to make), a HIPed waste form is apt to be more durable than a glass; i.e., last for even more eons after it is no longer sufficiently radioactive to pose a threat to anyone. Utilizing concrete mixing/filling technologies greatly simplifies the overall process.

INL's remaining liquid sodium bearing waste[31]

It's too late to do what should have happened over twenty years ago; i.e, sugar-calcine it (Loeding 1961, Petrie 1965) and then store that product in INL's already built-and-paid-for binsets until someone decides for sure what's to become of its calcines. Since then, its calciner (NWCF) has been destroyed (decommissioned) and INL's subsequent steam reforming boodoggling hasn't accomplished much other than making lots of work for its contractors[32]. Consequently, its decision makers should start over again from scratch. If I were in charge, I'd contact GTS Duratek and see if it might be willing to redo DOE's one and only « Vitrification and Privatisation Success » at its Idaho Site. SBW is compatible with that same glass formulation and only about 50% as much glass would have to made[33]. Since GTS Duratek *almost* broke even with its $13.9 million fixed-price bid circa 1995, it might be willing to tackle INL's project now for, let's say, $75 million which is surely under 10% of the tax dollars that have already been boondoggled away trying to get its steam reformer to work. The one thing

[31] Almost 100% of INL's reprocessing wastes had some sodium along with its chemical-cousin, potassium, in them. INL's SBW had a higher proportion of such alkali-type metals (along with more plutonium and mercury) because they had originated from "not first cycle" separation activities (in DOE-world, many things are defined in terms of what they're <u>not</u>).

[32] On 14Mar2019 I got another note (CNN 323337) from FLUOR the subcontractor currently in charge of INL's steam reforming project, announcing that DOE is submitting another Class 3 permit modification request to Idaho's Dept. of Environmental Quality to make yet another set of 11 major and 1 minor changes to that facility.

[33]My estimates assume 900,000 gallons of SBW converted to a glass containing 20wt% Na & Pickett et al's (Pickett 1995) figure of 206,000 gallons of glass.

that Duratek's CEO should insist upon though, is that INL's waste management gurus not be allowed to manage its project.

If in order to save face, DOE's decision makers insist upon using INL's billion dollar "reformer", I'd suggest running it under the same conditions that would have worked with NWCF :

- add jet-type mixers to the SBW tanks so that everything in them, not just clean supernates, are processed
- heat the reactor via on-bed combustion of kerosene rather than coal - don't bother with making/adding steam
- run it at about 500 rather than 700°C because doing so would mitigate « bark » formation)
- Mix sugar with the SBW squirted into the reactor via a mixing « tee », not by premixing everything together in a big feed tank.
- Continuously blow its « carbonate product » (calcine) over into binset number 7.

If/when that reformer/calciner plugs up, do the same thing that we did when NWCF did s : i.e., shut down, dissolve out the bed with nitric acid, return that solution to the SBW tanks, & then start up again. It should not take more than two years to complete the entire job.

APPENDIX X. Greater Confinement Disposal

The scientific basis of Dr. Winograd's proposal was subsequently thoroughly investigated by SANDIA which renamed it "Greater Confinement Disposal". In 1984, DOE-NV acted upon the evidence and had a contractor (REECO) bury 500,000 Ci of ^{90}Sr and 200,000 Ci of ^{137}Cs in the lower 50-foot sections of two 120 foot-deep, 10 foot-diameter, holes augered into the NTS's Frenchman Flats (Area 5) (Dickmann 1989, Bonano 1991) utilizing the same equipment used to emplace the "devices" which caused that region to appear pockmarked with smaller versions of Dr. Winograd's Sedan Crater repository site (see « GOOGLE EARTH » 37.178N116.047W). The hotter of SANDIA's « new » repository-holes contains roughly 3 kilowatts worth of fission product radioactivity – about one-thirty fifth of that in the INL's entire accumulation of calcined reprocessing waste. Approximately 1000 Ci of transuranic waste including 6 kg of weapons-grade plutonium along with hundreds of kilograms of uranium released by devices that had "fizzled" rather than explode, was buried in another set of four boreholes. The total amount of plutonium in all of INL's radwaste is about 35 kg - roughly 1% of the amount deposited both within and upon the NTS by DOD/DOE's weapons testing program.

This sort of cheap disposal scheme should eliminate the single greatest action-paralyzer/cost-driver in the USA's approach to radwaste disposal – the ridiculously high costs assumed for such waste's final burial plot.

SANDIA has since released several formal "performance assessments" (PAs) of DOE-NV's GCD (Baer 1993).

They contain the following conclusions:

- No even-moderately-probable chemical/physical/mechanical mechanism other than direct deliberate human intrusion can cause that repository to fail within 10,000 years. [In this context, "fail" means to not meet the requirements of 40 CFR 191.]

- In spite of the buried fission product elements' (esp. ^{90}Sr & ^{137}Cs) far greater initial radioactivities and greater "leachability" as indicated by the leach tests that the developers of high-tech waste forms use to compare their wares at DOE-sponsored radwaste management conferences, those components do not dominate the hazard index of that repository - the much longer-lived « transuranic » (TRU) elements do. This means that short of an actual meltdown[34], any GCD disposal system (such as Winograd's) suitable for TRU wastes is "conservative" with respect to any fission products or chemically toxic stuff that might be mixed in with it. Most

[34] If the burial crew is even remotely competent (heat generation is easy to measure), a melt down is impossible.

defense-type HLW is mildly « hot », somewhat chemically toxic (contains things like cadmium and mercury), and includes enough miscellaneous transuranic actinides to be deemed « transuranic » waste) as well.

- The natural mechanism apt to cause the greatest degree of actual leakage of radiation from the GCD to the biosphere during the next 10,000 years involves the gaseous transport of trivial amounts of gases (radon and tritiated water vapor) upwards to the earth's surface - not the leaching of anything down to an aquifer situated more than six hundred feet below the burial zone. Geoscientific research has shown conclusively that there is not now nor has there been for at least 600,000 years (through several comings/goings of glacial ice sheets over much of the USA) sufficient water at the NTS to make the leaching of materials buried at appropriate depths an important dispersal mechanism.

Conclusion: In a competently sited geological repository, the leach resistance of the waste form material itself is irrelevant.

- DOE-NV and SANDIA are so convinced of the validity of the GCD disposal concept that they have repeatedly and publicly advocated that it be seriously considered for the disposal of the DOE-complex's "orphan wastes"; i.e., wastes for which the existing set of assumptions/laws do not provide even "pretend" repositories like yesterday's Yucca Mountain (Bonano 1991).

How many boreholes would it take to make a competent repository for the INL's calcined reprocessing waste? If we assume that decision makers would not want to exceed the heat-loading of the "hottest" existing GCD borehole (three kilowatts) and also that the holes are the same size and depth as were the original ones, the number needed works out to be ~60 (see APPENDIX IX for a discussion of heat issues). The volume represented by the lower 50' sections of 60 individual, ten-foot-diameter, boreholes is 6660 m^3 – about the same as that of the concrete needed to "encapsulate" all existing ICPP waste.

What would such a repository cost US taxpayers? Sandia reported that each of the boreholes in its original GCD cost $20,000. If we apply a 5% inflation factor compounded for 38 years to sixty times $20,000, the cost of the proposed repository works out to $7.7 million dollars. That is approximately 0.4% of INL's current annual payroll cost.

Most of the reasons why an augered-shaft GCD repository would be "better" lie in the intrinsic nature of NTS alluvium. First, both because the soil in question is extremely dry and the little rain that does fall in « Area 5 » (about 10 cm/year) evaporates before it can reach a significant depth, convective transport of buried material is negligible. Diffusion, the only other natural process driving readionuclide migration, is vanishingly slow in vadose-zone (dry) soils possessing high ion-exchange capacity. Second, plant populations are very sparse, not of the varieties eaten by humans, and their roots don't go down 100 feet - so the food poisoning « what if » doesn't hold water either. Third, because the NTS's alluvium accumulations cannot support open fractures ("cracks"), any future tectonic activity in that area would have minimal consequences. [This is not a trivial point because it means that no hypothesized "crack" could channel water from a hypothesized future flood directly through the burial zone to the underlying aquifer – flood water would have to diffuse downwards uniformly. Vulnerability to hypothetical "failures" caused by hypothetical cracks is a fundamental weakness of brittle, hard stratified rock, repository sites such as Yucca Mt, which is what made it so difficult (and terribly expensive) to "prove" that it could work for either 10,000 years or « forever »[35]. Fourth, the vertical-shaft design of a GCD repository minimizes the footprint of the disposal system which means that the probability of inadvertent human intrusion is minimized relative to mined repositories. Fifth, the geologic setting of the NTS's alluvial plains is such that potential future change, natural or man-mae, would have little effect on overall system performance. Sixth, the thick alluvial deposits in question not only happen to be situated in the driest part of the USA's driest desert, they have also been thoroughly contaminated by about 925 nuclear "events," over 120 of which were deliberately set off above ground. If there is any other place within the United States that's apt to be considered by the average US citizen/taxpayer/voter as a better place for a nuclear garbage dump, my studies have not yet revealed it. Seventh, it is simpler and therefore safer to emplace a drum (canister) of waste straight down a shaft and then backfill it than it would be to emplace the same object into one of the maze-like configurations usually envisioned for engineered geological repositories. Eighth, and perhaps most important, unlike the situation with Yucca Mountain, a GCD repository has already been implemented and already performance-assessed with real waste.

It would be both cheap and easy to improve upon DOE-NV's original GCD. For example, since it happens to be situated where the water table is relatively shallow by NTS standards (780 feet down), it cannot be fairly characterized as the most "conservative" site therein. [The portion of Yucca Flats that Winograd proposed for the nation's TRU repository has a water table 2½ times deeper]. The existing GCD was not sited at Yucca Flats because the same hydrogeological features that make it the best place to site a GCD also made it the most "defensible" place for DOD/DOE to do underground nuclear testing – the overriding mission of the NTS (nobody pulls more political weight at the NTS than does the US military). Secondly, SANDIA's performance modeling indicates that it would probably be better to bury wastes somewhat deeper than that existing GCD’s 70'. Three decades ago, REECO engineers told me that the NTS possessed drilling rigs capable of drilling 12-foot diameter holes to depths exceeding 2000 feet (they were originally built to emplace big nuclear "devices" and test equipment). This means that waste forms could easily be buried at any depth considered optimal by Sandia’s performance assessment modeling experts [probably below the 30-meter figure that the NRC considered to be

[35] DOE’s trans scientific” YM modeling exercise never did (or could) succeed in “proving” that YM couldn’t “fail“ any more than you or I could prove that a meteorite couldn’t possibly take out Air Force One next Tuesday.

the lower bound of "near surface"][36]. Next, since competent waste forms would be buried instead of raw waste, the disposal system should be credited for the well-documented retardation/sequestration properties of the waste's matrix. [SANDIA allowed no "waste form credit" in its performance assessment of the existing GCD; i.e., modelers assumed that the waste is neither solidified nor contained within any engineered barrier]. Finally, it would be a very simple matter to pour a cementitious grout around and over the so-emplaced drums of waste before backfilling the holes. Doing so would meld the individual drums of concrete into huge monoliths having a much smaller surface:volume ratio to leach from and, more importantly, would provide enough chemical buffering to stabilize the entire system for millions of years.

As a concession to Nevadan's political sensibilities, I should point out that if the cluster(s) of boreholes constituting such a new repository were to be drilled over existing bomb "chimney(s)", the concrete caps that would be put over them to direct rainwater off to the side would also direct that same rainwater away from the unremediated radioactive waste (often including several kg of plutonium) left by the original "events". It is also worth noting that waste disposal would provide a new and worthwhile mission for the hundreds of Nevadan site workers who are probably wondering how they are going to support their families now that the USA's cold war-inspired bomb testing is over (I hope) and DOE's 15 billion dollar Yucca Mountain study has ended. Finally, I should mention that no European nation has any such easy choices to make regarding the siting of their radwaste repositories. No EU nation is blessed with such a large desertified region possessing the requisite hydrogeology and none have already contaminated large areas of their own soil with hundreds of nuclear blasts. The USA's decision makers ought to consider its Nevada Test Site (NTS) to be yet another of their country's unique natural assets and put it to productive use.

Radioactive waste disposal is a political (trans scientific), not technical, problem.

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[36] Most of the approximately 240,000 m^3 of radioactive waste buried in INL's "Radioactive Waste Management Complex" is covered with under one meter of soil.

APPENDIX XI. How «high» are DOE's high level wastes?

The absorption of ionizing radiation by anything generates heat energy within it. The safe dissipation of such heat is a key criterion in the design of nuclear equipment, waste form materials, and waste repositories.

According to the USA's Nuclear Regulatory commission (NUREG 2000)), in 2000 AD Hanford's ~55.5 million gallons (~210,000 m^3) of tanked reprocessing wastes had a total of about 5.92E+7 curies of ^{90}Sr and 5.43 E+7 Ci ^{137}Cs in them -these isotopes are such waste's primary heat producers. Since that waste has decayed for another 20 years and both isotopes have ~30 year half lives, it is now ~63% [0.5^(2020-2000)/30)] as hot as it was then meaning that it now contains about 178 Ci/m^3 of ^{90}Sr and 163 Ci/m^3 of ^{137}Cs. This means that Hanford's « high » level wastes are considerably less radioactive than the USA's Class C low level wastes (LLW) can be because the latter can contain up to 4600 Ci/m^3 ^{90}Sr or 7000 Ci/m^3 of ^{137}Cs.

Furthermore, because the decay of ^{90}Sr and ^{137}Cs generate about 7.8 and 5.6 milliwatts per curie respectively[37], the heat generated by Hanford's tank wastes is now ~2.2 watts per cubic meter. Since a burrowing mouse generates more heat than that, it should not be difficult to understand why it would now be perfectly safe to grout glass gem « aggregate » made from it, pump it back into Hanford's « best » (non leaking) waste tanks, and let it set up to form million-gallon concrete wasteforms.

According to INEEL/EXT-98-00455, Rev 4 (Calcined Waste Storage at the Idaho Nuclear Technology and Engineering Center - Google it), >99% of its radioactivity is due to the decay of roughly 2000 Ci/m^3 each of ^{90}Sr and ^{137}Cs. That translates to a heat generation rate per cubic meter of about 23.6 watts [(2000+2000)*3.7E+10*1.6E-19].

On the other hand, the concentrated first cycle raffinates going into a typical commercial fuel reprocessing plant's glass melter would have roughly one mole per liter of fission products in it. Assuming that 10% of those fission products still behave like ^{137}Cs and ^{90}Sr (haven't decayed yet), the heat generated by 1 cubic meter (1000 liters) of such HLW would be about 7058 watts

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[37] One Curie=3.7E+10 d/s and one ev = 1.6E-19 J therefore one Curie's worth of 1 MeV decay generates 3.7E+10*1E+6*1.6E-19 or 0.0059 J/s worth of heat.

[1000 l/m^3*1 mole/l*6.023E+23 atoms/mole)*1.6E-19 J/ev *1E+6ev/atom)**ln2/(3600*24*365*30*] - that's about 3500 thousand times « hotter » than is Hanford's HLW

decay/s = Bq = number of radioactive atoms**ln2/half life in seconds*

(where ln2=0.693)

See https://en.wikipedia.org/wiki/Radioactive_decay

APPENDIX XII. An example of how the nuclear industry's « experts » have misled us

"*A well-known lawyer, now a judge, once grouped witnesses into three classes: simple liars, damned liars, and experts. He did not mean that the expert uttered things which he knew to be untrue, but that by the emphasis which he laid on certain statements, and by what has been defined as a highly cultivated faculty of evasion, the effect was actually worse than if he had,*"

Unsigned letter to *Nature*, Thursday, November 26, 1885

The purpose of this APPENDIX's little rant is to demonstrate that understanding a procedure's technical details is important in determining whether what you are being told about it supports its presenter's contentions. I consider the behavior that it exemplefies to be evil because it undermines the credibility of our government's scientific institutions and missions.

During the time that INEEL served as DOE's lead radioactive waste management lab, the key criterion for evaluating candidate radioactive waste form materials was their performance on the «Product Consistency Test » (PCT). That test is performed as follows :

- the sample is shattered and then ground to a powder
- particles between 75 and 150 microns in diameter are isolated by running that powder through calibrated screens
- that size cut is subjected to a quick rinse with water or ethanol to rinse off fine dust after which it is dried (the hows of such rinsing was originally left to the discretion of the analyst)
- the rinsed/dried particles are weighed into into a Teflon or stainless steel « bomb » and 10 times as much deionized water is added
- The bomb is sealed and put into a 90°C oven for exactly one week
- Its contents (water leachate plus undissolved glass) are then filtered to isolate the liquid (leachate)

- That leachate is analyzed to determine the fraction of each of the sample's constituents solubilized (leached)

The pass/fail criterion for DOE's HLW glasses both then and now is whether a higher fraction of the sample's alkali metals (usually its most intrisically leachable/soluble major constituents) ends up in solution than does from a portion of its benchmark « Environmental Assessment » (EA) standard glass run through the same protocol. About 12% of EA glass's alkalies generally dissolve (EA glass is not a very durable glass – DOE sets itself « easy » standards).

The PCT is relatively quick/easy to perform and, <u>if</u> the sample in question is a glass (homogeneous frozen liquid), generates a genuinely meaningful result because everything within them is « released » at about the same concentration-normalized (fractional) rate; i.e., if 10% of the specimen's alkalies end up in solution, 10% of the radionuclides and chemical toxins have been «unsequestered» as well.

The rationale ginned up by DOE's experts to support its contention that « mineralized » steam reformer product would be « better than glass was that it is *«… primarily composed of nepheline (ideally* $NaAlSiO_4$*) and the sodalite family of minerals (ideally* $Na_8[AlSiO_4]_6(Cl)_2$ *which includes nosean (ideally* $Na_8[AlSiO_4]_6SO_4$*). Semi-volatile oxyanions such as* ReO_4^-*,* TcO_4^-*, are expected to replace sulfate in the larger cage structured nosean and halides such as* I^- *and* F^- *are expected to replace chlorine in the nosean-sodalite mineral structures – thereby immobilizing them.* »

In reality that's not the case. When INL's SBW simulants were «reformed» the majority of the stuff going into the « product » receivers was « fines » consisting of <10 micron-sized, poorly mineralized dust mixed with lampblack-like elemental carbon particles. X ray diffraction spectrometry (XRD), the technique utilized for characterizing the minerology of such things, is « blind » to much of that stuff because it's not very crystalline and XRD doesn't identify what's within its crystalline moiety (e.g. chlorine, ^{99}Tc, or sulfate) - only its structures (XRD is a qualitative not quantitative analytical method).

The PCT protocol's 's 75 micron lower particle size cut-off dictates that the analyst deliberately <u>not</u> test ~2/3's of what most such steam reforming's demonstrations actually produced – its relatively poor-performing fines product fraction. That fraction contained the bulk of the waste's intrinsically volatile constituents (e.g. cesium, iodine, chlorine, sulfur, technetium, cadmium, etc.) remaining in either of its solid products and also tends to be more water soluble (leachable) than the coarser sand-like bed product particles (Siemer 2005).

Furthermore, almost all of the solids produced by a steam reformer are multiphasic which means that their constituent elements are present in different forms exhibiting different characteristics - not dissolved within a homogeneous frozen liquid (glass). This, in turn, means that literal adherence to the formal PCT protocol is apt to generate wildly optimistic (misleading) results. For example, a quick water leach of either of the products of INEEL's (fines and its « grapenuts like » granular product) steam reforming demonstrations removes most of their chloride (Siemer 2005). Since the original version of ASTM C1285-02 (the one used during the crucial initial decision-making phase of the project) left sample powder-washing to the discretion of the analyst, an “official” test performed for the purpose of determining the leach rate of chloride could be done on material that no longer actually contained chloride – which, in turn, means that the final analysis’s apparently very low Cl^- result might be (and was) interpreted to mean that steam reforming had immobilized it within   a leach resistant tectosilicate mineral (sodalite, $Na_8Al_6Si_6O_{24}\,Cl_2$) . The same rationale supported claims that other tough-to-vitrify species (e.g. sulfur and ^{99}Tc) would end up within another leach resistant aluminosilicate « cage mineral » (nosean).

Additional deliberate confusion was generated by normalizing[38] the PCT’s raw “fraction leached” results to bogus surface areas.

For example, one gram of cubic, mid range-sized, 2.6 g/cc PCT sample particles (diameter = 0.01125 cm [0.015 +0.0075)/2]), would have a geometric surface area of ~205 cm^2 [6*0.01125^2/0.01125^3/2.6]. However, since a steam reformer’s solid products are intrinsically porous, their BET surface areas are far larger than their geometric surface areas[39].

In a typical such leach test that I’d performed myself (Siemer 2005), ~12.5% of the sodium in a 50:50 mix of INEEL’s pilot plant steam reformer’s fines & bed products dissolved. If that figure is normalized to its « geometric » surface area,   its leach rate in the usual units works out to   6.1 g/m^2/week [0.125/(205/10000 cm^2/m^2)], or about the same as that of DOE’s go/no-go standard « high level » EA glass. However, to make the steam reformer product’s granulated product fraction seem superior, DOE’s leach test experts at both SRS and Hanford decided to normalize fraction-leached PCT results to a “total” (BET) sample particle area[40] rather than upon the figure based upon particle size and density dictated by the PCT’s protocol (Pariezs 2005).

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[38]In science, “normalizing” often serves a useful purpose (e.g., pointing out that 50% of honest coin flips will come out “heads’) but is also done to deliberately obfuscate/confuse. I much prefer to see 100% of the real data & procedures in papers/reports - not just references to obscure, paywalled, “assumed”, or otherwise unavailable information. I/we can and should be able to do our own normalizing.

[39] The BET surface area of a 50-50 by weight mix of the as-generated fines and bed products produced during the “optimized” demonstration described in APPENDIX IV was $83 m^2/g$. The samples subsequently characterized by SRS were first subjected to an overnight “cook” at 500°C which would almost certainly serve to reduce BET-type surface areas as well as burn off the “coal”. Nevertheless, they still exhibited BET surface areas over a hundred times greater than would the same screen-sized glass particles.

[40] The BET measures the amount of an inert gas condensing upon on a powdered sample at a temperature near the boiling point of that gas. The amount so condensed is measured by the pressure reduction within the system when sample is introduced. All open pores, inclusions, irregularities, etc., penetrable by the inert gas (usually nitrogen) are

Reporting such « normalized » results made that stuff appear to be >100 times more leach resistant than DOE's benchmark glass and therefore gave great reassurance to those analysts' decision-maker customers. However, it's also transparently(?) silly because any material possessing a surface area/gram greater than about 1640 cm^2/g (205*1/0.125) could totally dissolve during the PCT and still be characterized as "better than glass" (this little technical detail was never pointed out by the DOE Complex PhDs writing such reports[41]).

Even more important, it is unreasonable to characterize a "mineralized" (or any other) calcine as superior to glass (or even to a properly-made concrete) based solely on PCT results – even results obtained with a "conservative" version of that test (Siemer 2005). The reason for this is that glass is intrinsically monolithic and calcine is intrinsically dust-like. Since real world leaching occurs at « outside » surfaces, the surface area of the *intact* waste form is what would count in a repository. For example, a one million-gram glass monolith (smaller than most real or proposed US glass waste forms) possesses a geometric surface area of about 3 m^2. Its "real" surface area isn't much greater than that because glass is basically just a non-porous super-viscous liquid (Wesson 1983). About one gram (exact amount depends upon how its area is measured) of INEEL's mineralized FBSR test products possessed that much surface area.

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accounted for which means that anything that's intrinsically porous (e.g., charcoal, silica gel, or FBSR calcines) exhibits a far larger BET than geometric surface area.

[41] A reason for this was identified by Upton Sinclair about a century ago: "*It is difficult to get a man to understand something, when his salary depends upon his not understanding it*"

APPENDIX XIII. Example of a promising concept that needs experimental verification as soon as possible

The data in Table 9 (below) is excerpted from ORNL 2751 (Alexander 1959). Its numbers were based upon calculations performed with a 31-group, multiregion, spherically symmetric, diffusion code UNlVAC program named “OCUSOL”. Group-averaged cross sections for the elements of interest were based upon then-available data. Where such data were lacking, reasonable interpolations based upon resonance theory were used. Estimated neutron reaction cross sections were made to agree with measured resonance integrals where available and saturations and Doppler broadening of thorium’s resonances as a function of concentration were estimated.

Table 18 ORNL 2751’s Case 35 Spherical “clean core” two salt thorium breeder

Core diameter ft	3.0	Neutron absorption ratios continued	
Mole% ThF_4 in fuel salt	0	Core vessel**	0.0902
Mole% ^{233}U in fuel salt	0.592	L i and F in blanket salt	0.0233
^{233}U atoms/cc of fuel salt x10^19	21.1	Thorium in blanket salt	0.9722
Neutron absorption ratios*		Leakage***	0.0477
^{233}U(fissions)	0.8754	Core volume	400 liters
^{233}U capture (n,y)	0.1246	Regeneration ratio	0.9722
Be, Li, and F in fuel salt	0.0639		
*ORNL assumed 2.1973 neutrons/fission (=’s a total absorbed per neutron absorbed by ^{233}U)			
**ORNL assumed a one-third inch thick INOR 8 core tank			
***ORNL assumed a two foot-thick, 25 mole% ThF_4/75mole% ^7Li F, blanket salt			

The reasons why tests investigating the conclusions of this particular set of ORNL’s calculations should receive immediate attention include:

• If Weinberg’s team was right, then the full-sized tube-in-shell concept that I’ve described (Figure 63) is likely to behave as predicted and therefore represent the “best”(quickest) way to implement a sustainable nuclear renaissance

- It would be a relatively cheap system to both build and operate (much cheaper/simpler than any sort of solid-fueled test reactor)[42]

- Its operation would enable the generation of real data[43] relevant to every aspect of both building and operating breeding-capable MSRs

- Systems like it could be readily scaled up by substituting one or more cylindrical cores for the single spherical core contained within its big blanket salt tank

- Reprocessing (fuel cleanup/recycle) would be simple/cheap because neither its core (fuel) or banket salt wouldn't contain much of anything either that's either nasty (gases, « heavy TRU isotopes, or salt soluble/stable FP) or valuable (U's isotopes). By either sparging or distillation both of which technologies were subsequently successfully demonstrated by ORNL's then-unfettered technical nerds.

The reasons why it should be at least as capable as ORNL's modelers predicted include:

- It seems that ORNL underestimated the number of neutrons generated per ^{233}U fission (i.e. >2.3 rather than 2.2) which would boost Table 9's predicted CR (0.9722) to well over 1.0 (Uranium 233, 2019)

- There's no compelling reason to assume that a 3 foot diameter core tank immersed in a blanket salt would would have to be one-third inch thick – a thinner core tank wall would also boost CR

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[42] For instance, its core would require only about 32.6 kg [400 liters*1000 cc/liter*21.1E+19/6.023E+23*0.233] of ^{233}U fissile to achieve criticality (operate). Depending upon how much heat is to be generated/dissipated during its testing, that figure would be somewhat bigger. For example, if we assume that 9 cubic meters of outside core volume is sufficient to remove 3 GWt (the figures estimated for the EU's MSFR), a 50 MW test reactor would require 150 liters of additional core salt boosting its total fissile requirement to 45.6 kg. Similarly the Hastelloy N "supermetal" required to make a three foot diameter, one quarter inch thick spherical core tank would weigh about 637 kg and cost about $16,000 (see https://www.alibaba.com/showroom/hastelloy-n.html). If 316 stainless steel (SS) were to be substituted for it instead, its core tank would cost about one fifth that much. With proper redox control, 316 SS would probably last for at least a year or so.

[43] Its salt streams would provide something real for the folks working out any fluoride salt MSR concept's fuel clean up and waste management schemes to do their experiments with. Its behavior would provide updated neutronics data enabling better prediction of that of a full-sized system. Finally, realistic corrosion/neutron damage rate data would be generated – almost 100% of the recent MSR-relevant materials corrosion testing has been done "cold" (no neutrons) with pure salts containing no fission product surrogates.

- There's also no compelling reason why the blanket salt tank couldn't be considerably bigger which would reduce neutron leakage and therefore, again, boost CR.

APPENDIX XIV. INL's steam reforming process

During the 1990's, a Swedish firm, STUDSVIK, developed a process to "burn" the organic wastes generated by civilian nuclear fuel cycles (mostly the ion exchange resins utilized to purify LWR coolant water) in a way that avoided the negative connotations that had come to be associated with "incineration"[44]. It utilized superheated steam (hence "steam reforming") to decompose such materials to simpler molecules (methane, hydrogen, carbon monoxide, etc.) under the conditions developed for converting "biomass" to gaseous fuels and methane to hydrogen. When it became apparent that US DOE wanted a substitute for calcination too, the "same" (?) process was suddenly construed to be the "best" way to treat salt-type wastes as well. Consequently, in 2002 Studsvik joined with Westinghouse Government Environmental Services Company LLC to form a new company, THOR Treatment Technologies to further develop, promote and deploy that technology (see THOR no date).

The resulting fluidized bed steam reformation(FBSR) process possessed four key virtues: 1) its "Denitration and Mineralization Steam Reformer" (DMR) would not directly oxidize organic components of such waste streams with elemental oxygen, hence it's not waste "incineration" (real DOE tank wastes contain little or no organic matter & therefore can't be "incinerated"); 2) since the immediate solid products produced under its strongly reducing (fuel>>oxygen)

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[44]. By circa 2000 DOE's gutless decision makers had buckled under to its anti nuke, anti anything, critics and promised that it would no longer "incinerate" wastes. Incineration (burning) was then and is still the best way to convert anything s "organic" (burnable) to a harmless, low volume, ash along with innocuous gases. The best way to do it with anything that's not too radioactive is to substitute that waste for some of the coal or oil heating a cement plant's rotary kiln. However, to enhance "productivity" & avoid over-regulation hassles most of the incineration currently being done is with relatively small purpose-built systems that don't burn garbage nearly as cleanly (see APPENDIX XVI for an example of an especially timely application). Sweden, Norway, Switzerland and several other countries require burning of trash. Two reasons: (1) contains soaps and other chemicals that solubilize heavy metals and other nasty materials into groundwater and (2) lots of toxic materials from old medicines to who knows what. Those countries have lots of granite so it is much easier to contaminate groundwater. They do get a lot of energy from trash burning. Oslo burns a lot of trash from the U.K., getting paid to heat Oslo in the winter or produce electricity and sell back to those dumb Europeans. Any timeframe over a few decades, burial will begin to release methane. All of those trash plants systems have state of the art scrubbers so no air pollution-
+++ (Chas Forsberg).

There is the option to gasify and convert to liquid fuels. If tax on fossil fuels, that may occur.

reaction conditions were mostly carbonates, not oxides, it wasn't "calcination" either[45]; 3) since alkali nitrate salts should decompose under such conditions (eventually anyway), it's supposed to prevent bed agglomeration and simultaneously eliminate the offensive giant plume of NOx emitted by INEEL's traditional approach to radwaste calcination (the same things that sugar calcination would have accomplished); 4) the inclusion of powdered clay along with the solid fuel granules[46] employed to provide reaction heat[47], serve as a reductant, and generate a clean-burning[48] intermediate offgas, was supposed to convert SBW to a poorly soluble "Grapenuts-like" mineralized product purported to be a "better than glass" disposal form; and 5), several of the especially troublesome (to glass makers) anionic components of DOE's salt wastes (e.g., sulfate and chloride) were also supposed to be simultaneously sequestered within leach resistant aluminosilicate "cage minerals".

The following pages (smaller font) are excerpted from a report that I wrote/presented in 2004 describing experiments performed to determine whether the product(s) of a local "demonstration" of THORT's technology could be rendered "nondispersable" with cements (Siemer, Grutzeck, and Scheetz 2004). There's an error in its second footnote: I subsequently discovered that THOR's "open access" technical reports had misrepresented both its subcontractor's (HAZEN's) experimental system (process) and its products – fines apparently were never successfully 100% recycled and thereby just one, "grapenuts like" product produced as claimed.

During Dec. 2001 several tests of Studsvik's "mineralization" process were performed by Hazen Research, Inc, of Golden CO. 570 liters of a concentrated (~44% solids) aqueous salt solution representing a typical "low level" Hanford tank waste were processed in a six-inch diameter reactor. The primary component of this simulant was ~ 8 molar sodium ion balanced by (in order of decreasing concentration) hydroxide, nitrate, carbonate, nitrite, carbonate, aluminate,

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[45] This is another example of something being characterized in terms of what it's not rather than in terms of what it is. Reforming is nicer-sounding too – Norway "reforms" its murderers instead of "frying" (incinerating"?) them in electric chairs.

[46] (coal, charcoal, etc. – use of a solid fuel/reductant constitutes the "novel" feature of THOR's patent)

[47] Sufficient oxygen was added to burn enough of the coal (but certainly not all of it) to keep the DMR's reactor hot enough to function.

[48] The final version of THORT's steam reformer (THOR no date) differs in how its DMR's off gas is burned. After most of the dust is removed via cyclones & blow back filters and sent to a "product" container, the DMR's gaseous products (mostly steam along with nitrogen and combustible hydrogen, ammonia, carbon monoxide, hydrogen, cyanogen, etc.) passes into a second even hotter (~1000°C) "Carbon Reduction Reformer" (CRR - another fluidized bed reactor) to which sufficient additional oxygen is added to burn it to a mixture mostly comprised of elemental nitrogen, excess oxygen, carbon dioxide, and water vapor.

sulfate, fluoride, phosphate, and chloride. It also contained lesser amounts of several other metals plus about 80 grams per liter of an assortment of the organic chelating agents used in Hanfords' processes. The reactor's alumina bed particles were fluidized with superheated steam and ground coal was added to create a strongly reducing environment. Sufficient kaolin (nominally Al_2O_3. $2SiO_2$. $2H_2O$) and powdered quartz (SiO_2) were slurried with the waste simulant to produce a product with roughly the same gross composition as nepheline, $NaAlSiO_4$. Samples of it were submitted to the Savannah River Technology Center which subsequently issued a report supporting Studsvik's claims and recommending that DOE pursue the technology.

component	g/l	molarity
Al	19.5	7.22E-01
H+	2.9	2.90E+00
Ca	2.95	7.38E-02
Na	47.8	2.08E+00
K	8.59	2.20E-01
Fe	1.51	2.70E-02
NO3	417	6.73E+00
SO4	17.5	1.82E-01
lead	0.234	1.13E-03
Cd	0.449	4.01E-03
Hg	1.18	5.76E-03
137Cs	8.32E-04	6.07E-06
90Sr	3.53E-04	3.92E-06
239Pu	8.04E-06	3.36E-08
235U	0.0384	0.000163

Table 1: INEEL tank WN 180 SBW simulant

In January 2003, a demonstration of how it could deal with a representative INEEL liquid SBW (Table 1) was performed at the Science Applications International Corporation (SAIC) Science and Technology Application Research (STAR) center located at Idaho Falls, Idaho. This test was performed under conditions mutually agreed upon by THOR and INEEL personnel and, while it was subsequently deemed "successful", it was also agreed that there was a good deal of room for improvement. Consequently, in November 2003 a two week-long "optimization run" was run at the same facility. This paper describes what was produced while the reactor was being run with a mineralization flowsheet (i.e., with clay added to the SBW) and how cementitious technologies could convert this material into a superior waste form.

Experimental: Figure 1 depicts the FBSR reactor used for SAIC/INEEL's most recent FBSR test. It basically consists of a 30-inch length of six-inch internal diameter pipe reaction zone situated under a five foot-long, expanded (12 inch diameter) particle disengaging (or "freeboard") zone. Both sections are made of an especially corrosion resistant INCONEL alloy. Table II lists typical operating conditions. One of the reactor's two feed streams consisted of an aqueous slurry comprised of various proportions of sugar-syrup with Table I's SBW simulant plus kaolin.

This cream-like slurry was sprayed into the lower end of the reaction zone with a pneumatic nebulizer utilizing nitrogen as the motive gas. The other feed stream consisted of coarse granules of activated charcoal plus occasion additions of an iron oxide "de-NOX catalyst". The external surfaces of the reactor & its disengaging head were covered with clam-shell electrical heaters. A distributor plate situated immediately above the flat bottom of the reaction zone introduced superheated steam which served both to fluidize the bed particles and provide a portion of the heat required for the strongly endothermic "reforming" reactions. Any additional heat required to maintain the system at the desired temperature was provided by "reforming" elemental oxygen added to this steam. A cyclone served as the primary collection system for the "fines" (comprised of small particles of the reactor's product plus elemental carbon dust) elutriated from the reactor. A screw auger continuously recycled that dust back into the base of the reactor[49]. Particles too small to be captured by the cyclone were collected by a bank of sintered metal blow-back filters situated within a cyclone-shaped housing. This portion of the reactor's "fines" plus the material that's retained within the bed ("bed product") constitute its product streams[50].

Typical FBSR reaction conditions

- Gases: 7 kg/hr steam + 3 kg/hr N_2+1 kg/hr. O_2
- Liquid Feed: 4.5 kg/hr SBW/clay slurry[51]* + 3 kg/hr of 55wt% sucrose syrup
- Solid Feed: varying amounts of coarse activated charcoal** + occasional additions of FeO_x
- Temperature: ~720°C

Filtered offgas was diluted with propane plus excess air and passed into a ceramic-lined thermal oxidizer large enough to provide a mean gas residence time of approximately one second at 1000°C. After the temperature of the burner's offgas was lowered to roughly 300°C by spraying water into it, it was sucked through a venturi scrubber into the scrub tank. The quenched/scrubbed gas exiting that tank was passed through a demister, reheated to roughly 120°C to prevent condensation, sucked through a three-stage bed of activated charcoal, and, finally, blown through HEPA filters to the stack.

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[49] Occasionally this auger would be reversed in order to collect samples of the cyclone catch.

[50] The fact that this portion of the reactor's fines was not recycled to the reaction zone constitutes the most significant difference between the HAZEN and SAIC/INEEL tests – HAZEN produced only a "bed" product.

[51] 290 grams of kaolin were added per liter of SBW: this much clay increases the volume of the liquid by 10% and its SpG from ~1.25 to ~1.38. The sugar feed rate varied considerably but was always well in excess of that required for stoichiometric reduction of nitrate to elemental nitrogen.

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Since the primary purpose of this paper is to discuss "monolithification" of the reactor's product, its description of how the "reformer" itself performed will be limited to the following observations:

1. The processing of sufficient SBW/clay slurry (498 kg) to generate 126 kg of mineralized product produced a total of approximately 74 kg of "fines product", 3.6 kg of cyclone dust samples, and 44 kg of "bed product"[52]
2. On-the-fly samples of both products during the run generally contained a substantial amounts of elemental carbon (dust in the fines fraction, 1-5 cm chunks in bed samples) – the amounts of "product" carbon depended upon the feed rate of activated charcoal to the reactor
3. Bed product samples generally contained mineralized agglomerates[53] which tended to grow larger and more numerous as the run continued
4. On two (three?) occasions those agglomerates grew large enough to cause bed defluidization which immediately shut the process down
5. Regardless of charcoal feed rate, "on the fly" samples of either solid product fraction never contained more than 0.1% residual nitrate (or nitrite) – generally none at all

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[52] This figure (44 kg) does not count the ~52 kg of ~0.5 mm-diameter, sintered alumina "starting bed" charged to the reactor on two separate occasions.

[53] The water solubility and carbonate concentration of these lumps (both low) were similar to those of the non agglomerated bed material

6. Offgas samples taken upstream of the offgas burner generally contained several thousand ppm (by volume) ammonia plus readily detectable concentrations of HCN. The ammonia concentration correlated directly with charcoal feed rate[54]
7. Total NO_x (NO_2+NO) concentrations at the same point was generally somewhat higher than that of ammonia and inversely related to charcoal feed rate
8. The scrub liquor was always strongly acidic – pH generally less than 2.5 – and contained very high concentrations of sulfate, phosphate, chloride, and cesium relative to iron, sodium, aluminum, etc.

These observations support the following conclusions:

1. FBSR tends to volatilize more of a radwaste's semi-volatile components than does rotary kiln calcination
2. FBSR's lessened NO_x production comes at the price of producing much more of such reduced nitrogenous species as ammonia and hydrogen cyanide – any kind of calciner is going to need subsequent offgas treatment!
3. There's little evidence that the "sodalite-like" cage minerals purported to immobilize anions such as chloride actually formed

FBSR product characteristics: The following is based upon analyses of samples of what was in the two drums into which filter fines and bed products were dumped throughout the duration of the test.

- Ten-minute exposure of either powder to 100-fold as much 90°C water solubilized only a small fraction of the sodium - about 20% of that in the fines fraction, about 4% of that in bed product. This suggests that FBSR does indeed "mineralize" most of the sodium.
- The primary cation present in water leachates was sodium balanced by an equivalent amount of (in order of concentration) aluminate, carbonate (in fines, not bed), phosphate, sulfate, chloride, silicate, and fluoride ions.
- The bulk density of the filter fines product fraction was about 0.35g/cc[55] - that of the bed product, ~ 0.8 g/cc.
- Several intrinsically volatile components of the SBW simulant – rhenium (technetium surrogate), cesium, chloride, sulfate, and phosphate – were present at much higher (several times as high) concentrations in the filter fines product fraction than in the bed product

[54] The reasons for this are 1) fluidized bed reactors require higher gas flow rates; 2) the temperature required to make "water gas" are two hundred degrees higher than is required to efficiently sugar calcine radwaste; and 3) the vapor pressure of a molten metal is generally greater than that of its oxide

[55] The bulk density of a powder is not an absolute number because the result depends upon its degree of consolidation (settling) before its volume is measured. The figures given in this paper were obtained by dumping powder into a tared 10 cc glass graduated cylinder, tapping it for about 30 seconds, and then measuring its mass and volume. That much tapping typically reduces the volume of a dumped "fines" sample by about 50%

- The sum of all of sulfur-bearing species (sulfate, sulfite, and sulfide) found in both product fractions (plus the scrub liquor) accounted for less than one-third of the sulfate-sulfur fed to the reactor
- The loss-on-ignition (primarily elemental carbon) of the final bed product composite was ~4.5% vs ~15 wt% in the filter fines drum
- There was under 1 ppm of either ammonium or cyanide ion in either product
- Hot water would dissolve the same amount of chloride from either product fraction as would high temperature fusions performed with NaOH or Na_2CO_3

The overall degree of "volume reduction" achieved by "reforming" this SBW was not very impressive. For example, if we assume that …

1) a total of 385 grams of mineralized product is produced per liter of SBW
2) the mass-wise proportions of bed and fines products is 40:60
3) "Bed" is 5 wt% carbon &" fines" is 15% carbon
4) the bulk density of these fractions are 0.8 and 0.35 g/cc

a reasonable estimate of the volume of calcine generated from one liter of SBW would be …

$$((0.6x385)/0.85)/0.35 + ((0.4x385/0.95)/0.8 = 979 \text{ cm}^3$$

To a "grout" chemist, both product fractions were excellent from a purely chemical point of view and rather poor from a physical standpoint. "Good" because a nepheline-like mineral assemblage is chemically compatible with silicate-based cements. "Poor" because their low bulk densities and high BET surface areas causes them to exhibit high "water demand" (fines more so than bed). In practical terms, this means that a large amount of liquid is required to produce a grout that would flow well enough to readily fill a mold (waste canister). Since the total pore volume of fully-cured grout (concrete) approximates that of the water in the original formulation, this in turn, means that high water demand translates to a physically weak, porous, concrete. It also translates to low waste loading, both weight and volume-wise.

Due to time and funding constraints, only four fundamentally different types of grout were investigated and the total number of specimens produced was twenty-one. The waste simulant in these specimens generally consisted of a 50:50 weight-wise mix of bed and filter fines. Similarly, the weight-wise percentage waste loading was also usually 50% (i.e., the mass of dry cementitious agent(s) equaled that of the calcine).

Etc., etc

A comparison of the observations that others made during this demonstration (also see Soelberg et al, 2004) with how THOR's reports characterized it (see THOR no date) differ in many ways, the most important of which (to me anyway) is that THOR doesn't bother to mention that only about one third of the waste surrogate's primary ash forming constituents (sodium, aluminum, etc.) ended up in its much ballyhooed mineralized "grapenuts-like" product – the majority ended up as fines. They also don't reveal that much of the surrogate SBW's intrinsically volatile stuff (e.g., rhenium (^{99}Tc surrogate), chlorine, and sulfur) didn't end up in either solid product – such things were mostly converted to gases, not sequestered within durable "cage minerals" as THOR's DOE-Complex "helpers" often suggested. More importantly (to me anyway), the reports written by the national laboratory personnel that chose to "help" THOR didn't point those things out either.

To date (4April2019), the roughly one billion dollars subsequently spent by INL's clean-up contractors on its steam reformer hasn't yet succeeded in converting any of its remaining SBW to either a "carbonate" or "mineralized" product. The problem seems to be the same one that plagued us during the "demonstrations" performed at INEEL's STAR center almost two decades ago, fluidized bed agglomeration and "bark" formation. The chunky-stuff accumulations holding things up are probably comprised of the DMR's fluidized bed particles glued together with waste surrogate-derived sodium/potassium carbonate. The much higher temperatures (~700°C) required to denitrate such waste with THOR's proprietary solid reductants rather than with a water-soluble reductant (sugar's ~500°C) are responsible for this. A reductant like sugar is intimately mixed with what it's to reduce (the liquid waste's nitrate ions), not within an entirely separate phase, and therefore can completely react at temperatures well below those likely to melt/fuse the "carbonate product".

APPENDIX XII describes one of the approaches used to sell steam reforming to DOE's stakeholders.

APPENDIX XV. A solution to plastics pollution

There's currently a tremendous amount of handwringing going on about how plastic pollution is destroying the environment (especially the oceans) and that we're not really doing anything about it.

Let's look at this "terribly difficult problem" the way that a technically savvy environmentalist (or decision maker) should.

First of all, today's glut of plastics is the result of how cheap it is to make it, buy, and use as an industrial material—in part because of the subsidies that have long been granted to the fossil fuel industry.

Recycling is not the solution. Only ~9% of all plastic produced gets recycled—and that number is likely an overestimation. One reason for this is political : plastic waste exported from the country where it was discarded counts as "recycled," regardless of its actual fate. Another is that virgin plastic is so cheap that there is no financial incentive for most companies to use recycled plastic in their products. At the local level, almost 100% of the communities that have « committed » to recycling some (never all) of the plastics discarded therein have discovered that it was cheaper to to dispose of it as garbage (usually via land fill) than to recycle it and consequently do so. In short, plastic recycling is a myth and always has been.

Hand-wringing, bitching, (see Why Bioplastics Will Not Solve the World's Plastics Problem - Yale E360) & begging for contributions to support noble causes won't solve it either.

Total world plastic production is currently about 380 million tonnes per year, approximately one tenth of which (~40 million tonnes) is the relatively tough-to-burn chlorinated plastics - mostly polyvinyl chloride (PVC) [https://en.wikipedia.org/wiki/Polyvinyl_chloride]

In 1975/1976 the Canadian government conducted a large scale chlorinated hydrocarbon (including PVC plastic) incineration demonstration at the St Lawrence Cement Co in Missaugua, Ontario ("Burning Waste Chlorinated Hydrocarbons in a Cement Kiln", a GOOGLABLE 1978 EPA report]). The test materials contained up to 46wt% chlorine and chlorine feedrates varied from 0 to 0.8wt% total Cl/total clinker. They were destroyed with >99.98% efficiency and no high molecular wt. chlorocarbons (e.g. dioxins) were detected in the off gas. That should be expected in view of the reaction conditions (strongly oxidizing , temperature >1300°C, ~20 second gas residence times and lots of "free" lime). The amount of kiln dust produced – mostly a mix of sodium and potassium chloride salts often used as fertilizer – increased in stoichiometric proportion to the amount of chlorine fed to the kiln[1]. Burning the waste reduced the amount of fossil fuel required to make clinker and improved its quality because less alkali had been retained.

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[1]The reason for this is that sodium and potassium chlorides have boiling points about 500 centigrade degrees lower than that of calcium chloride.

Its tests were simple to perform because that kiln was fitted with an off-the-shelf feed system enabling worn-out rubber car/truck tires to be dumped into the middle of its slowly rotating kiln tube upon each revolution. These feed systems can feed anything burnable that's been baled up into tire-sized chunks.

Global cement production is now about 4 billion tonnes [https://en.wikipedia.org/wiki/Cement]. A typical Portland cement is about 62 wt% CaO (molecular wt (MW)=56 g/mole) meaning that the limestone calcined to produce it contained about 1.95 billion tonnes [4*1E+9*0.62*44/56] of carbon dioxide (MW=44 g/mole) all of which was dumped into the atmosphere. A typical large, wet process rotary cement kiln, fitted with drying-zone heat exchangers, produces about 1000 tonnes of clinker per day and burns 0.25–0.30 tonnes of coal fuel per tonne of product clinker to do so.

Assuming the highest carbon, highest heating value, coal (anthracite -~100% C, ~33 MJ/kg heating value) the amount of its burned to satisfy the world's current cement demand would be ~1 billion tonnes [0.25*4E+9] the combustion of which would generate 3.67 (1.0*44/12) billion tonnes of CO_2 which is dumped into the atmosphere.

Most plastics exhibit about the same heating value as crude oil (~ 42 MJ/kg) meaning that if 100% of the plastics made/consumed per year were to be burned in the world's cement kilns rather than dumped into oceans or landfills, the amount of coal burned to make cement would be reduced by nearly 50% (380 billion/1000 billion *42 MJ/kg /33 MJ/kg = 0.485 billion tonnes). Because plastic has a somewhat higher heating value per carbon atom than coal, that substitution would also reduce the total amount of CO_2 generated/dumped per tonne of cement.

What makes plastic recycle difficult/expensive is the effort required to isolate discarded plastic items from garbage, sort them into the right categories, and then clean them up. On the other hand, it's easy/cheap to simply bale up a waste's combustibles. A cement kiln can be fueled with almost anything that's combustible, doesn't care about how clean it is, and many of them are already outfitted with tire feeders capable of feeding baled-up anything.

What's so tough about addressing plastic pollution other than our all-too "human nature"?

Plastics are one of civilization's great inventions, not of one its big problems. We need to properly deal with them - not ban them. Proposed substitute plastics made from crops like maize, wood, or sugarcane instead of fossil fuels are considered sustainable because plants bind CO_2 which compensates for the carbon released into the atmosphere when those plastics are disposed of. However, with increasing demand for raw materials for bioplastic production, the areas currently under cultivation may not be sufficient meaning that more of the world's natural forests would be cut down or burned. This in turn releases large amounts of CO_2. The fact that more bioplastics won't necessarily lead to more climate protection has now been confirmed by researchers at the University of Bonn, Germany (Escobar & Britz 2021).

I propose that every good-sized city should have an old fashioned slurry-fed cement plant nearby to burn its combustible wastes, esp plastics. They represent the best possible "incinerator" (see this book's APPENDIX XV) while simultaneously generating a useful product and industrial/residential heating service. After "peak oil" really does set in, we're going to have to pave our roads and runways with aggregates bound together with cement, not asphalt.

Discarded aluminum cans pretty much disappeared as soon we decide to pay people a few cents to pick 'em up * deliver them to collection points. Let's do that with cement kiln fuels too.

(posted on https://www.facebook.com/PlasticPollution/ 3/19/2021)) disappeared by the next day without reason or comment.

APPENDIX XVI. Statement from someone brought in (too late) to try to straighten-out INEL's Naval fuel

reprocessing boondoggle (Names deleted)

"I don't remember or know what may or may not have been promised to the Admirals. I also do not contend that the bureaucracy (both DOE and predecessors and the Chem Plant management) did not promote unknown or unproven technologies as being turnkey. The new FDP plant was built and designed for reasons that cannot be fully revealed because of classification aspects. That is why "even I can't reveal that our system didn't work as we had promised". The original Chem Plant developers, the secretive XXXXX XXXXXX and XXX XXXXX did not appreciate that the old efficient E-cell process could not be translated directly to the FDP. Their early process didn't work. At the time, it was widely perceived in the Complex that we had another Rocky Flats fiasco. That was when I was brought in to do address the problems. Being totally ignorant of all the classified stuff, I was not biased to any existing chemistry and started from scratch to develop it for the specific fuel. Yes, we did have to shoe horn some of it into the existing equipment. If I could reveal classified stuff to you, I could explain clearly to you how well the process actually worked in the end, though differently than may have originally been promised. And, as I've explained, our advanced process that may be implemented is an order of magnitude improved. Don't know why that was not looked at originally. This Zircex process was developed in the 1960s for naval fuels. This was, of course, subsequent to building the E-Cell process that started up in 1953. I guess that the new Fluorinel plant design was just doing more of what they had experience with. We now recognize the great benefits of Zircex.

One contributor to the bloating costs that changed from the old E-cell days and after we started the FDP process was the rapidly exploding regulatory, QA, safety and security organizations that increased our staff and operating budget greatly. Also, as previously mentioned, the HLW quantities and management costs were substantial. Yes, this was a factor in the shutdown process. However, criticism of the technical aspects of the process, itself, other than some deficiencies in the original plant design, for example, a single PTV, though you may perceive as bad, *is not warranted. Again, if we could have a sit down full discussion of the classified aspects, you would understand.*

Your general criticism of the government bureaucracy is valid. Attempting to dredge up a four decades ago decision, IN ABSENCE OF SPECIFIC CLASSIFIED FACTS, is treading on thin ice. It leads to incorrect suppositions. Better to focus on more recent and currently on-going fiascos such as the IWTU (misnomer, because the original plan to yank out the steam reforming vessels and install hipping for calcine, thus "Integrated", could not have been physically accomplished). And, of course, the Hanford Vit Plant and process makes IWTU look like kindergarten. Yes, goal line shifting is a perfected art!"

APPENDIX XVII. Some educated guesses about US Naval reactor fuel

The demise of DOE/INEL's Naval fuel reprocessing project marked the end of its "Chem Plant's" constructive era – its next three decades were devoted to "decommissioning" and «waste management" boondoggling.

The reason for that project's fate was that its newly built fuel dissolution system did not function nearly as quickly or efficiently as "promised" resulting in that project's cost/benefit ratio rising to a point deemed unacceptable to decision makers in light of the fact that the USSR's collapse had lowered the value of « second hand » fissile.

Because the "Chem Plant" had previously successfully reprocessed a good deal of more or less conventional PWR fuel, it's highly likely that its new dissolution facility's issues were due to differences between such fuels not considered by its designers.

While virtually everything about the Navy's reactor fuels remains a closely guarded secret, enough is known about them to hazard some educated guesses about what those technical issues might have been.

To begin with, what isn't a secret is that Admiral Rickover decided that his reactors would be PWRs fueled with highly enriched uranium imbedded one way or another in zirconium.

Conventional PWR reactor fuel consists of roughly 8 mm diameter 2 cm long cylindrical pellets of a brittle UO_2 ceramic tightly encased within ~ 3 meter long, thin-walled zirconium tubes. The navy's fuel is different because its needs are different – its reactors must be much more compact and their fuel must last much longer; e.g., >30 vs 2-3 years. It also differs in that the US military isn't bound by the Nuclear Non-Proliferation Treaty's rules and can spend as much money on fuel as its leaders wishe, hence its use of HEU instead of low enriched uranium (LEU).

There's been a good deal speculation about that fuel's makeup largely driven by the fact that other countries' naval reactors seem to operate perfectly well with LEU (<20%^{235}U- not « weapons grade ») uranium-based fuel.

The following speculations are based upon four reports GOOGLED -up 8/22/19. One is a MIT master's thesis from (McCord 2014), another is a Russian report describing another "advanced" fuel being developed for its PWRs (Fedik 2004), and two are US written/published having to do with proposals to fuel US Naval reactors with LEU (Ma & Hipple 2001 & Haghighat 2015)

Current naval fuel, while classified, is widely believed to be a 'cermet' design, meaning that it is a combined metal-ceramic dispersion material. In this case the metal is zirconium and the ceramic is almost surely uranium dioxide, UO_2. The fuel pellets are likely manufactured by mixing powdered zirconium and tiny, somewhat porous UO_2 particles together, hot pressing them to form cylindrical pellets, which are then sealed within zirconium (Zircalloy) tubes. I also suspect that those tubes are plated (or alloyed) with the mysterious metal about which no one at INL could speak to render them more corrosion resistant.

Here are some facts(?) gleaned from the aforementioned references along with some ball park guesses based upon them about what they might mean.

A Los Angeles class nuclear submarine possesses a 130 MWt reactor that supposedly runs for an average of about 6 months per year during which time its averaged output is about 25% of its maximum rating. Its reactor's initial fuel loading is also supposed to last for its entire lifetime, 33 years.

Some of Russia's icebreakers are similarly powered (135 MWt) with PWRs about which more details have been revealed. One fact in particular is that the "smear density" (grams of uranium/cc fuel) of their fuel is 4.5 g/cc.

Total energy generated by LA-class sub's fuel = 135E+6*3600 s/hr*24 hr/d*365 d/yr*6/12*.25=1.69E+16 J

Which requires the fissioning of 5.28E+26 [1.69E+16/3.2E-11] atoms of fissile (^{235}U)

Which is 877 [5.28E+26/6.023E+23] gram moles or 206 kg of ^{235}U "burned" over 33 years

(Incidentially, those sneaky Russians also discovered/revealed that adding 3% of an especially special element about which we here cannot speak rendered their fuel's Zr cladding more durable)

The Russians' UO_2/zirconium CERMET fuel pellets possess a diameter of ~0.8 cm and consist of ~10% porous UO_2 granules embedded in zirconium metal. The volumetric ratio of ceramic to metal within them is about 3:1 (75% UO_2) and they are contained within ~0.5 mm thick walled zirconium tubes with an "air" gap between them of about 0.1 mm[2]. They are also expected to achieve 120 MW day/kg U burn up. Since the theoretical density of pure UO_2 is 10.97 g/cc, the density of that within the fuel pellets must be 10.97*0.9 or 9.873 g/cc

Since the density of zirconium is 6.49 g cc & it represents 25 vol% of the pellet, that pellet's density must be [9.873*.75+0.25*6.49) = 9.027 g/cc

[2] The purpose of using deliberately porous UO_2 and an "air gap" is to provide room for the fission products generated when some of the fissile fissions. That FP would otherwise over-stress the cladding tube's walls.

The smear density of the uranium in it would be 5.959 g/cc [0.75*9.027*235/(235+2*16)]

Pellet end-on area = 0.5027 cm^2 [(0.8/2]^2*3.1416]

End-on area of the fuel « pin" = 0.6648 cm^2 [(0.4+0.06)^2*3.1416]

fuel assembly uranium smear density = 4.506 g/cc [5.959*0.5027/0.6648] (which figure agrees with the Russian paper's claim)

120MWd/kg = 1.037E+13 [120E+6*3600*24] J/kg

100% fission/kg = (1000/235)*6.023E+23/3.2E-11 = 8.2015E+13 J/kg

fraction ^{235}U burned = 5.7024E+12 /8.20153E+13 = 0.126

total U in core = 206 kg burned/0.126 f burned=1630kg

core volume sans water etc = kg tot U/ fuel U smear density = 1630/4.506 = 362 liters

if fuel assembly pitch-to-diameter ratio is the same as that of a 17 by 17 PWR's (12.6 to 9.5 mm) then the volume of the core's hot region must be about 362*(12.6/9.5)^2 or 637 liters (if a right circular cylinder it'd be just over a yard (three feet) both high & wide)

APPENDIX XVIII. A comparison of different approaches to providing public transportation

Whenever I feel myself becoming too complacent about how great the USA is relative to foreign countries, I do a bit of GOOGLING*. For instance, two years ago 8/25/2019), I learned that Spain's 25 year-old 100% electrified, high-speed, passenger trains run at speeds of up to 190 miles/hour and enable fast connection between Spain's cities. For example, there are 17 trains/day to/ from Madrid/Seville (about 240 miles) that take about 2 hours, 21 minutes/trip & a 2nd class seat ticket costs ~$30. That works out to 12.5 US cents per mile). (https://www.eurail.com/en/get-inspired/trains-europe/high-speed-trains/ave)

AVE's (Spain's) passenger trains feature:

Air conditioning
Audio system
Liquor Bar
Child supervision
Children's play area
Coffee bar
Disabled facilities
Newspapers/magazines
Power sockets
Restaurant/bistro
Video screens

…***and*** Spains train seating experts don't try to shoehorn 187 people into something the size of a Boeing 737.

Here's a review by someone (a« foreigner ») who's obviously been "spoiled" by the EU's rail-based long distance people transport system

"*Overall the trip is satisfying. However, the price is a bit high*. "

A bit more GOOGLING revealed that…

A one way train trip between Philadelphia and Pittsburg (about 260 miles, with 12 intermediate stop service) takes 7 hours and 25 minutes (~35 miles/hr) & the ticket costs $68 (about 26 US cents/mile). There's also just one trip/day service.

https://www.cheapoair.com indicated that a next day's one-way airplane ticket cost between those same cities ranges from $210 to $540 depending upon times and airline - that's $0.81 to $2.08 per mile. (« gas mileage » = 70-100 miles/gallon/seat)

At the other end of the world's public travel-cost spectrum, a typical Chinese "slow train" route of about 220 miles, features 28 stops, and moves at an average speed of ~43 miles/hr. However, its tickets cost its riders only about 1.5 US cents per mile (21 Y/350 km).

Non-public transportation : The USA's most popular POV, Ford's F150 pickup truck, apparently gets a real-world average of about 12 mpg & Pennsylvania's current gas price is ~$2.61/gallon.Those figures plus an assumption that an average American would average 60 miles/hr between Philidelphia & Pittsburg, suggest that his/her trip would take 4hrs and 20 minutes and its gasoline would cost $55.56 (21 cents/mile).

*The American Dialect Society considered GOOGLING to be its "most useful word of 2002." It certainly deserves that appellation.

APPENDIX XIX. Best-yet explanation of how "renewables » are being subsidized

(Rogers 2019)

The solar energy industry is telling its pals in Congress that it is willing to lose most of its subsidies. The current subsidy for solar is 30% of the construction cost. To that subsidy, an additional 10% subsidy is available due to special fast depreciation for solar energy plants. The 30% subsidy is scheduled to ramp down to 10% by 2022 and thereafter remain at 10%. This is not a consequence of declining costs of solar that makes the industry no longer in need of such a large subsidy. Solar electricity is a mature industry, and cost declines are moderate. The real reason the solar people are happy with a lower subsidy is that the 30% investment tax credit (ITC) is not their most important subsidy. The real subsidy is more complicated and better hidden. The real subsidy is rooted in renewable portfolio requirements in about 30 states. These states require that a certain percentage of electricity. The real subsidy is rooted in renewable portfolio requirements in about 30 states. These states require that a certain percentage of *electricity come from renewable sources. The quota ramps over time. For example it might ramp from 20% now to 50% by 2030. These quotas create a chain of events that guarantee solar and wind energy a market for years to come with a guaranteed profit. If that is not enough, the industry is trying to freeze the quotas into state constitutions so as to make it difficult for the electricity consumers to get out of the trap that has been set for them.*

Renewable energy has been defined in an illogical way so as to favor solar and wind. The ostensible motive for increasing renewable energy is to lower carbon dioxide (CO_2) emissions and thus avoid a supposed global warming catastrophe. But hydro and nuclear are prohibited from being used to meet the renewable energy quota, even though they don't emit CO_2.

Electricity is responsible for 28% of U.S. CO_2 emissions. The rest is from transportation, heating, and industrial processes. Yet the emphasis on reducing CO_2 is focused on the electricity sector. The U.S. is responsible for 14% of world CO_2 emissions, and our electricity generation creates less than 4% of world emissions. All the effort being put into U.S. renewable electricity will have no important effect on global warming, assuming that global warming is even real. The real source of CO_2 emissions is China and India among others.

I will explain how renewable energy quotas subsidize solar. The argument for wind is similar but different in various details. To see how big the subsidy is, I will compare an imaginary, unsubsidized solar electricity business with the existing situation, propped up by subsidies and quotas.

Our imaginary unsubsidized solar business is going to sell electricity to various utilities that its electricity can reach via the transmission networks that are open to companies exchanging electricity.

Solar electricity is erratic electricity. You get it during the day, when the sun is not obscured by clouds. The utilities that deliver electricity must supply electricity in a predictable and non-erratic manner. Why would any utility even want erratic electricity? The answer is that the utility can use its existing plants to compensate for the erratic nature of the solar. The value to the utility of the solar electricity is the value of the fuel saved in its existing plants when solar electricity is actually flowing. Solar can't replace existing plants because sometimes it's not there, *particularly in the early evening, when electricity demand often peaks. On the negative side, solar lowers the utilization of its existing plants and stresses them more, increasing the cost of electricity from existing plants.*

To summarize a complicated story, solar electricity is worth about $20 per megawatt-hour to a typical utility.

Our imaginary company with a speculative market and no guarantees would need an 8% return over a 10-year period to justify the investment. Under these conditions, it is not remotely possible to sell solar electricity for $20 and get the 8% return appropriate to this speculative business. The company would have to get about $100 per megawatt-hour to stay in business. One hundred dollars per megawatt-hour is the true price of solar electricity in a free market.

But suppose the solar company has a 25-year contract with a utility guaranteeing a market and price. Then our not so imaginary company could be financed with a rate of return of 4.5% over 25 years. Under these conditions, the company could prosper by selling electricity for $37 per megawatt-hour. Take it one step farther and assume we have the full 30% ITC, which, in combination with rapid depreciation, is a 40% subsidy. Under those conditions, the company could sell electricity for $22 per megawatt-hour. That $22 per megawatt-hour is in line with the lowest-cost solar agreements being signed at the present time. The subsidy is $100 - $22, or 78%. Take it one step farther and consider when the ITC ramps down to 10%. The subsidy from the ITC and the rapid depreciation will then be 20%. In this case, the electricity can be sold for $30 per megawatt-hour and the company will still get its return.

Because utilities are forced to search out renewable electricity due to the quota, they have to provide terms that will cause the installations to be built. Those terms are driven by long-term interest rates and the cost of building the solar installations. When, and if, the ITC is reduced from 30% to 10%, we can expect the best power purchase agreements to rise from $22 to $30 per megawatt-hour, or a bit less if the industry lowers its costs. The profits of the industry will remain the same. The renewable portfolio quotas protect the business. The payer of the subsidy shifts from taxpayers to electricity consumers when the direct subsidies are reduced.

If the quotas were repealed, the utilities would have little incentive to offer long-term contracts to solar energy producers. The utilities might be willing to pay $20 for the electricity, but without the long-term contracts, the required rate of return needed for a viable business would be much higher, and that would be unobtainable with the $20 amount the utilities would be willing to pay. Even with the 40% existing federal subsidy, the solar producers would need about $60 per megawatt-hour to get an 8% return over 10 years.

What this comes down to is that if you guarantee a market and price for 25 years, that is of great value to the company receiving it. You have taken away most of the risk, and risk requires higher returns. A company with such guarantees is more like a government bond than a normal enterprise.

The proselytizers for renewable energy have cleverly created a good business by convincing states to set quotas for renewable energy. Because there is a quota, the utilities will sign contracts that will result in providing the needed supply. The quotas are justified on the grounds of saving the Earth from global warming, but even if global warming is a real danger, the problem is in Asia, not in the U.S. electricity sector. By banning hydro and nuclear on spurious grounds, the wind and solar industry has fended off the competition for CO_2-free electricity.

Experts like James Hansen and Michael Shellenberger, that really, really believe in global warming, are loudly saying the solution is nuclear, not wind or solar.

APPENDIX XX. Worked-out water/CO_2 equilibria examples

(Problems like the ones in this APPENDIX are the reason that God has (Bill Gates) has given us EXCEL; e.g., if pH=7.9 (meaning that [H+]=10^-7.9) EXCEL can translate that to [H+} = 1.26E-8 within about one microsecond.

If things keep going the way they are now, "God’s" TERRAPOWER team may be first to develop a practical, sustainable, nuclear fuel cycle & thereby "save the world" (Yeah God!).

(see also http://lawr.ucdavis.edu/classes/ssc102/section5.pdf)

This TABLE lists several especially relevant water pH buffering reactions

Reaction no.	reaction	Log10 k
1	$K1=(H_2CO_3)/(_{CO2}atm)*H_2O)$	-1.46
2	$K2=(HCO_3^-)\ (H^+)/(H_2CO_3)$	-6.36
3	$K3=(CO_3^=)*(H^+)/(HCO_3^-)$	-10.33
Calcite dissolution	$Ksp=(Ca^{++})*(CO_3^{--})$	-8.48

Two others include

Ksp calcite: $CaCO_3 \rightarrow Ca^{++} + CO_3^=$ dissolution of calcite= 3.3E-9

(Ksp =solubility product = concentration of Ca* conc. carbonate)

Kw $H_2O \rightarrow H^+ + OH^{--}$ Dissociation of water 10^{-14}

The table's dissolved species concentrations are in units of gram moles per liter – the gaseous specie ($_{CO2}$) is in standard atmospheres (or BARs)

The equilibrium constants (Ks) represent the ratio of the product of product species (right side)/ reactant species (left side) e.g. for rxn. no.2, $K= (H^+)(HCO_3^-/H_2CO_3$

These K's are for distilled water at 25°C and vary with temperature (T) & salt concentrations ("ionic strengths)

The activity (effective concentration) of water in almost any aqueous solution is 1.00

Examples:

#1 if atmospheric P = 1 BAR (sea level) & that the air contains 400 ppmv $_{CO2}$ what's $H_2CO_3°$?

since to a good first approximation all gases occupy the same space/gram mole (~22.4 liters at one atmosphere pressure & 0°C) this example's partial p_{CO2}= 400E-6 atm, so $H_2CO_3° = 10^{-1.46}$* 400E-6= 1.38E-5 molar

What's the pH of distilled water in contact with it?

$H_2CO_3°$ partially dissociates to form one H^+ cation plus one HCO_3^- anion

so, H^+=($H_2CO_3^-$) = $^-$ (1.38E-5*10^-6.36)^.5 = 2.45E-6

(it's distilled water therefore no other ions)

pH = negative log H^+ =-log10(2.25E-6) =5.61

An important reaction in most soils and waters is the precipitation of calcium carbonate because calcium is Nature's most common carbonate-precipitating cation (calcium <u>bi</u>carbonate is freely soluble as are sodium/potassium carbonate/bicarbonates))

Ksp (solubility product) in low-salt water at 25°C is 3.3×10^{-9} = [Ca^{+2}]*[$CO_3^=$]

#2 What's the pH of water in equilibrium with Ca carbonate & the atmosphere at 25°C?

From what we've already done above, we know that the amount of $H_2CO_3°$ is 1.38E-5 molar

We also know that H^+ + 2*Ca^{+2} (equivalants of cations) = OH^-+ $H_2CO_3^-$ +2*CO_3^{-2} (equivalents of anions)

To solve this turkey we must express everything in terms of what we know; i.e., H_2CO_3, the constants & what we're looking for; i.e., H+

i.e., H^+2*Ca^{+2} = OH^-+HCO_3^-+2*$CO_3^=$

When you've done so, you end up with a quadratic equation in terms of H^+

H^++2*$H^{\wedge2}$*Ksp/10^-(k2+k3)/ $H_2CO_3°$=Kw/ H^+ °+(H_2CO_3)*10^k2/ H^+2*(H_2CO_3)*10^-(k2+k3)/$H^{\wedge2}$

It can be solved elegantly or by simply substituting inputted guesses for H^+ into both sides of the equation until you get a charge balance (I do it that way because I'm old, have forgotten how to solve quadratic questions, & now have EXCEL to do that sort of scutwork.)

The result I got (you might want to check it) is an H^+ concentration of $6.4E^{-9}$ molar which corresponds to a pH of 8.19.

It's no accident that that pH is close to what we used to see in the world's oceans (their pH is currently about 0.1 pH unit lower due to anthropogenic acidification)

Here's a link to the ACS's explanation of oceanic carbon chemistry https://www.acs.org/content/acs/en/climatescience/oceansicerocks/oceanchemistry.html

APPENDIX XXI. Methane's Global Warming Potential (GWP)

In oil and gas production "associated natural gas" (a by-product of oil extraction)-is often disposed of via flaring for a host of mostly economic reasons[3]. Methane is the main component of natural gas, so captured emissions can be sold as fuel. The energy sector accounts for ~40% of all methane emissions from human activity, second to agriculture.

A recent report by the International Energy Agency (IEA) showed that the fossil fuel industry is failing to tackle methane emissions despite its pledges to uncover and fix leaking infrastructure.

In 2022, the global energy industry released some 135 million tonnes of methane into the atmosphere – a potent greenhouse gas responsible for roughly a third of the rise in global temperatures since the industrial revolution.

Last year's emissions rose above 2020 and 2021 levels and were only slightly below the record amount released in 2019, despite high energy prices and surging demand for natural gas that provided extra incentives to capture it.

[3] The petroleum industry and its regulators refer to flared and vented natural gas as "waste." Independent experts see it as a valuable resource being squandered due to weak regulation, ineffective tracking of flaring and venting, and a lack of economic incentives to capture. Wikipedia entries indicate that North Dakota consumes ~1.68 Twh of electricity per year most of which is generated by burning its low grade ("dirty") coal and 3.5% by burning its natural gas. Assuming 50% heat to energy conversion, the 88 Bfc that the USA's energy business model permits NoDak's energy entrepreneurs to waste corresponds to 1.47 Twh

Data on gas flaring and venting are collected from producers by some (not all) petroleum producing states who then share it with the Energy Information Administration (EIA). Those data indicate annual gas flaring volumes of 225 - 285 billion cubic feet (Bcf) per year during the mid-1990s. After dipping to under half that during the early 2000s, reported flared volumes have again risen to between about 200 and about 300 Bcf per year during the 2011-2017 as fracking increased oil production. In 2021, Texas producers flared a total of 101 Bcf and North Dakota 88.5 Bcf - 10 to 20 times the volumes reported by the other states volunteering such information which reflects their greater oil and natural gas production.

Even when such information s available, flaring data is questionable because real flares aren't 100% efficient at converting hydrocarbons to CO_2/water and sometimes aren't even lit Gas Flares Might Release More Methane Than Thought, Study Finds - The New York Times (nytimes.com). It's unlikely that anyone really knows how much natural gas (mostly methane) is being leaked directly into the atmosphere. For example, Weber and Clavin's paper (one of many) compared shale & conventional gas leakage "carbon footprints » (Weber 2012 - like most such literature, this paper is paywalled).

Its ABSTRACT says that "…*most likely upstream carbon footprints of these types of natural gas production are largely similar, with overlapping 95% uncertainty ranges of 11.0-21.0 g CO(2)e/MJ(LHV) for shale gas and 12.4-19.5 g CO(2)e/MJ(LHV) for conventional gas*".

To draw a relevant conclusion from this information we first need to determine how much methane must be burned to generate one MJ's worth of heat energy. Wikipedia says that its heat of combustion is 50.1 kJ/g which means that that figure must be 1E+6/50.1E+3 or 19.96 g methane/MJ

To come up with a fractional leakage figure, let's assume a carbon footprint of 20 g CO_2e/MJ

Both the EPA & IPCC *usually* use 100-year GWP (mass-wise Global Warming Potential) figures which for methane is about 34 which, in turn, means that 100-year mass-wise methane loss/leakage is 1/34 of its CO_2 equivalent.

For one MJ's worth of methane, fractional leakage would then be 20/34/19.96 or 0.0295 (~3 %)

However, had that paper's authors based their conclusions on methane's 20-year GWP figure (86) instead, fractional gas leakage would be 1.16% - in other words, like all such modeling exercises, its conclusion depends upon assumptions that are often not clearly stated.

Greenhouse gas modeling conventions have powerful framing effects, often resulting in significantly under-reporting of emissions and obscuring the impact of shorter-lived GHGs. A recent interdisciplinary Australian case study (Wedderburn-Bishop 2015) re-calculated global warming potentials utilizing 20, not 100 year (GWPs), a timeframe more relevant to averting catastrophic change. Doing so makes a big difference. For example, Australia's annual GHG equivalent emissions more than doubled, with agriculture producing 54% of the national total due primarily to ruminant livestock, not fossil fuel burning.

This issue's bottom line was more clearly summed up by Klemun & Trancik's open-access 2019 paper: "*We find that CH_4 emissions from the power sector would need to be reduced by 30%–90% from today's levels by 2030 in order to meet a CO_2-equivalent climate policy target while continuing to rely on natural gas."*

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APPENDIX XXII. Especially relevant real wind power reliability data

Rachel Morison, "*Britain Has Gone Nine Days Without Wind Power*", June 6, 2018, (https://www.bloomberg.com/news/articles/2018-06-07/u-k-wind-drought-heads-into-9th-day-with-no-relief-for-weeks)

" *Forecasters see wind output staying low for at least two weeks"*

" Wind generating 4.3% of U.K. electricity on Wednesday"

"Britain's gone nine days with almost no wind energy and forecasts predict that that wind drought will last for another two weeks."

Additional 2018 British data
https://en.wikipedia.org/wiki/Wind_power_in_the_United_Kingdom

…a total installed capacity of over 22 gigawatts: 13,532 megawatts of onshore capacity and 8,483 megawatts of offshore capacity.

Table 19 battery backup ball-parking for UK windfarms

2018	21,700	57,100	30.00%	18		317.2222222		36.25396825	
data	Capacity	Generation	Capacity	% of total		calc tot demand		av power demand	
	(MW)	(GW·h)	factor	electricity use		TWh		GW	
	if three weeks at 4.3 percent vs 18% need					9.01175E+15	J's worth of storage		
					that's	2503264000	kWh		
		cost @ Powerwall $7000/13.5 kWh =				1.30	$ trillion		

Table 19 battery backup ball-parking for UK windfarms

APPENDIX XXIII. More French stuff

France is the world's 9th largest electricity producer (~560 TWH/a) and its second largest producer of nuclear power, behind the United States but ahead of Russia and Korea. In terms of nuclear's share of total domestic electricity generation, France has by far the highest percentage portion of any country, ~80%. It's also the world's largest exporter of electricity.

French nuclear power facilities are almost entirely owned by its government.

It used to be that all of its domestic hot water heaters had to be oversized and under the control of the local electric utility. That utility would charge them at night, in order to level load. There was enough domestic hot water consumption so that hot water would levelize diurnal electric load variation five days a week but not enough to manage weekends. The plan was to build reactors with enough load following capability to manage weekends (which they then did). A current Google search didn't mention any of this.

Trust the French to get there first when it comes to doing/mandating anything rational about how electricity should be both produced & used. I had a brainstorm about something like that back when I first moved to my 1978-built, all-electric home out in the boonies north of Idaho Falls,ID (no nearby natural gas line). Back then (1991), Idaho Power had just decided to let its customers go to a dual-rate system, cheap on weekends, holidays, & at night, 50-60% higher otherwise. Anyway, I figured out that if I were to build a tightly insulated closet big enough to hold ~6, "naked" (no insulation) 50 gal electric water heaters somewhere downstairs I could heat the house during the winter much more cheaply by storing heat during cheap times & blowing it out into the house during expensive times (energy arbitrage). I never did it because it would have taken up space that my wife could stash her stuff into & because we were both rich "site workers", we didn't really have to pay much attention to utility bills. I did make some non-obtrusive foamboard "inside" window shutters and added more insulation elsewhere though.

It's too bad that the French insist upon being such pushy foreigners – otherwise we might be willing to learn something from them.

APPENDIX XXIV. letter written to the chairperson of the nuclear engineering department of one of Idaho's universities circa 2008.

(Most of the research done by that department's faculty members was/is funded by DOE)

« I haven't heard back from you yet so I 'm assuming that that you are still trying to convince XXXXX et al that his students & colleagues won't be irreversibly 'damaged' by learning about molten salt thorium breeder reactors.

Did you read David's (Leblanc’s) CNS paper yet?

Here's my opinion of of INL's nuclear R&D program.

I don't think that GNEP has been well thought-through. Building its fuel reprocessing plants, sodium cooled fast burner reactors, enrichment facilities, and fuel-fabrication plants is going to be unbelievably expensive. All of this just to sustain the wasteful fuel habits and excessive waste (esp TRU) production that's part & parcel of today’s uranium fuel cycle (See my other ATTACHMENT).

Fuel qualification for INL's propose VHTR is supposed to last until 2019...that's an incredible length of time--especially when 'qualifying' a liquid fluoride fuel (by comparison) could be done in a high- flux reactor like HFIR within one year.

Since modern water electrolyzers are about 75% efficient, is mounting a decade-long effort to attempt to make reactors run safely at 1000°C (or 950°C) really worth the risk? Any sort of reactor can produce electricity, hence hydrogen. What we need to do is come up with a plan that makes a renaissance of nuclear power less 'impactful' to the environment and our pocketbooks.

Is DOE apt to develop a sufficient market for nuclear generated hydrogen? What this country really needs is a practical 'transportation fuel' - hydrogen is impractical for that purpose unless it's first converted to something that's a lot easier to safely cart around in your vehicle (e.g. liquid ammonia). Is anybody at INL working on or even aware of that option? (hint, have them check out Kordesch's pubs at the APOLLO ENERGY SYSTEMS website).

In my opinion, INL's VHTR would move us even further away from a 'sustainable' nuclear fuel cycle than we are right now (have you ever tried to reprocess graphite-based (eg., TRISO) fuels - we did at the Chem plant & it's damn near impossible to accomplish efficiently or cleanly). Mr/Dr Werner says that VHTR is the nearest-term solution(???) and has attracted the most interest of the Gen-4 partners -is that the main reason that INL has chosen it? Is INL or its industrial 'partners' supposed to be leading the federal govt's nuclear R&D program?

Solid fuel qualification & devising a politically viable large-scale solid fuel reprocessing scheme for it/them seems to drive everything in INL's plan. DOE is apparently hoping to do a series of eight fuel tests in the Advanced Test Reactor. Each such test will be a time-consuming process that requires first fabricating specimens, irradiating them for several years, and finally conducting the post irradiation examination and safety tests. DOE/INL is just beginning this process. In particular, DOE officials said they have successfully fabricated the TRISO fuel for the first test and addressed previous manufacturing problems with US fuel development efforts in which contaminants weakened the coated particle fuel (the Germans had worked it out decades ago). However, the irradiation testing of the fuel in the Advanced Test Reactor has just begun. The first test was scheduled to begin early in fiscal year 2007 and to be completed in fiscal year 2009. The eighth and final test is scheduled to begin in fiscal year 2015, and the fuel testing program is scheduled to conclude in fiscal year 2019. As a result, DOE will not have the final results from all of its fuel tests before both design and construction begin.

For example, INL's 'new' (how is it really different than Ft St Vrain?) reactor's commercial attractiveness could be affected by competition with other high-temperature gas-cooled reactors currently under development and most likely commercially available much sooner, such as the South Africa's (actually Germany's) thirty-year old pebble bed-type reactor.

DOE "officially" acknowledges the risk of designing and building a plant which is not commercially viable and has taken initial steps to address this challenge. For example, DOE has established what it considers "aggressive but achievable" goals for the plant, such as producing hydrogen at a cost low enough to be competitive with gasoline.

This sounds like the AEC’s Clinch River Breeder Reactor boondoggle all over again; i.e., first let's build it, then let's hope it's economical, then let's hope that somebody will build a reprocessing plant for it, then let's 'study' how to decommission it, then let's....

In my opinion INL's plan is just another boondoggle like "IWTU", its highly-promoted, already 4x over- budget, water soluble-dust-producing, reprocessing waste treatment system - driven by politics, phony assumptions, bull-headed refusal to consider more promising alternatives, and a working environment & management team that stifles the creativity and initiative of its employees.

Come to think of it, maybe I really am 'too dangerous' to expose XXX's NucE students to. However, Kirk (Sorensen) might prove to be even more 'dangerous' because while he's a lot more more politically correct than I am (he's LDS), he also knows a lot more about MSBRs (aka 'LFTRs) & would probably do a better job of explaining why 'studying' them would make more sense than does INL's official 'path forward'.

Update (Feb2020) Kirk no longer speaks to me because I’ve decided that his LFTR concept doesn’t represent the best path forward.

Here’s a note recently sent to me from a ~45 year old university “Research Assistant NE Professor “ who’s been trapped for over a decade in the same sort of soft money, academic gig employment morass that I used to think that only “post docs” had to put up with. Observing how the latter were treated while I was still in graduate school convinced me that I’d never settle for anything short of a « real » job. He’s a sharp young guy (MSR expert) that’s never actually gotten much done because whatever he does/says always has to be consistent with whatever his funding source's (DOE's) decision makers want - = which guidance is as about as consistent as a wind vane's direction during a tornado.

- "*Well yes, as you know to survive at a university you have to bring in funding. Which means DOE funding. Second, after the proliferation of gen-ed requirements, "-studies" courses, and limits on total credit requirements for graduation, pushed by the administration, what remains from our undergraduate classes is stuffed to the brim with fundamental technical basics. We have a SINGLE one-semester course in nuclear reactor physics, for instance. One could teach a technical elective graduate course, but if it is not a core curriculum one has to find a spare time, and in my case I'd have to provide salary recovery from somewhere in addition. Tenure-track / tenured profs do it exclusively in support of their research program. I do not think it is much better anywhere else*[4].

APPENDIX XXV. Ontario Society of Professional Engineers (OSPE's) library of energy reports and seminars (courtesy Paul Acchione, P. Eng., FCAE)

OSPE Formal Energy Policy Reports

OSPE energy policy reports can be downloaded from the OSPE website by doing a web search for the title. For convenience the links are listed below. In case of difficulty you can request a copy from: Paul Acchione, OSPE Volunteer, email: paulacchione@gmail.com

Energy Policy Report List:

R-1: Ontario Electrical Grid and Project Requirements for Nuclear Plants (Mar 2011) - discusses the power system related technical requirements for nuclear plants installed into the Ontario power system. The report was written to advise the provincial government after an inadequate specification was used to seek bids for a new nuclear plant that did not contain the unique Ontario system requirements.
https://www.ospe.on.ca/public/documents/advocacy/submissions/2011-nuclear-plants.pdf

R-2: Wind and the Electrical Grid – Mitigating the Rise in Electricity Rates and Greenhouse Gas Emissions (Mar 2012) - discusses the limitations of Ontario's power system to incorporate large amounts of intermittent wind generation. The report was written to advise the provincial government after the 2010 Long Term Energy Plan was issued and proposed far more wind generation than the Ontario power system was capable of integrating effectively.
https://www.ospe.on.ca/public/documents/advocacy/2012-wind-electrical-grid.pdf

R-3: Engineering a Cleaner Economy – Examining Ontario's Carbon Pricing Program and the Role of Innovation (Sep 2015) – examines carbon tax programs and a cap-and-trade programs and the benefits of having a well-designed program that puts a price on carbon emissions. The report was written to advise the provincial government of the engineering community's views on carbon pricing programs and innovation opportunities for the economy.
https://www.ospe.on.ca/public/documents/advocacy/2015-engineering-cleaner-economy.pdf

R-4: Ontario's Energy Dilemma – Reducing Emissions at an Affordable Cost (Mar 2016) – examines various technologies that can help Ontario reduce emissions in the heating and transportation section now that electricity emissions are already 90% below 19990 levels. The report also describes Ontario's experiences with reducing emissions in the electrical sector and the lessons that were learned. The report was written to advise the provincial government that emission reductions in the heating and transportation sectors will be more difficult and expensive than the electricity sector unless we are creative and leverage the clean electrical sector effectively.
https://www.ospe.on.ca/public/documents/advocacy/2016-ontario-energy-dilemma.pdf

R-5: Retail Electricity Rate Reform – Path to Lower Energy Bills and Economy-Wide $_{CO2}$ Emission Reduction (Apr 2019) – examines the benefits of reforming Ontario's retail electricity rate plans on a voluntary basis so consumers can affordably use surplus clean electricity to displace some of their fossil fuel use. The report was written to advise the provincial government that innovation in rate design is a less costly way to reduce greenhouse gas emissions.

https://ospe.on.ca/wp-content/uploads/2019/11/FINAL_FULL_REPORT_Retail_Electricity_Price_Reform_April_2019.pdf

Ontario Society of Professional Engineers (OSPE) Energy Policy Seminar Outlines
Most seminars are formatted for a 1-hour presentation unless otherwise noted. OSPE energy policy reports can be downloaded from the OSPE website by doing a web search for the title. In case of difficulty you can request a copy from: Paul Acchione, OSPE Volunteer, email: paulacchione@gmail.com

Energy Policy Seminar List:

E-1: Limits to Renewable Energy Penetration (Dec 2013) - discusses the technical limits to how much wind and solar can be installed on the electrical grid. The presentation includes:
• Benefits and challenges of wind and solar generation
• Present electrical grid constraints and their impact on wind and solar generation
• Cost impact of dispatching generation (load following)
• Wind and solar production profiles compared with actual electrical demand
• Why dispatching down (constraining output) of wind and solar generation has become necessary
• Limits to how much wind and solar can be installed on the grid

E-2: Electrical Energy Storage Options (Oct 2015) - discusses the benefits of storage and the costs involved. The presentation includes:
• Ontario's electrical demand profile
• Cost impact of dispatching generation (load following)
• Benefits and challenges of storage
• Alternatives if we don't use storage
• How much storage is needed to effectively integrate renewables
• Storage technology options and their costs

E-3: Wind and the Electrical Grid (updated Jun 2019) - discusses the challenges posed by wind generation to ensure dependable electrical supply. The presentation includes:
• Why Ontario wind generation is out of step with electrical demand
• Why wind generation is difficult to integrate into Ontario's electrical grid
• Why electricity market prices collapse and even go negative in Ontario
• Why Quebec's hydroelectric storage capacity is not available to Ontario
• Why wind generation results in higher GHG emissions in Ontario's grid
• Why nuclear generation is needed if low GHG emissions is a requirement

E-4: The Real Cost of Electrical Energy (Nov 2014) - discusses the comparative cost of electricity and the carbon dioxide emissions that would result from a wind, solar, nuclear or natural gas generation grid. The presentation includes:
• Why the demand profile is critical to understanding the real cost of production
• Price confusion - the different prices for electricity
• The cost impact of load following (dispatching)
• Solar production profiles and how that impacts generation & storage capacity
• Wind production profiles and how that impacts generation & storage capacity
• The total delivered energy cost of solar, wind, nuclear and natural gas

E-5: Productive Use of Nuclear Spent Fuel (May 2016) - discusses how we can consume our used fuel waste in new Generation IV fast neutron reactors to make energy. The presentation includes:

• The CANDU and PWR (open) fuel cycles in Canada and USA
• Spent fuel properties of current CANDU and PWR reactors
• Usable components of used fuel and how they can be extracted
• The difference between thermal and fast neutron reactors
• Difference between thorium and uranium fast neutron reactors
• Reducing life time and radio-toxicity of used fuel
• Advantages of reprocessing used fuel to generate energy

E-6: has been replaced by E-17
E-7: Challenges Facing Nuclear Energy After Fukushima (Jan 2015) - discusses the problems nuclear needs to overcome to gain public acceptance. The presentation includes:
• Natural gas prices and their impact on nuclear
• Interest rates and their impact on nuclear
• Growing fleet of wind turbines and their impact on nuclear
• Load following requirements and the impact on nuclear
• Public safety concerns - used fuel repository, reactor accidents
• Cost and schedule over-run experience on recent projects
• Large capital requirements and corporate risk

E-8: Straight Talk on Energy Challenges – Canada, USA, World (Jan 2017) - discusses energy policy challenges and the lessons learned from Ontario's experience. The presentation includes:
• Some inconvenient energy facts
• Policy challenges
• Current energy demand – Canada, Ontario, USA, World
• Current electricity demand - Canada, Ontario, USA, World
• Cost of various generation technologies in Ontario
• Case study – Ontario's grid
• Lessons learned from Ontario's experience

E-9: Ontario's Electricity Dilemma (Apr 2015) - discusses Ontario's challenges and policy changes needed to achieve low emissions at reasonable electricity rates. The presentation includes:
• Original Goals for Electricity System Transformation
• Technology Limitations
• Unexpected Surprises
• Ontario's Electricity Demand
• The Cost Impact of Curtailing Generation Output
• Why Are Electricity Prices Rising So Fast in Ontario ?
• Why Will Emissions Double as We Add Wind and Solar Plants ?
• What Can We Do to Mitigate Increases in Rates and Emissions ?
• What Are the Enabling Policies and Technologies That We Need ?

E-10: has been replaced by E17.
E-11: The Electrical Grid (Sep 2015) – this is a 4 part educational series of 2 hour seminars each covering how the grid works, how greenhouse gas emissions can be reduced, current challenges the grid is facing and potential solutions to those challenges. (8 hours total time). Shorter presentations of 40 to 60 minutes on a portion of the contents can also be provided upon request.
• • Part 1 – How It Works (2 hour presentation with Q/A)

- • Historical Perspective - T. Edison, N. Tesla, Sir Adam Beck
- • The Electrical Grid
- • Consumer Load Demand – daily, weekly, annual
- • Generation Technologies
- • Storage
- • Load, Frequency and Voltage Control
- • Wholesale Auction Market
- • Retail Electricity Prices
- • Stranded Debt

- • Part 2 – Achieving Low Greenhouse Gas Emissions (2 hour presentation with Q/A)
- • Greenhouse Gas (GHG) Emissions from Each Technology
- • Consumer Load Demand – Weekly and Annual
- • Generation Production Profiles
- • Using Storage Economically
- • Integrated Generation Solutions
- • Minimizing Greenhouse Gas Emissions
- • Reducing Greenhouse Gas Emissions in Other Sectors
- • Using Electricity to Facilitate Carbon Reduction in Other Sectors

- • Part 3 – Current Challenges (2 hour presentation with Q/A)
- • Government Energy Policy Goals

• Challenges and Their Impacts • Rising Greenhouse Gas Emissions
• Rising Electricity Prices
• Ineffective Retail Price Plans
• Low Power System Load Factors
• Curtailment (Waste) of Carbon-Free Energy
• Conservation Program Creates Surplus Carbon-Free Energy
• Adding Capacity During a Period of Flat Demand

- • Part 4 – Potential Solutions (2 hour presentation with Q/A)
- • What Problems Do We Need to Solve ?
- • Reducing Electricity Rates
- • OSPE's Voluntary Smart Price Plan
- • Reducing Greenhouse Gas Emissions

E12 – The Electrical Grid and the Wholesale Electricity Market (May 2016) – discusses the components in the electrical grid and a basic description of how the wholesale market works in Ontario. The presentation includes:

- • Historical Perspective - T. Edison, N. Tesla, Sir Adam Beck.
- • The Electrical Grid
- • Consumer Load Demand – daily, weekly, annual
- • Generation Technologies
- • Storage
- • Load, Frequency and Voltage Control
- • Wholesale Electricity Market
- • Grid Scale Storage and the Wholesale Market

E13 – Electricity – Displacing Fossil Fuels in Other Sectors (Sep 2016) – discusses which combination of electricity prices and carbon prices are needed to enable electricity to displace fossil fuels in the transportation and building sectors. The presentation includes:

- • Greenhouse Gas (GHG) Emissions from Ontario's Electricity Sector
- • Electricity versus Natural Gas for Home Heating/AC
- • Electricity versus Gasoline for Transportation
- • Ontario's Surplus Carbon-Free Electricity
- • Potential for Fossil Fuel Displacement by Electricity
- • Energy Policy Implications

E14 – The Marriage of Nuclear with Natural Gas: Low Emission Affordable Electricity (May 2016) – discusses how nuclear units for base-load capacity and natural gas units for peak load and reserve capacity can be combined to provide an electrical grid that meets the international goal of an 80% reduction in greenhouse gases at an affordable price. The presentation includes:

- • Natural Gas Is Key to a Low Emission Affordable Future
- • Carbon Dioxide Emissions from Ontario's Power System
- • Creating a Low Emission Affordable Future
- • The Electrical Demand Profile
- • The Optimum Roles for NG, Nuclear and Renewables
- • Generation Costs
- • Energy Policy Implications

E15 – Ontario's Energy Dilemma: Reducing Emissions at an Affordable Cost (Apr 2017) – discusses the challenges we face to reduce emissions across the economy and the opportunities to leverage a low emission electrical system to facilitate carbon emission reductions in other sectors like transportation, buildings and industry. The presentation includes:

- • Power System Carbon Dioxide Emissions
- • Power System Supply and Demand
- • Marginal Cost of Zero Emission Electricity
- • Availability of Surplus Zero Emission Electricity
- • Case Studies
- • Policy Barriers to Productive Use of Surplus Zero Emission Electricity

E16 – Ontario's Electricity Rates: What Went Wrong? (Jul 2017) – discusses what caused Ontario's electricity rates to rise almost 2x faster than the rest of North American between 2009 and 2016. The presentation includes:

- • Constructive Policies
- • Power System Carbon Dioxide Emissions
- • Unexpected Economic Turmoil
- • Ontario's Excess Capacity
- • Sub-Optimal Policies that Drive Rates Higher
- • The Government's Fair Hydro Plan
- • Where Do We Go From Here?

E17 – Retail Electricity Rate Reform – a Zero Cost Way to Reduce Emissions (Mar 2019) – discusses Ontario's growing surplus of emission-free electricity and how we can use it to displace fossil fuels for our heating needs. The presentation includes:

- • Major Energy Systems
- • Why Do We Have Surplus Emission-Free Electricity?
- • Deficiencies of Current Retail Electricity Price Plans
- • Attributes of Smart Retail Electricity Price Plans
- • OSPE's Smart Price Plans

• • Implications for Energy Policy

E18 – Small Modular Reactors – Innovation in the Nuclear Industry (May 2019) – discusses the design features of the new SMRs and the advantages over current large water-cooled thermal reactors.

- • Challenges with the Current Generation III+ Large Nuclear Reactors
- • Advantages of Small Modular Reactors
- • Small Modular Reactor Technologies
- • Role of SMRs in Climate Change Mitigation
- • SMR Development in Canada
- • Policy Implications for Canadian and Provincial Governments

E19 – Energy Strategies for Ontario and the Planet (Sep 2018) – discusses strategies for a low-emission, affordable, economy-wide energy system. The presentation will draw on experiences to date on the transformation of energy systems. The presentation includes:

- • Ontario's electrical sector supply mix and emissions
- • Ontario's GHG economy-wide emissions
- • Benefits of integrating the electrical and natural gas systems
- • Benefits of natural gas, thermal and electrical storage
- • Economy-wide integrated energy strategies
- • Opportunities and challenges for northern off-grid First Nation and mining communities
- • Export potential for Ontario's energy expertise
- • Policy implications

APPENDIX XXVI. Factors determining the cost of nuclear power in today's world. (Paul Acchione)

" *Nuclear has several different costs per kWh and we should all be careful how we use them in technical papers and media articles. They are:*

(1) marginal costs for producing the next MWh (or kWh). That is primarily a variable operating cost (typically fuel and consumable chemicals).

(2) fixed costs independent of the production. That is mainly labor, depreciation and financing charges on the bonds that built the plant. These fixed costs are often expressed in cents/kW but that means the plant capacity factor will affect these kWh costs significantly.

(3) operating costs per kWh (typically item (1) plus labor from item (2) divided by the production quantities.)

(4) levelized cost of electricity (LCOE) per kWh (all the items in (1) and (2) divided by the production quantities.)

In addition to the direct nuclear production costs above there are also transmission and distribution costs to allow that electricity to get to the consumer. The consumer pays a retail price for nuclear supplied electricity of about 50% more than the nuclear plant LCOE.

Nuclear operating costs are currently low but typically only include fuel, consumable chemicals and labor – not depreciation and financing charges. Both the operating costs and LCOE will be affected by the plant's capacity factor. The LCOE is more sensitive to the plant's capacity factor than the operating costs because the fixed costs are higher. When the plant is fully depreciated and the bonds are retired the LCOE will be the same as the operating costs. However, most nuclear plants are not in that situation, especially if they get a mid-life infusion of capital to extend their life.

In a new base-load large nuclear plant operating at 90% capacity factor you will likely be looking at an LCOE of about 8 to 10 cents US/kWh. Vogtle 3 & 4 are likely beyond that range due to poor project performance. SMR's are expected to have an LCOE less than that range. However, no-one has mass produced SMRs yet so the projected cost per kWh is currently speculative.

As you reduce the capacity factor to follow the load the price per kWh rises inversely with the capacity factor due to labor, depreciation and financing costs that do not become less when the plant is idle more often. At about 45% capacity factor the levelized cost per kWh nearly doubles. All you save at low capacity factors is the fuel cost. Fuel is only 10 to 15% of total costs.

If you used flexible nuclear plants to operate a typical grid with a load factor of 65%, then the reactors will likely operate at a combined capacity factor of about 55% (i.e., 90%x65%). However, while all the reactors can be operated in parallel at the same load factor that is not how a real grid is currently operated. Producers bid into the energy market at their marginal costs of production and all plants that are dispatched ON will get paid the same market clearing price for that operating interval. The highest marginal cost reactor would be pushed out of the market until the grid peak demand occurs. Then that highest operating cost plant will be called upon to produce electricity. That plant will therefore only operate about 50 hours a year or less than 0.6% capacity factor. Its total levelized cost of production, including fixed charges like labor, depreciation and financing, will be so high on a per kWh basis that the producer will go bankrupt unless they can get the utility commission to pay the fixed charges as a markup on retail rates."

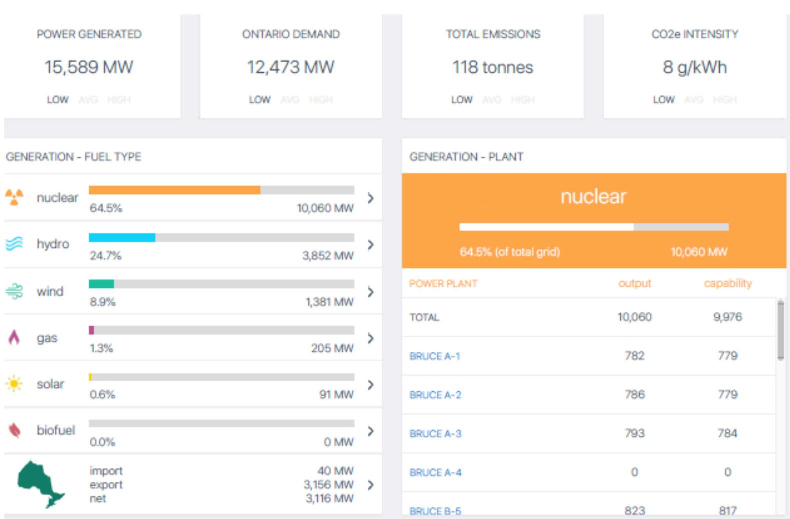
That is unlikely to happen because there are lots of ways to get 50 hours of peak demand without paying those high prices for a nuclear plant. The 50 hours of peak demand will typically *represent about 10% of total grid load so we are talking about a seriously large nuclear plant (actually a multi-unit plant) on standby for most of the year for most grids).*

Meeting the highest summer or winter peak demand with nuclear generation is not a viable economic proposition. I would burn gas for that short a period of time using a peaking gas turbine plant and too bad for the CO_2 emissions. The grid will still operate better than 99% carbon-free and you save a lot of money.

If you slice the load demand in 1,000 MW steps you will find nuclear doesn't make economic sense when you get installed nuclear capacity above about 60% of the annual peak load. At that installed capacity, nuclear will operate at about 85 to 90% capacity factor in most grids.

France went much higher with about 75 to 80% nuclear. That is why they had to spend more money on controllable electric water heaters in homes to level the grid load and also scheduling reactor outages on the weekends. Some units were fitted with grey rods instead of black rods to allow some load following but the amount of load following is not large with PWRs. All kinds of operational issues, like Xenon transients, spatial flux tilts, differential fuel burnup, etc. make most utility PWRs and BWRs poor load following reactors. If you want to load-follow with PWRs or BWRs you really need a steam bypass system to the condenser. That way you can lower electrical output without lowering reactor output. This approach assumes there is no thermal load that can use the wasted energy"

For example, here is a screen copy of the Ontario grid's supply mix Sunday morning at 10 AM, 5Apr2020. The current wholesale price of electricity was \$9Can./MWh or about 0.63 US cents/kWh. The entire system's carbon emissions were 8 grams CO_2 per kWh compared to about 1,000 for a coal fired plant or about 400 for a natural gas plant (excluding CH_4 leakage). The 205 MW of natural gas generation was likely running to provide minimum spinning reserve requirements or to simply keep the turbines hot to enable peak load demand load pickup during the dinner hour.



The low price means that ~1,500 MW of hydroelectric is being curtailed (probably 1/3 is still being stored this morning for the afternoon/evening peak, the rest is being spilled (wasted). Ontario's power system doesn't have a lot of storage capability (its hydropower is "run of the river")

Most of Ontario's solar is installed in local lower voltage distribution systems so their output isn't depicted in this screen shot. Only 480 MW of solar is installed in the high voltage system operated by IESO (Ontario's ISO). The screen shot indicates that those facilities were currently producing 91MW..

The screen shot's numbers suggest that all of Ontario's wind and solar power is being exported to the US and Quebec at very low prices. I say that all the solar and wind are being exported because all of the solar and wind capacity was installed after the nuclear and hydroelectric plants were built meaning that "last built, first exported or curtailed" to be the correct way to determine the value of that additional "renewables" electricity generation. Ontario consumers pick up the tab for the difference between producer contract prices and the wholesale market price which is one of the reasons why its residential customer retail prices are over an order of magnitude greater than the system's wholesale prices.

Nuclear was carrying 65% of the total load (85% of the domestic load) with only 34% of the system's total installed capacity. Three nuclear units were down, two for long term refurbishment and one for short term maintenance.

The screen shot demonstrates the truly impressive value of nuclear. It does all the heavy lifting for both required domestic production and required dependability. Here is the web link if you want to watch real time supply mix data : *http://live.gridwatch.ca/home-page.html* . .Ontario's IESO data including its wholesale electricity price is plotted on a graph over the course of the day including the you can see that at: http://www.ieso.ca/Power-Data

….Paul Acchione, P. Eng., FCAE

APPENDIX XXVII. Notes/opinions of a caring, concerned, and alarmed senior Canadian P.Eng., PhD nuclear engineer.

The first (below) was in response to another member of Dr. Pavlak's "Future of Energy Initiative" ZOOM group who had opined that a big-enough nuclear renaissance could be implemented with business as usual (converter/burner-type reactors).

His second note has to do with the fact that the policies driving ERCOT's (Texas's RTO/ISO) decision making encourages its decision makers to replace that system's reliable thermal (coal, nuclear, and combined-cycle gas) power generators with unreliable wind (mostly) & solar power plants, backed up with hype, BS (a biofuel?), and involuntary "load shedding" (blackouts).

The third is another addressed to someone who's recently entered the USA's SMR sweepstakes with another MSR concept consistent with its current paradigms - small, modular, unsustainable, and designed to temporarily fill the same void that fracted natural gas currently does for wind and solar power-dominated ISO's – not solve the world's multiple energy conundrums .

Number one:

"The uranium currently being mined in Canada is way off on the right hand tip of your uranium concentration graph. Look for the price of natural uranium to go up 10X to 100X by 2050. The ocean contains a lot of natural uranium but at 3 parts per billion it is very expensive to recover. Meanwhile the world is swimming in used nuclear fuel and depleted U-238. We have enough used nuclear fuel in storage right now to power the entire country for over 300 years. We need to automate the known electrolytic process for extracting fission products from used fuel and re-burn the used fuel in fast neutron reactors running a U-238 to Pu-239 breeding cycle with supplementary TRU burning.

The Chinese reasonably anticipate starting to build thorium power reactors by 2030. Based on what I know about their collaboration with the UK that schedule is reasonable.

The people at INL know what to do and how to do it with respect to sodium cooled reactors but political corruption in the USA driven by the fossil fuel industry is preventing it from happening. Not so in Russia which already has two large sodium cooled reactors up and running.

However, the combination of a carbon tax, loss of its wild fish resource, forest fires, floods and electricity load growth in Canada is going to force decisions. Our federal government is supposed to make a decision about the Teck mine (a huge new tar sands development) by the end of February. We will see what happens. If the Teck mine does not go ahead it will be the beginning of the end for Canada's fossil fuel industry. If it does go ahead, it will be the beginning of the end for our current minority government and maybe the two largest Canadian political parties. Presently they are both corrupt to varying degrees. Unless there is a distinct *change in direction, our third party (socialists) will acquire a lot of sway. Our socialists have credibility because they were responsible for cutting our costs of medical care two-fold with respect to the USA. That is really the basis of Bernie Sanders campaign in the USA.*

Interesting times ahead!

Regards,

Charles Rhodes "

…………………………………………………..

Number two:

I think that the inverter problem is the deal killer, but people do not realize it because they have never addressed it. Up until now they have avoided that issue by maintaining a sufficient fraction of fossil fuel generation that implicitly includes moment of inertia (big spinning turbogenerators). The issue that ERCOT now has is that, as you have pointed out, the ERCOT electricity pricing system has made building new generators possessing that characteristic uneconomic. If ERCOT wants more system stability it must economically incentivize increasing the ratio of moment of inertia to peak power generation. There is no provision for that in its existing energy-only electricity market system.

Within FOEI (http://www.futureofenergyinitiative.org Paul and I have been saying for over 3 years that there must be dependable capacity payments. Today dependable capacity implicitly includes moment of inertia, although that may not be true in the future. I think that it would be better to explicitly require that capacity include a minimum ratio of moment of inertia to peak power.

For the last 13 years I have been telling anyone who will listen about the importance of moment of inertia. The criteria for electricity system stability lie in math and physics. Smart ass economists ignore these criteria at their peril. It is culturally just like the Trump administration ignoring the COVID-19 problem until the US death rate from COVID-19 reached 10X the US death rate from automobile accidents.

If you want a physical analogy, think of trying to run a railway train using uniform radius wheels rather than wheels with flanges. If the track were perfectly straight and level and if the wheel radius was perfectly uniform the train could run along the tracks and not fall off. However, the real world is not like that. In the real world neither the tracks nor the wheels are perfect. Hence wheel flanges are necessary to create railway car stability. The role of moment of inertia in an electricity system is similar to the role of the wheel flanges on a railway train.

In mathematics this issue is expressed as 2nd order differential equations with complex stability terms. If the real part is negative an equation's solution will converge to a stable value. If the *real part is positive the solution will diverge (there is no stable solution). The complex part sets the frequency of oscillation during solution convergence or divergence. If the stability term has both real and imaginary parts (the usual real situation) the result is either a damped oscillation or a growing oscillation. A growing oscillation following a perturbation will eventually trip a safety device. That is almost certainly the problem in parts of the ERCOT system right now.*

No amount of legal hocus pocus will solve this problem. ERCOT's leadership/experts must recognize that the conditions for electricity system stability must be met. Existing market arrangements are not addressing system stability requirements. Even capacity payments alone will not solve this problem unless the capacity includes a minimum ratio of moment of inertia or the electronic equivalent to peak power.

I taught this issue of complex network differential equation solution stability in the Department of Electrical Engineering at the University of Toronto 50 years ago (1969-1971). In today's digital world people seem to have forgotten about it. Electric power systems are analog, not digital.

I remember solving network problems of such complexity that each term required an entire page to write in long hand. Shortly thereafter someone devised a computer program (SPICE) for solving complex networks. However, lost in the shuffle were the fundamental concepts of network stability. Unless an engineer understands the significance of the stability terms a computer solution has little merit. Steady state power balance alone does not result in system stability.

Regards,

Charles Rhodes

(for more detailed discussions of this and related subjects , see *http://www.xylenepower.com/Generation%20Valuation.htm* *)*

Number three.

Dear Dr.-------,

Most power reactors operating today are essentially of a late 1960s or perhaps early 1970s design. The reality is that each generation of power reactors has a life of about 50 years. The pace of climate change is such that mankind does not have the luxury of spending several times 50 years to develop and widely deploy fuel sustainable power reactors. Unless there is an expectation of getting things done a lot faster than that mankind as a species is doomed.

During WWII US nuclear reactors went from a laboratory prototype to making bombs in about three years.

During the 1960s the US went from a sub orbital space capability to landing men on the moon and returning them alive in less than a decade.

During 2020 the US developed, and field tested a vaccine for a previously totally unknown and frequently lethal virus in less than one year.

I have great respect for US led industrial capability when it is suitably motivated and directed. However, your reactor development time frame expectations are not remotely sufficient to address the present climate emergency. You may be very intellectually qualified but at this time the US nuclear industry needs a leader with the authority, drive, vision, and delegation capacity of General Groves during WWII. I believe that he was also responsible for the construction of the Pentagon before he took on the Manhattan Project.

There is no point aiming low. Absent development and wide deployment of a fully fuel sustainable power reactor technology the present human population can measure its future in decades rather than in millennia. Half measures will not accomplish the desired goal. Reactor technologies that do not lie on the critical path are simply resource consuming diversions.

The goal is a fuel and waste sustainable power reactor technology that can be duplicated worldwide in the range 20,000X to 60,000X during the working lives of persons already alive today. Anything less than that is not consistent with sustaining the present world human population. If you are not happy with that expectation, stay out of the way. Please do not use your influence to promote unsustainable reactor technologies where the principal goal is someone making a quick buck at taxpayers' expense.

At this time the US needs real leadership, especially with respect to electricity markets and advanced nuclear power reactor development. Please figure out how to arrange that leadership under the new Biden-Harris administration.

I suggest that John Kerry will need on-going advice from experienced nuclear industry persons who have a shared goal of rapid development of fuel sustainable nuclear power. In every direction in the USA, and elsewhere, people need to either get on board with fuel sustainable reactor development and electricity system harmonization or get out of the way.

President Biden was elected on a platform of improving social equity in the USA. Providing social equity costs serious money. The Republicans have been blocking the tax increases necessary to fund US social equity programs. The result is that the US is simply printing money to fund these programs which is causing rapid inflation. Viewed from outside there is a loss of confidence in the continuing value of the US dollar with respect to other currencies. There is presently simply too much debt in the USA that must either be written off or inflated away.

In the international market for many years most products were priced in US dollars. Today if a foreign supplier sends a commodity to USA and is paid in US dollars two months later that supplier might lose as much as 10% on the transaction due to rapid decline of the US dollar with respect to other currencies.

Consequently, the US is facing price increases and commodity shortages across the board. Even US citizens are being advised to dump their US dollar holdings.

If you want to put an end to this nonsense, tell your Republican representatives in both the US House and Senate to approve rather than block major tax increases. The simple reality is that US Republicans want to maintain low taxes by preventing social equity. The price of that policy is social violence right across the USA. The Democrats have promised to deliver social equity. Absent Republican co-operation on the necessary tax increases the US government is printing whatever money it needs to to fund its existing social equity programs. That money printing is causing inflation.

This same "conservative" logic applies to electricity generation. The Republicans would rather burn fossil fuels because in the short term they cost less. Again, either tax or electricity rate increases are necessary to fund nuclear generation and related transmission. The Republicans have a religious opposition to increased electricity rates or taxes. However, there are some things that governments can often do more efficiently than private industry. One is the provision of health care and another is the provision of reliable electricity.

If the people of the USA want both social equity and modest imported commodity prices they must accept big US tax increases. Absent those increases all imported commodities will become more expensive and in short supply. Viewed from the outside, the USA is in a social war. There is enormous wealth disparity. There is extraordinary gun violence. Several years ago, Elizabeth Warren reasonably estimated that it would take a 2% per annum tax on all wealth in the USA to even begin to restore social equity. Until the US population as a whole faces that reality things are going to keep getting worse.

If you want to fix this situation, stop fossil fuel interests from funding the election campaigns of Republican politicians. Absent a wealth tax the USA needs about a 20% value added tax on all commercial transactions to fund social equity. At present most well-to-do US citizens are unwilling to face that reality. The USA's internal war will keep getting worse until that message finally sinks home.

Regards,

Charles Rhodes

APPENDIX XXVIII. Note from a recently retired US Professional Engineer (chemical) who had spent his career doing work related in one way or another to implementing this book's "nuclear renaissance". This one mostly has to do with the USA's (over) regulatory system.

"Agreed, increasing demand generally increases prices when supply is limited at the original demand. There is no precedence in the commercial market for predicting Th supply demand responses. A credible fundable business plan for U or Th fueled reactors must include a well-planned and substantially proven complete fuel cycle including reprocessing of existing and future spent fuel. I can lead you to a low-level radioactive waste site in UT where EPA disposal policies forced my former employer (32 yrs) W. R. Grace to dispose of 7000 tons of Th waste left from extracting rare earths from Monazite. This was done in the very plant in Chattanooga, TN where the US Gov. built the Vitro plant to extract Th from monazite for 233-U breeding work. This plant was owned by Nalco who Grace bought from Vitro. When I started with Grace in '73 at another former Nalco catalyst plant in South Gate, CA, one of the foremen had worked at the Vitro plant and he had many tales to tell about the goings on at that operation.

By late 80's I was working for Grace in Baltimore in Research for cracking catalyst materials and processing. The discovery of high temperature superconductivity in YBCO 123 in '87 triggered a flurry of people trying to figure out how to make this stuff in quantity and how could it be used. In '88 one of my colleagues Dr. Nicholas Spencer and I developed a synthesis that could make consistent high purity 1kg batches of HTSC YBCO 123 powder. We are co-inventors on a patent for this synthesis. Sources of yttrium were very constrained at that time. We all were hyped that his material was going to change the world. My office mate was sent to the Chattanooga monazite extraction plant to investigate possibilities for extracting yttrium from various raw materials. While he was there the EPA was snooping around and found the large Th residue pond at the site. They decided this could not be left to over flow into a nearby stream and must be interred somewhere else. It was determined that several decades of processing monazite had deposited about 8kt of Th in the pond.

The main go-to company at that time for nuclear waste was "Chem Nuclear" and they were going to charge as much as $1000 per cubic foot of waste! Management realized that that liability would bankrupt the company. At that time Chem Nuclear had a near monopoly on high level nuclear waste disposal and were regarded as "mafia" by my colleagues. The plant manager ----- ------ had a long credible relationship with TN state and Federal radiation regulatory personnel. After a year or so of back and forth, the EPA determined that the Th wastes could be interred as low level radioactive waste. This was a huge breakthrough for Grace. The material had to be dredged from the ponds and dried. Grace agreed to build an onsite storage silo to hold 1000t of the dried waste into perpetuity. The remaining 7000t were sent to disposal somewhere in UT as I recall.

The point is there is a lot of Th around and people know how to extract it, but these regulatory constraints must be dealt with openly and up front. Funders are not stupid about the liabilities. Monazite does have small amounts of U in it that have to be disposed of as well. That was another disposal issue. Even after 30+ years from discovery, the promised miracles of high temperature superconductivity have yet to yield any world changing products because they are very hard to fabricate into durable useful structures. So the massive need for yttrium has remained a dream.

Th breeder designs as we discuss them can barely produce as much fissile as they burn let alone build fissile inventory to fuel other reactors. This is not where we need to put our limited funding during the next 20 years if we want to grow the breeder fleet fast. Even Pu breeders take a long time to produce enough fissile to start another reactor with several fuel reprocessing steps during that time which we see as about 40 yrs in the shortest interval and out to 200 years for a slower fissile production rate. There is no fission reactor powered future in any case without robust total fuel cycle processing capability with all of its nitpicking regulatory snags. Everybody needs to get together now and work on a secure fissile fuel supply otherwise there is no future for fission power of any type.

Cheers,

John Rudesill"

APPENDIX XXIX. What history tells us about intermittent energy's cost impact upon the USA's "heavy" industries

(facts & links courtesy of John Rudesill)

Here's (below) a 2017 Reuters article on US aluminum smelter closures and re-openings since 2000. Enron's entry into the USA's then recently "privatized" electricity market proved to be "*the vector of death*" for many such industrial endeavors.

https://www.reuters.com/article/us-aluminium-ahome/can-trump-resurrect-u-s-aluminum-and-who-killed-it-anyway-andy-home-idUSKBN1A201M

Another Google search (link below) for what had happened in MD revealed that its "Allegheny Power" system would not meet the price that its "Eastalco" aluminum smelter required in order to stay competitive. Prior to that time what it had been paying for electricity was already ~40% higher than the global average.

https://www.google.com/search?rlz=1C1EODB_enUS524US526&sxsrf=ACYBGNQmswYa5yp9EEXfvMwVdLXdSJnjGg%3A1580934566277&ei=piU7Xo3EEIWJ5wL5s4eABA&q=aluminum+smelter+in+WASHINGTOn+CLOSED&oq=aluminum+smelter+in+WASHINGTOn+CLOSED&gs_l=psy-ab.3..35i39.26680.26680..29253...0.2..0.68.68.1......0....1..gws-wiz.......0i71.bN_zkcUt_hI&ved=0ahUKEwiNr_GZoLvnAhWFxFkKHfnZAUAQ4dUDCAs&uact=5

Similarly, there used to be a big silicon solar PV manufacturing plant in Frederick MD - "Solarex", then BP (British Petroleum)-owned. Its big electric melters zone-refined the raw Si ingots used to make its single crystal-type PV cell products. Up to circa 2008 Solarex built/sold completely fabricated PV panels 100% wired and ready for shipment. Very few of its workers were originally from that region - the majority were from East Asia and South America but had moved to and settled down around there. It's uncertain whether the USA's ballooning power costs caused its demise or BP's (British Petroleum) decision makers had finally concluded that it couldn't compete with "foreigners" in that business anymore.

Like many other states, MD's leadership has not seen fit to retain that sort of heavy manufacturing. Its policies default to off shoring both the factories and the jobs they provided and then having to somehow provide more welfare for more displaced workers with reduced tax revenues. That's one of the reasons why the USA's public schools and other such services have become so poorly supported. It's also the reason that Mr. Trump became our POTUS.

This is the sort of brilliant planning & policies responsible for the USA's current degree of political polarization –its “working class” has indeed been left behind meaning that especially stable, reality show geniuses can readily manipulate and take advantage of them[5].

APPENDIX XXX. ERCOT data, not modeling , based, nuke+wind+solar+storage power system optimization

This Appendix compares different future power supply scenarios for the Great State of Texas. It’s based upon 4 years’ worth of that region’s *hourly* demand and wind/solar condition data (~140,000 measurements). That data is real, not averaged, “smoothed”, wishful, or theoretical.

The program and data were compiled by Dr. Eugene G. Preston, PE -an exceptionally rational Texan.

“*I have posted a small program on my web page (https://egpreston.com/) that can be used to design fossil fuel free power supplies. Instead of calculating reliability indices, it just assigns natural gas as needed to serve whatever the load happens to be. The printout tells you how much gas capacity and energy is needed. You enter your many years of demand profile in an hourly text file along with profiles for those historical years for hydro, two wind profiles, and two solar profiles. Tell the program you want to add certain amounts of EV load, storage, and nuclear capacity and let it run to see if you have added enough of them to not need natural gas backup. It takes a lot of storage capacity to provide seasonal storage but can work with an all wind & solar powered system if you put in enough. I have posted the Python program (& also a Fortran version) on my web page along with three sets of ERCOT* study cases for 2010-2013 historical load and wind data, some of which was put together based upon earlier Panhandle wind velocity data. Native ERCOT peak demand is 75 GW load profiles in hdata.txt are 2010-2013. There is no hydro in Texas. Wind 1 (W1) is non- coastal *34.3% CF). Wind 2 (W1) is coastal wind (33.4% CF). Solar 1 (S1)is Pecos area tracking solar (28% CF). Solar 2 (S2) is Austin/San Antonio rooftop solar (19% CF). Nuclear is dispatched first if +MW and after renewables is -MW nuclear. Storage first captures spare energy from renewables, then from nuclear, and finally from gas.”*

[5] A much-frustrated junior WW-1 German non-commissioned officer’s outstanding self-taught oratory skills had a great deal of influence upon the fate of his nation, Europe’s Jews, other minorities, and the outcome of WWII.

Wind costs $1/W to build plus $2/W for additional transmission/integration.

Tracking Solar is $1/W plus $2/W transmission/integration

Rooftop Solar is $3/W

Gas is $1 Watt build cost plus ten years' worth of $3/million BTU gas.

The program file can be downloaded from & used in your job, teaching, or whatever. There are no restrictions and no guarantees. If you see an error or have a question, please send me an email (Gene Preston g.preston@ieee.org).

Table 20 lists inputs and outcomes of a number of ERCOT-relevant supply/load/storage scenario calculations.

1. In all cases, I've assumed a peak system demand of 75000 MWs (75 GWe) sans EV charging (an optional variable).

2. In all but one case (second row) I've assumed EV battery charging demand of 8 GW (approximates 20 million, e "premium" Tesla Model 3's with 75 kWh batteries driven 40 miles /day).

~24,000 mile circumference

3. In most cases a grid stabilizing storage capacity of 200,000 MWh (200 GWe) is assumed for 20 million Grid Integrated Vehicles (GIVs) because no more than ~10 kW can be drawn/added to each EV via residential-type EV hookups. No costs were assigned to grid storage service because the cars would be bought for and serve purposes other than occasional grid stabilization/backup. 200 GWh's worth of dedicated storage capacity would likely cost about 80 billion of today's dollars.

5. Very high nuclear power plant GWe capacities (66 and 67 GW_e) were assumed in two cases (much more than Texas's current ~5 GW_e) because my purpose was to identify those actions/decisions that would make the most sense over the long haul, not what's currently considered "reasonable"

Table 20's topmost row's inputs (columns 1-5 and 7) approximate ERCOT's current (2020) source situation with the addition of 20 million GIVs serving to add 8 GWs additional demand and provide 200 GWh's worth of "free" lithium battery-type grid stabilization storage. Its second and third rows represent 100% gas scenarios (no wind, solar, or nuke) both with and

ev load	W1	W2	S1	S2	storage GWh	nuke	% W+S	peak gas	GWh gas	$B	tonnes/a CO2
8	22	6	4.5	0.7	200	5	26	64	225907	234	8.76E+07
0	0	0	0	0	0	0	0	75	365686	156	1.42E+08
8	0	0	0	0	200	0	0	78.3	435741	175	1.69E+08
8	25	25	12.5	12.5	200	5	46	55	193454	343	7.50E+07
8	50	50	25	25	200	5	77	52	57697	535	2.24E+07
8	100	100	50	50	200	5	89	43.3	3686	964	1.43E+06
8	200	200	100	100	200	5	100	25.4	542	1846	2.10E+05
8	0	0	0	0	200	66	0	0.54	462	265	1.79E+05
8	0	0	0	0	200	67	0	0	0	268	0.00E+00

Table 20 ERCOT data-based electrical system modeling scenarios.

without the GIVs. The 4th through 7th scenarios/rows assume EV load/storage with a modest (today's) amount of nuclear power (5 GW_e) with differing amounts of two kinds of wind (W1 & W2) & solar (S1&S2) -sourced power capacities. The total nominal capacity of which renewable sources range up to eight times the system's current maximal demand (i.e., up to 8*75 or 600 GW_e) The last two scenarios (rows 8 and 9) assume 66 or 67 GW_e's worth of nuclear power plants with "smart" EV car battery backup but no windmills or solar panels.

I've assumed a $4B/$GW_e$ capital cost for nuclear build outs because that's what recent Asian experience suggests represents a reasonably conservative figure (i.e., that the USA chooses to become competitive again).

The last column lists each scenario's total CO_2 emissions assuming 55.5 MJ/kg methane & 46% heat-to-electricity gas turbine energy conversion efficiency.

Another consideration is that since Texas's Permian Basin gas-mining operations leak ~2.7 E+6 tonnes of methane per year and gram-for-gram it's ~86 times worse GHG than is CO_2 (Zhang et al 2020), Texas's gas addiction is likely adding another 232 million tonnes CO_2 equivalents of GHGs to the atmosphere (in other words, gas leakage incidental to "gas power" is likely more harmful GHG-wise than is the CO_2 generated by burning most of that "mined" to so use.)

A final consideration is that all of the scenarios invoking EVs would greatly reduce Texas's vehicle CO_2 emissions. 20 million, 25 mpg (miles per gallon), ICE cars driven 40 miles per day would emit ~114 million tonnes of CO_2 per annum – considerably more than does its current natural gas-dominated electrical supply system.

It is currently unfashionable for Texans to "believe" that GHG emissions are important, but it might become easier for them to do so after the next "*100 year hurricane*" wipes out another of their coastal cities.

Please note that the 100% nuclear-powered scenario is relatively cheap, much simpler, and, of course, doesn't pollute the atmosphere with anything.

APPENDIX XXXI. **Battery-powered farm tractors?**

In a 100% politically correct, all renewables-powered world, its farm tractors might have to be powered in the same fashion as Mr. Musk's TESLA cars; i.e., with electric motors "fueled" with storage batteries that could be charged up with solar panels and/or windmills whenever local weather conditions permit. A little GOOGLING & calculating suggested to me that it wouldn't work very well. A 270 hp, 4-wheel drive, typical Iowa-type farm tractor (e.g., John Deere 8240) run at 75% max could do a short-by-farming-standards day's work (10 hrs of ploughing) with "only" 31* of Mr. Musk's 1200 pound, 85 kWh Tesla S battery packs (19 minutes between switch-outs). The last quote I saw for a single "fresh" such battery pack was $12,000.

That would mean that a politically correct, 100% renewable's-powered future's food-eaters would have to be pay even more farm subsidies than we do now. Implementing a fine-sounding scheme like this one is indeed "possible" but unlikely to be considered desirable by the people forced to pay for it.

* I'd assumed 50% discharge per cycle so that my basis Iowa farmer's precious battery packs wouldn't all "die" during their first two seasons.

APPENDIX XXXII. "Balanced" two-component veggie (wheat, soybean, maize, and peanut) dietary combinations

	kcal	protein g/100	fat	carbs	Ca mg/100g	P dl Mo	Fe*	Zn*	Mg*	thiamin*	niacin	vitamin C
MDR	2500	60	70	130	1250	450	11	11	400	1.3	16	74
corn	365	9.42	2.74	74.3	48	210	2.2	2.7	127	0.39	0.2	6.8
soybeans	446	36	20	30	277	704	16	4.9	280	0.9	1.6	6
flax	534	18.3	42	28	255	642	5.7	4.3	392	1.6	4.1	0.6
peanuts	567	25.8	49.5	16.1	92	376	4.6	3.3	168	0.64	12.1	0
wheat	339	13.7	2.7	71	34	508	3.7	4.2	144	0.42	0.67	0
rice (white)	367	9.4	0.7	74	28	115	0.8	1.2	23	0.07	1.6	0
sorghum	368	13.3	2.4	73	180	429	7.6	3.6	184	0.4	3.4	0
quinona	368	14.4	6.1	64	47	457	4.6	3.1	197	0.36	1.5	0
potato	77	2	0.08	17	12	27	0.8	2.9	23	0.08	1.1	20
onions	40	1.1	0.1	9.3	23	29	0.21	1.7	10	0.12	0.05	7.4
carrots	40	0.9	0.2	9.6	33	33	0.3	0.3	12	0.07	1	5.9
dried red peppers	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	76
dandelion	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	35
WFM's $1/100g mixed salad	31	1.2	0	6	29		?	?	?	?	?	?
lemon	29	1.1	0	9.3	26	16	0.6	0.06	8	0.04	0.1	53
chicken - meat only	121	21.4	3.1	0	12	173	0.9	1.5	25	0.07	0.82	2.3
4:1 corn/soy bean g/100	381.2	14.736	6.192	65.44	93.8	308.8	4.96	3.14	158	0.492	0.48	6.64
4:1 corn/peanut*	405.4	12.696	12.092	62.66	56.8	243.2	2.68	2.82	135	0.44	2.58	5.44
g/2500 kcal→ ↓	total grams											
g 4:1 corn/soy/2500kcal	649	96	40	425	609	2004	32	20	1023	3	3	43
4:1 corn/peanut/2500kcal	602	76	73	377	342	1463	16	17	813	3	16	33
4:1 wheat, soy 2500 kcal	684	124	42	430	565	3743	42	30	1171	4	6	8
food compositions		https://fdc.nal.usda.gov/			https://en.wikipedia.org/wiki/Rice					(several grains)		
MDRs		https://health.gov/our-work/food-nutrition/2015-2020-dietary-guidelines/guidelines/appendix-7/										

APPENDIX XXXIII.
Dr. Pavlak's CARES Report*

Maryland's Options for Affordable, Reliable 100% Clean Electricity; Part 1, Clarifying options in support of Maryland's The Clean and Renewable Energy Standard (CARES) CARES planning effort (Pavlak 2019).)

EXECUTIVE SUMMARY

Maryland's new goal, 100% clean electricity, should shift its decision makers' focus away from making the "best" immediate incremental step to devising a final design. Rational development derives the best next step from the best final design.

Lessons learned from previous attempts to implement similar systems (see §3.0) show that:

- Solutions are regional; every system is unique with different optimal solutions.

- The three systems featuring the highest percentage of variable (wind and solar) generation (Denmark, Ireland, Germany) all have high GHG emissions (similar to PJM today) and the EU's highest power prices.

- Its costs are huge - Germany spent > $180 billion over the past 5 years. The big risk is that its politicians blow the budget on the wrong solution then cannot afford to repair their mistakes in a timely manner.

- Hydro dominated systems (Brazil, Norway, and Quebec) have zero emissions. But hydro requires the right geography and is unavailable to Maryland or PJM.

- The three systems with the highest percentage of nuclear power (Sweden, France, and Ontario) all have nearly zero emissions with moderate retail prices.

- Ontario's is the only system that has successfully transitioned from high to low emissions over the past 15 years. It was accomplished by replacing coal with rebuilt CANDU reactors (aee APPENDIX XXV).

- Variable generators without storage contribute little or no value to a clean system.

- On a high carbon system, variable generation saves fossil fuel. On a clean grid there is no fossil fuel to save and variable generation by itself has no value. For wind and solar to contribute value to a clean grid they need to be combined with storage.

- The combination PV+ storage can be a viable niche component of a reliable clean electric power system. A system concept design study is necessary to quantify the amount of storage and to quantify cost/benefit.

- Land use is a political objection to onshore wind and solar power: providing 50% of Maryland's electricity consumption via PV would require roughly 80% of Charles County land area.

- 50% of Maryland's electricity consumption from wind would require roughly 21% of Maryland's total land area.

- Overbuilding 2-3-fold would require proportionally more land.

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APPENDIX XXXIV. COVID-19 : The good things that today's pandemic might bring about

The COVID 19 pandemic has revealed that far from living in an age of incessant technological advances, we have been neglecting innovation in some of the areas where it's most needed. Faced with a 17th-century plague, we pretty much had to fall back mainly on the 17th-century's quarantining and theater-closing. While innovation has indeed been speeding up in some arenas, in others it has been quietly stifled. Like happened during the last century's 2nd world war, this pandemic is apt to bring about some long overdue and badly needed paradigm shifts. A lot went wrong with America's uncoordinated response to it but one thing that didn't was how parts of its corporate, profit-driven, healthcare system were temporarily shoved aside in the interest of getting its citizens the care they needed.

It's easy to forget how new most of the technologies that we now take for granted - the internet, widespread digital connectivity, and zillions of useful apps - really are. On January 10, 2020, an Australian virologist, Edward Holmes, published a modest tweet announcing that a Chinese colleague, Zhang Yongzhen, had rushed to sequence the genome of the mystery virus from Wuhan—his team had worked practically nonstop, completing that sequencing a mere 40 hours after a sample had arrived at his Shanghai office. Both that & the fact that many of the world's governmental leaders insisted that they do so, caused the world's big pharmaceutical laboratories to cooperate in turning recent advances in synthetic messenger RNA (mRNA) biotechnologies into a slew of effective COVID 19 vaccines in well under one year—the previous record for vaccine development was four years and had been set in the 1960s.

CNN's pandemic statistics as of 13March2021 (total deaths ~243,000) indicated that COVID-19 infections have a death rate of about 1.8% and have increased the USA's annual morbidity by ~8%. In the middle of November 2020, the New York Times reported that 54 million verified world-wide cases had caused ~1.3 million deaths - a 2.4% death rate. However, another report released at that time said that epidemiologists estimated that 40–81% of the world's population (about 7.5 billion) may have already been infected which, if true, would lower its deathrate to under 0.04%.

My conclusions are that 1) COVID-19 is not terribly dangerous to most of us and, 2) that the majority of those who do die already have one foot in the grave for one reason of another. It certainly doesn't seem to be another "Spanish Flu" which killed about 10% of the ~half billion people so-infected https://www.cdc.gov/flu/pandemic-resources/1918-pandemic-h1n1.html a century ago. Moreover, most of the Spanish flu's victims were relatively young and otherwise healthy meaning that they lost far more of their lives than have COVID-19's. Since the start of the epidemic, the mortality of the "over 80" hospitalized with Covid-19 has almost halved because we're learning how to better fight it.

As far as I'm concerned, since I'm now a senior citizen myself (76) with God knows how many still sorta-hidden comorbidities, I've decided to quit French-kissing of total strangers (damn!).

Isn't it a shame that thousands of people are still dying every day in first-world countries like ours (USA) because their governments haven't insisted that their medical practitioners treat the lungs of its near-death COVID victims with ~half-Sievert X ray doses (Feinendegen 2010, Calebrese & Dhawan 2013, Skinner 2020, Sharma et al 2020, Flemming et al 2020, Hess et al 2020, Moyses et al 2020, Sanmamed et al 2020)?

On the other hand, many countries' response to COVID-19 caused millions of extra deaths from cancer, heart disease and suicide along with job losses, bankruptcies, social disintegration and mental illness, especially among the young people at least risk from the virus itself. Consequently, to me anyway, the conclusion is that if we protect the old and vulnerable, the rest of us can go about our business(s) pretty much as if this were a typical flu season. The biggest risk is that our financially "optimized" medical system's response capability could be overwhelmed leading to increased collateral deaths.

While there is overwhelming support in the scientific community for a national lockdown, most of its members along with our public servants (civil service and medical professionals) have secure public-sector salaries and think in top-down, not democratic, ways.

Good things.

1. We here in the USA may come to realize that many of the people currently deemed to be « essential workers » (cops, soldiers, USPS workers, garbage collectors, meat packers, Walmart workers, etc.) , are indeed essential (not expendable) and should be so-treated/considered regardless of whether or not there happens to be an epidemic going on.

2. It's reminding us that there still are some US politicians possessing the characteristics that leaders should have (e.g.,, Joe Biden, Pete Buttigieg, Mitt Romney, Amy Klubochar, Elizabeth Warren, & Arnold Schwarzenegger (an immigrant).)

3. One of the changes I expect to see is that young people and their parents may finally come to realize that it should not be necessary to spend four or more years attending a $70 k/year university to learn how to make a living (see https://sfs.mit.edu/undergraduate-students/the-cost-of-attendance/annual-student-budget/) The quickest way to pick up anything « tough » is to combine supervised (the teacher's job) on-the-job-training (problem solving) with immediate access to the now-cheap technologies invented by people like Eric Schmidt, Bill Gates, Sergey Brin, Larry Sanger, & Jimmy Wales, not Noble Prize winners (yet) . There's absolutely no excuse for « our » schools to do things like forcing students to shell out thousands of dollars for temporary access to mandated textbooks or forcing them to pay for instruction/classes that they could « test out » of. We should adopt ways that people can get credit for having learned how do something other than by jumping through a gauntlet of hoops held/controlled by special interest (professional) groups or for-profit educational institutions.

4. It's apt to make more of us realize that the USA's ridiculously expensive "privatized" health care system doesn't work when things get really tough for its citizens[6] Ditto for most of its other « privatized » public services, utilities (e.g. ERCOT), etc.

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[6] Building/maintaining sufficient medical equipment, drug, and hospital surge capacity for occasional uses hurts that business sector's bottom line. Market forces encourage the development of drugs suited for common chronic not occasional acute infections. Consequently, the big investments for viral drug development are for diseases like AIDS and hepatitis B. For the equally expensive to develop/test/market cancer drugs, there will always be plenty of people (customers) stricken by cancers to rationalize big investments. Pandemics are infrequent and rarely linger for more than a year or two which renders drug development unprofitable. A hefty percentage of Big Pharma's "research" is done to come up with slightly different versions of old drugs whose patents have run out so that ensuing advertising blitzes keep the "big" money coming in. Finally, health service company CEOs, board members, and

5. It may remind us that tax-supported organizations like Idaho's biggest golden goose (Idaho National Laboratory) should be doing the research necessary to devise something able to address the now-near future's peak oil and peak gas conundrums, not just build itself more shiny new office buildings, do more "road mapping, and help its "industrial partners" sell us smaller versions of more of the same.

6. Ditto for government in general; e.g. why isn't the internet access that's become absolutely necessary for most[7] of the younger generation's eventual success essentially free for everyone? Why is it apparently still "legal" for our elected representatives to enrich themselves by taking advantage of "insider information" to dump their stocks when situations like today's cornonavirus pandemic come along? Why are « government jobs » considered to be best suited for unexceptional people primarily interested in becoming drones in our country's « safer » hives ? Public service jobs (e.g. teaching) should become tougher to get, better regarded, and better rewarded – not just relatively secure.

"*Teaching is the profession that makes every other profession possible"*

Fareed Zakaria

7. The current global epidemic has starkly revealed the pernicious effects of the over bureaucratization of key governmental agencies and services everywhere ; e.g., CDC, WHO, China(?) and many of the western world's state, provincial, and national governments. Previous examples of the conséquences of such behavior in just local regions (e.g., Flint Michigan's lead-in-tapwater issues, the federal government's response to the hurricane devastation of New Orleans and Costa Rica, and California's refusal to impose zoning rules that would have prevented its recent wildfire deaths) haven't yet generated enough fuss to convince us to insist that our governments change how they "do business".

8. It may finally become sufficiently obvious to its citizens that the USA has become a "pretend democracy" that they will insist that their representatives enable them to have greater influence upon what happens. For instance, it's become quite difficult for many to vote because its more conservative but better-organized political party has been systematically suppressing voter turnout ever since Newt Gingrich taught them how to think (Clawson 2020). The USA needs nationwide same-day registration, online registration, uniform voter registration ID laws (and

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their bigger stockholders can helicopter-off to their « safe » wilderness retreats (e.g., New Zeeland) during pandemics – the « essential » people doing civilization's hard work, can't hide from pandemics without losing their livelihoods.

[7] Not the born-rich kids of course.

then no further ID requirement), equitable access to polling places, ballots that can be seen and recounted, and so on. In other words, we need to, 1) insist that the USA become more like a genuine democracy and 2) become willing to demonstrate that we have learned how to properly assume that responsibility ; i.e.,take/pass some civics lessons taught by someone who's both bright and totally non-partisan politics-wise.

Here is a list of some of the long-overdue changes that need to happen if we're to take advantage of what COVID-10 should be reminding us of.

- Abolish the Electoral College
- Pass a new "Voting Rights and Responsibility Act"
- voting day should become a holiday
- ex-felons should be permitted to vote, etc.
- everyone should become able to pass the same civics test that "foreigners" seeking to become US citizens must.
- Ban gerrymandering
- End the filibuster
- Get 'dark money' out of politics
- Introduce term limits for the Supreme Court
- Grant statehood to Washington DC and Puerto Rico
- Lower the voting age to 16 provided that they pass their civics test (like Sweden's Greta Thunberg our smart young people should be allowed to vote)

9. The coronavirus pandemic has sped up a revolution in home-working, leaving offices around the world empty. But what was the point of them anyway? Consequently, it's apt to cause both employers and employees to question/change how much of the USA's business is done. For instance, the internet & today's communication technologies render us able to do what most of us do for a living almost anywhere. This epidemic has forced thousands of businesses to let that happen for a time sufficient to evaluate how it would actually work out. It will in many cases meaning that it's likely that we're not going to be willing to do as much superfluous commuting & business traveling as we did before. That's good because it would significantly reduce fossil fuel consumption/pollution and allow more parents to see/watch/help their kids grow up.

10. It's bringing out mankind's « humanity ». For example, the late-night network TV shows that some of us watch after the evening news, now mostly consist of unscripted, pleasant conversations between exceptionally bright people in their homes surrounded by their cats, dogs, and children communicating one-on-one with other similarly situated exceptional people. It's both fascinating and heartening to see how much we all have in common.

11. It also reveals why some of the world's « 'best » nuclear engineers have come to be so-regarded. For example, Charles Forsberg, recently observed to the little group of technically

minded, mostly retired, mostly senior citizens that I joined up with several few months ago that :

California has about one twentieth the number of cases as New York on a per person basis. The evidence is beginning to pile up on what may be the biggest pandemic story—the primary driver in the U.S. in terms of spread appears to be mass transit. If that is the case, some central cities may be shut down for a year or more—much longer shutdown than the rest of the country. If that is confirmed, we may create a couple of new Detroit's—the suburbs are doing well but the central city becomes economic ground zero where neither business or the middle class wants to be. However, since the major news networks are in New York, the obvious from a distance new story may be invisible to them in addition to such a story being an unacceptable conclusion. Could it be that we are seeing one of the USA's rare economic shifts?

12. It's going to become difficult for even the most rabid of Mr. Trump's "base" to ignore the fact that he's an incompetent peace-**and** war-time leader and should therefore be "retired" as soon as possible. Doing so might even prevent another world war – he might suddenly decide to punish China for his plummeting poll numbers by nuking it.

13. The USA's recovery program likely will cost several trillions of dollars on top of the mostly corporate/business-relief measures previously approved by Congress and Mr. Trump. Aggressive investments and well-designed policies could bring us back to a point well ahead of where we were before Mr. Trump's « Chyna « « poisoned us »[8]. Spending , one third of that magic money upon starting to implement this book's proposals would be a wise investment.

14. The oft-expressed goal of achieving zero fossil fuel use seems to be well underway thanks to ongoing COVID-19 scare lock downs (Berman 2020). According to Mr. Berman, we are (April 2020) learning how much of our world's activities are nonessential and the amount of fossil fuels they consume. He documents the decline in oil demand as lock downs curtail "nonessential" activities. Relative to the mostly-whispered discussions about the value of human lives relative to keeping the economy going, the term "non essential" has become a euphemism for valuing such peoples' lives and and livelihoods higher than those of people deemed essential. How different? In the extreme it could be zero or even negative where someone who only costs the economy and does not contribute positive productivity (e.g., a 75 year old, long- retired

[8] If COVID-19 did "escape" from a Chinese microbiology laboratory, it may very well have been something being developed/studied at the behest of the USA [NIH admits US funded gain-of-function research in Wuhan (nypost.com)]

government worker/trouble maker drawing two of its pensions). In the US we have seen roughly 30 million more unemployed non-salaried (not "professional") people since the imposition of lock downs because they were deemed "non-essential". Those figures may become much higher creating an economic death spiral that's apt to be more harmful due to more "deaths of despair" (https://en.wikipedia.org/wiki/Diseases_of_despair) than caused by the disease itself.

15. Today's biggest immediate crisis has also provided innumerable examples of just how talented, creative, nice, reasonable, bright, cooperative, and helpful many of us can be when properly motivated/challenged. However, like mules we occasionally need to be whacked up alongside the head to remind us of who we are and what we should be doing. Wars often do that - it remains to be seen if little tragedies like what's recently happened in Texas (February 15-18, 2021) will.

16. "*A pandemic is a test of a country's governance, and this is one the United States has failed. Much of that is on President Trump's colossal failure of leadership, but it also reflects a deeper skepticism about science and a proclivity toward personal irresponsibility — such as refusing to wear masks or get vaccine jabs. If American states were treated as countries, the places with the highest per capita coronavirus death rates would be Slovenia, South Dakota, North Dakota, Bulgaria, Iowa, Bosnia, Hungary, Croatia, Illinois, North Macedonia, Rhode Island, Nebraska, Kansas, Arkansas, and San Marino »*

(Kristoff 2020).

The fact that more people were (mid-December 2020) being killed every day by COVID-19 in the USA than had died in both Japan and So Korea since the beginning of that pandemic demonstrates the consequences of a technologically "advanced" nation's leadership downplaying and ignoring both science & predictable threats .Even though the prior administration had created a detailed pandemic "playbook" and US intelligence agencies had been briefing then-President Trump about it since the beginning of January 2020, that coronavirus found the United States unprepared and stubbornly incompetent. That finally-too-hard-to-ignore fact convinced just enough of the USA's electorate to render Mr. Trump a one-term President in spite of the fact that he'd managed to pack the Supreme Court, the US Senate, all of the USA's cabinet-level governmental posts, almost 50% of the House of Representatives, and about 47% percent of that electorate with like-minded sycophants.

17. Finally, the best news is that scientists have developed several vaccines that have already been proven to work which fact constitutes the best way to end a terrible year. Vaccination is humankind's most life-saving innovation, banishing scourge after scourge and halting the ravages of COVID-19 will probably prove to be at least as important as was the conquest of smallpox. By the beginning of 2020 China's scientists had already determined and published that virus's RNA genome meaning that utilizing today's technologies a host of effective vaccines

could be developed far more rapidly than with traditional approaches[9]. As recently as 2019, Wayne Koff, president of the Human Vaccines Project, had stated that: "*Vaccine development is an expensive, slow and laborious process, costing billions of dollars, taking decades, with less than a 10 per cent rate of success … There is clearly an urgent need to determine ways to improve not just the effectiveness of the vaccines themselves but also the very processes by which they are developed.*" It is disappointing that we had failed to speed up vaccine development before this year's pandemic. The private sector found them unprofitable, the public-health establishment preferred to lecture us about the perils of eating junk food and the World Health Organization itself had recently (2016) declared that the greatest threat in the 21st century to human health– was "climate change", not those aspects of human nature so amply demonstrated by Joseph Stalin, Adolph Hitler, and several of the world's current especially « populist » national leaders.

I left 2020 behind, a lot relieved, a little saddened, a lot disrupted, and also amazed at everything that had happened (I'd even moved to Iowa!) and eager to see if the positive changes that we've been promised really do come to pass.

APPENDIX XXXV. The reasons why DOE's technical people should pay more attention to enhancing their political acumen

My attitude about political correctness mirrors the definition usually attributed (probably wrongly) to President Harry S Truman, i.e., that..

"*Political Correctness is a doctrine, recently fostered by a delusional, illogical minority and promoted by a sick mainstream media, which holds forth the proposition that it is entirely possible to pick up a piece of shit by clean end.*"

My total lack of political skills/instincts rendered my career far less successful than it could have been. Consequently, when things got too much for me to take at INL, I had to retire early (at 62) rather than move sideways to another job that I'd be constitutionally better suited for.

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[9] Unfortunately, it's been almost impossible for China's pharma companies to test their own new vaccines because their own country's "Chyna Flu" infection rate was so low that it's statistically almost impossible to "prove" anything unless its subjects are deliberately exposed (China doesn't treat its own people like we did some of our colored folks who helped prove by their not getting them that antibiotics could cure a deadly disease.) .

Charles Forsberg, another ex-DOE Site worker, has been and continues to be much wiser - when things got similarly tough to take at ORNL he was invited to assume a Research Professorship at MIT. The following is an example of why our careers have been so different. About a year ago in response to one of Mr. Trump's idiotic tweets[10], I wrote & circulated a note to members of the little group (Alex Pavlak's) of mostly retired fellow technical nerds that I'd joined up with via SKYPE.

Five years ago, the USA elected a President who created a personality cult akin to that which dominated Germany throughout the 12-year duration of its "Thousand Year (aka Third) Reich". He has often been characterized as disagreeable, narcissistic, pathological, hypocritical, grandiose, vindictive, small-minded, evil, selfish, arrogant, cruel, and sometimes even "funny" (ha, ha). He has been writing/playing the role of Donald trump for decades, a fantasy that seems to attract/fascinate a surprisingly large fraction of America's voters including millions professing belief in the principles espoused by Jesus Christ but whose actions and attitudes mirror Trump's. The New Yorker reporter Mark Sanger famously characterized Trump as a real estate mogul, cheat, con man reality-TV star who'd somehow managed to achieve "an existence unmolested by the rumblings of a soul"[11] (McAdams 2016).

In other words, he's become a uniquely American political genius.

To which Dr. Forsberg responded as follows.

> *"The question is (your) goals. Great for the party faithful—does not work if trying to convince people to change positions"*

He then went on to reidentify the reasons that Mr. Trump is POTUS summarized in my aside near this book's Figure 82 having to do with "class warfare".

Dr. Forsberg is right of course – Mr. Trump is the President that we've collectively come to deserve – truly a "man of our people".

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[10] "*Maybe I should have been a doctor instead of running for President*" (www.washingtonpost.com › politics › 2020/03/06 reporting on Mr. Trump's visit to the CDC – its doctors had apparently been astounded at his immediate grasp of abstruse medical concepts. A few weeks later he also demonstrated astounding creativity in that discipline when he pointed out to his team of COVID-19 experts that they should look into how LYSOL injections would work - something that none of them had even thought about yet!

[11] McAdams DP, "the Mind of Donald Trump", https://www.theatlantic.com/magazine/archive/2016/06/the-mind-of-donald-trump/480771/

APPENDIX XXXVI. US Electricity markets

Sources: How Resources Are Selected and Prices Are Set in the Wholesale Energy Markets (iso-ne.com)

Explainer: How capacity markets work | Energy News Network

All of the USA's ISOs and RTOs run competitive energy markets wherein wholesale electricity is bought and sold periodically throughout each day. The goal is to minimize wholesale costs in a way currently deemed to be politically and environmentally correct. This is accomplished via two core mechanisms: economic dispatch and uniform clearing price.

Here's how they work.

Economic Dispatch: As electricity demand changes throughout each day, the ISO/RISO dispatches resources in economic merit order. Resources/bidders submitting the lowest-price offers are dispatched first. As demand increases, higher-priced generators are dispatched with the highest-priced resources dispatched last. As demand decreases, higher-priced resources reduce output in reverse merit order. "Resource" refers to any asset that can participate in the markets, such as a generator, an electricity import, a demand resource, or even a "virtual" trader. Demand resources are assets that help satisfy a system's electricity demand by reducing their own electricity consumption freeing up electricity for use by others and thereby providing "resilience". Virtual traders don't own any assets and instead trade on financial positions.

The energy price paid to all bidders/resources meeting demand is set by that resource in the supply stack that would satisfy the next increment of energy needed if demand were to increase. That price-setter is called the marginal resource. In the example depicted in **Error! Reference source not found.**, Resource D is the marginal resource or price setter. Every other resource that clears the market will get paid Resource D's price, regardless of the price they asked for in their supply offer. This type of auction is called a uniform clearing price auction and is common in competitive markets where commodities of all types (e.g., soybeans, corn, coal etc.) are bought and sold, and is used in all of the USA's competitive wholesale electricity markets.

However, in practice things are more complicated in that.

If demand increases during the period in question the ISO schedules the next-cheapest resource to increase operation—or to start operating if it was offline.

If demand decreases, the ISO tells the most expensive resource running to decrease its operation accordingly.

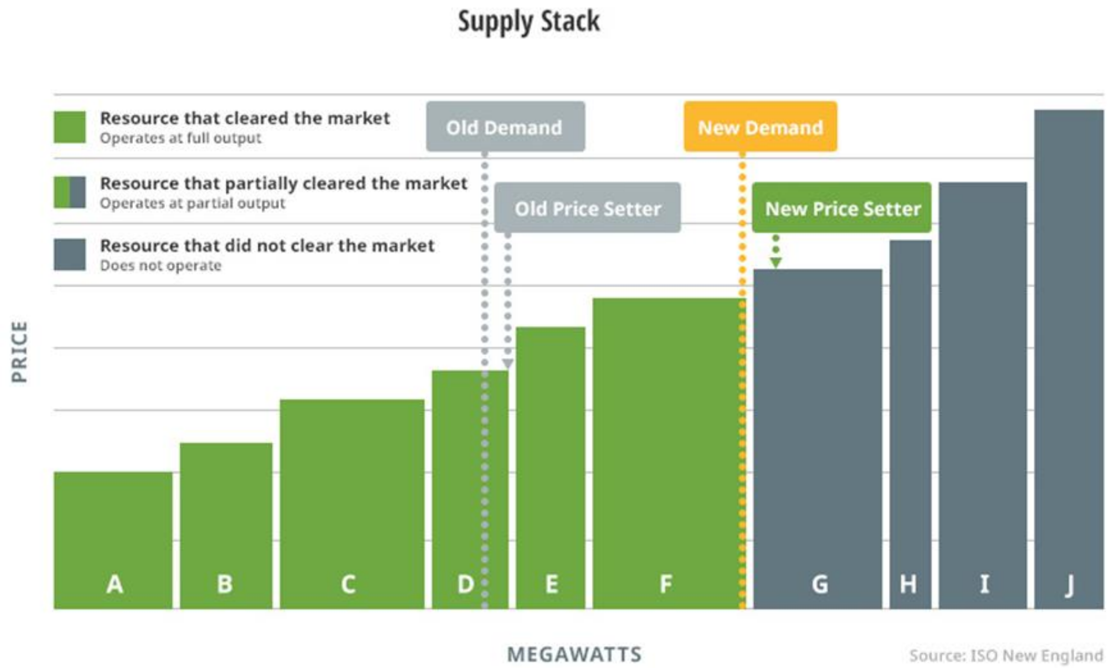

Figure 98 Dispatch Stack Example

These shifts can change the marginal resource and result in a new uniform clearing price. In the example below, demand for electricity has increased. Now Resource F is the last resource needed to satisfy demand, and Resource G is the marginal resource and sets the uniform clearing price for electricity, despite not having cleared the market.

It gets even more complicated. Sometimes, an ISO/RTO must dispatch power resources out of strict economic merit order to ensure whatever degree of system reliability that its ultimate regulator(s) (if there is one) demands. An example would be running a resource to maintain voltage in a load pocket within the range prescribed by federal and/or state, not the system's own "reliability" standards.

Capacity Markets

Some grid operators also incorporate a "capacity" (aka "forward") market which direct/rewards investment in facilities likely to enable the system to satisfy future demands. This is important because large, efficient, and reliable power plants are expensive and take lots of time to build which means that the risk that they may not succeed in "clearing the energy market" can and does discourage investment in them. A capacity market's goal is to generate price signals encouraging the development of sources capable of ensuring long term system reliability by compensating them for power that they will provide in the future. Every resource bids into a capacity auction at its total cost of operation, not its immediate/marginal energy production cost. Since power plants depreciate over time, such bids may sometimes be very low if a plant has been around long enough for its capital investments to be paid off meaning that its costs are limited to its operators, maintenance employees, and fuel. A new plant's total operational cost is often much higher because its bid must include capital costs as well. This means that the price that the owners of similar power plants bid into the market may vary dramatically. A 30-year-old nuclear plant could actually bid in lower than could a new zero fuel cost wind farm (the owners of a new nuclear plant today wouldn't have a snowball's chances in Hell of "clearing" most of the western world's privatized electricity markets).

APPENDIX XXXVII. Angola's Unfortunate Example

What's been happening to Angola's agricultural sector during the last few decades provides us with an example of Africa's special issues. The African Economic Outlook organization recently stated that "*Angola requires 4.5 million tonnes a year of grain but grows only about 55% of the maize it needs, 20% of the rice and just 5% of its wheat*" .Before it gained independence from Portugal in 1975, Angola was considered to be a breadbasket as well as a major exporter of bananas, coffee and sisal. However, since then, three decades of civil war (1975–2002) has destroyed much of its fertile countryside leaving it littered with landmines and driving millions of people into the huge slums surrounding its sprawling cities.

That country now depends on expensive food imports, mainly from South Africa and Portugal; while over 90% of its own farmers do so at a family subsistence level. Thousands of Angolan small-scale farmers are trapped in poverty and millions of its people routinely go hungry.

Freedom House's "Freedom in the World 2014" report classified Angola as 'not free' and the U.S.A.'s Department of State concluded (2012) that "The three most important human rights abuses were official corruption and impunity; limits on the freedoms of assembly, association, speech, and press; and cruel and excessive punishment, including reported cases of torture and beatings as well as unlawful killings by police and other security personnel."

A particularly toxic manifestation of Angola's peoples' lack of freedom is that its farmers aren't allowed to employ "agricultural biotechnology" and any imports containing genetically engineered (GE) components are still being limited to food aid (any such raw grains cannot be utilized as seed). In 2004 its Council of Ministers' Decree No. 92/04 restricted the use of biotechnology in Angola as a "provisional measure pending the establishment of a comprehensive National Biosafety System capable of properly controlling the importation, entry, use, and eventual production of GE organisms in the country". Since then, millions of Angola's people have continued to go hungry in spite of the fact that its " biocapacity" is about 20%

higher than is the world's average (1.9 vs 1.6 global hectares per person).

APPENDIX XXXVIII. Alex Pavlak's Marylandmatters.org OpEd (submitted 16Dec2020, published 22Dec2020))

Opinion: States Could Resolve Exelon's Dilemma With a Modest Temporary Clean Energy Investment

By

Alex Pavlak!

Earlier this year Exelon announced the early retirement of four nuclear reactors, and, in a recent conference call, the CEO commented on rumors that Exelon was considering separating its generation business from its utilities business.

In a guest commentary ["Is Exelon Spinoff Prelude to a Nuclear Bailout," Maryland Matters, Dec. 10], Tim Judson expressed concern that this was a prelude to a state bailout of nuclear and that states would be better off investing in 100% renewables. We disagree.

Our goal is the same as Gov. Larry Hogan's: sustainable, zero greenhouse gas emission, or GHG, electric power as soon as possible. The empirical evidence in favor of baseload nuclear is impressive. Of the eight largest clean electric power grids around the world (France, Quebec, Ontario, Sweden, Norway, British Columbia, Paraguay, and Switzerland) some combination of nuclear and hydro delivers 80% or more of the power.

In the 1970s, because of Arab oil embargoes, France decided to eliminate its dependency on oil for electricity generation. Over a 12-year period France built a fleet of 37 nearly identical nuclear plants resulting in an electric power system that is 80% nuclear, 10% hydro and 10% fossil. Today, 40 years later, France has the lowest cost electricity in Europe. France could eventually eliminate the last 10% fraction of fossil fuel by adopting demand management of electric vehicle charging.

Ontario, Canada, is an example of another successful transition. In 2005, Ontario's grid GHG emissions were 250 grams($_{CO2}$)/kWh, 70% of PJM's today. In 2019, its greenhouse gas emissions were 25 g/kWh. Today, Ontario has 94% carbon-free electric power, achieved by replacing coal primarily with nuclear.

In addition, Ontario is leading the development of (U.S. designed) small modular reactors. Ontario's dilemma is that it is forced to curtail (shut down) 25% of its wind, selling another 25% at deep discount prices. This is clean electric power, already paid for – yet the cheapest solution is to discard half of it.

The result is higher-than-necessary Ontario electricity prices. Today, Ontario is considering reforming its electricity markets to sell excess intermittent electricity at low wholesale prices (subject to availability) for electric vehicle charging, hydrogen electrolysis and off-peak heating.

Conceptually, intermittent energy has value on a high-carbon grid; whenever the wind blows, fossil fuel generators are throttled down to reduce emissions. Conversely intermittent energy has little value on a reliable low-carbon grid. The fundamental barrier is large scale intermittency, occasional long periods when there is little wind and solar generation — a low wind summer, the cloudy week.

Bridging these periods with any form of storage is, in most jurisdictions, prohibitively expensive. Around the world there is no empirical evidence of a closed system using intermittent generators that provide more than 30% of average power. So, getting to zero greenhouse gas is unclear.

The 100% renewables argument is based on modeling and should be regarded with skepticism because the models have not been validated. Good engineering models are validated by comparing model results with empirical data to show that models accurately reproduce variability, curtailment and firm capacity observed in real systems over multiple years.

Unvalidated (not good), models may obscure variability through inappropriate averaging and assumptions of independence, making intermittent generators appear less variable and more reliable than they really are. Nevertheless, existing models are useful in making relative comparisons among system configurations. A recent Princeton Study reveals that the introduction of some dependable low-carbon generators (e.g., nuclear, hydro) substantially reduces the cost of low-carbon systems.

Exelon complains that today's electricity wholesale markets inadequately value dependability. True. Exelon also complains that electricity wholesale markets place no value on clean. True. No new clean generation is currently cost competitive with natural gas when all system integration costs are considered.

Exelon's complaints will eventually be resolved through increased natural gas prices and market reform which will include more sophisticated valuation of the firm capacity of intermittent generators on real systems; greater dependency on more sophisticated capacity markets; a national clean energy goal; and environmental valuation such as a carbon tax or cap-and-trade schemes; and reorganization of our institutions to support more rational whole system design.

Exelon's dilemma is that none of this will happen soon.

Politicians view clean energy subsidies as an investment. So which investment is likely to achieve the goal of reliable zero greenhouse gas electric power at a reasonable cost? Exelon's existing dependable nuclear plants could be saved with a temporary investment on the order of 1 to 2 cents/kWh. For comparison, Maryland's commitment to undependable offshore wind commitment was 13.2 cents/kWh (in 2012 dollars) for 20 years.

Maryland also has the option of following former EPA chief Carol Browner's suggestion ["It's Time for States to Determine Their Own Clean Energy Futures," Maryland Matters, Dec. 4] and plan its own clean energy future. Choose the fixed resource requirement option and build additional nuclear reactors at Calvert Cliffs to become capacity independent of PJM. Voila! Zero greenhouse gas electric power; no games; no need to assume somebody will figure out how to deal with no wind, no sun, no power.

— ALEX PAVLAK

Dr Pavlak is a professional engineer whose day job used to be leading teams that developed new systems for the Pentagon. For the past 10 years he has been the chairman of the Future of Energy Initiative.

John Rudisill "Reply to Query on AAAS Community Blog regarding comparison costs of 1 kWh of solar PV and concentrated solar CSP."

EIA publishes LCOE (levelized cost of electricity) values for a full range of sources. They also caution that comparing LCOE's for 24/7 continuous base load sources with those of intermittent sources like wind and solar is not realistic. This is because wind and solar are not 24/7 sources and to provide power on that basis need back up of cheap to build fast response NG plants. When you dig deep into this stuff you find that back up requirements are not just an hour or two. Full seasonal back up of 30-60 days is required and that adds tremendous cost to the actual LCOE for an all wind + solar grid. Advocates of wind and solar often do not address this glaring reality that engineers who understand these systems find obvious.

I am one of three co-founders of www.futureofenergyinitiative.org (FOEI). We are a growing ad hoc group of mostly retired highly experienced experts in grid level energy systems including nuclear. We began almost a decade ago and we spend a great deal of pro bono time working to get our respective state governments to understand what the real challenges are to get off fossil fuels and what the real costs are. Our three founders are MD residents. We have colleagues in Ontario, CA, TX, CA, among others. We also find that academic papers and reports use models that are not validated with actual real time series empirical data that engineers demand to design real systems.

Reliability is a big deal. If people want zero emission energy with the availability, reliability, and affordable cost we are used to, they need to be very careful about what combination of resource technology they choose. California and Texas are headed for ever increasing blackout incidents because they are putting more and more wind and solar on their grids while they are retiring natural gas fueled plants which are the back up for the wind and solar. We know solar only operates when the sun shines. To make it a 24/7 primary energy source requires huge over build say 4-5x of average load to be able to charge storage for overnight supply. Some climates like here in MD we get long stretches of cloudy days where much longer storage capacity is necessary. The cost of such systems becomes very high. Our colleagues in Ontario, CA remind us that in January 2020 they had 6 days with no wind or solar output. If that was their only source they would all have frozen to death. Their highest load is of course for winter heat. PV provides little output at the time it is needed most so is a waste in high latitudes. In TX, the ERCOT system has maximum loads in summer for A/C. The wind is often slack during those times and the PV only works in the daytime.

What we at FOEI see is the necessity to move aggressively to a huge build out of breeder nuclear power plants (NPP's). Existing NPP's in several states are being retired due to markets that do not reward reliability only simple cost of operation with no accountability for back up function. The reality is that shutting down NPP's immediately increases GHG emissions because the replacement power comes mostly from natural gas fired turbine plants not renewables. If we are absolutely determined that we must switch to total energy from wind + solar and maybe some hydro and biomass, we are baking in very expensive and unreliable energy. Renewable advocates do not want to hear this and offer all sorts of dismissive excuses and arguments that are not valid in a pragmatic systems engineering perspective. The countries with the lowest GHG emissions from their electrical generation systems have smaller populations with large hydro resources and significant nuclear power such as Sweden, Norway, Costa Rica, and the provinces of Ontario, Quebec, and BC in Canada. France is pretty low also due to a large fraction NPP generated electricity. Countries like Germany and Denmark claiming high renewables energy contribution also have the highest priced electricity and they are dealing with potential blackouts. Germany has increased its GHG emissions due to shutting down its NPP's. and replacing them with coal burning plants!

NPP's are not classified as renewable even though the natural sources of thorium and uranium can power humanity for millennia if properly utilized. Nuclear power emits minimal GHG's and rightly is a "clean energy source". The proposed advanced NPP's do not have the big concrete containment domes because they don't use water as the primary working fluid so there is much less risk of leaking radioactive materials. There are many designs being developed and we are following these projects closely. Lack of funding and regulatory red tape is keeping the pace slow in the USA, but other countries like China, Russia, India, and Canada are moving ahead rapidly. The fears of nuclear energy are a challenge to overcome. Separating realistic fears from ones fed by excessive hype is the crux. People who spent careers in the nuclear energy realm know the difference and have minimal worries. I used to be scared but reading credible reports and learning from nuclear power professionals in their 70's I have come to realize it does not deserve the deadly risk reputation it carries and that fossil energy interests have contributed to anti-nuclear activism.

There is a ton of work that needs to be done to get off fossil fuels. The COVID-19 pandemic has shown that fossil fuel use can decrease with lock down impacts on travel and economic activity. Refinery closures are happening in the USA and EU. The fossil fuel industry knows it is doomed as do the manufacturers of ICE engine powered transportation vehicles. My worry is that the fossil fuel industry and supply can be collapsed far faster than we can replace it with clean energy. This is a very serious matter and we should not take joy in seeing it collapse. The fossil fuel providers are entering a tight squeeze. They are starting to be cannibalized by investors so that operating capital will fall causing their operations to degrade and be shut down. This can create fuel shortages and price spikes as the death spiral of this industry tightens. There will be stranded assets and polluted sites to manage. We need to be very mindful about how this is orchestrated no matter how much some folks might want to pull the plug tomorrow that is unwise and unhealthy.

APPENDIX XXXIX. Prof. Forsberg's August 2021 Nuclear Biofuels Video Conference

"Several things are coming out of our nuclear biofuels conference[1] *that may have major impacts on the big oil companies.*

1. A fairly clear transition route for the big refineries from crude oil to bio feedstocks is emerging. In some cases, transition with blending increasing quantities of biocrude with crude oil. In other cases, more different front ends.

2. In the near term, the hydrogen source will be steam methane reforming with CCS where cheap natural gas and good sequestration sites.

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[1] Can a Nuclear Biofuels System Enable Liquid Biofuels as the Economic Low-carbon Replacement for All Liquid Fossil Fuels and Hydrocarbon Feedstocks and Enable Negative Carbon Emissions? Three Wednesday Webinars (No Registration Fee): 10:00 am-1:30 pm EST; August 4, 11 and 18, C. Forsberg*, B. Dale1, D. Jones2 and L. M. Wendt3

3. Nuclear biofuels are probably the only cheap route to serious negative carbon emissions. In these systems vary liquid fuels production with carbon sequestration based on relative prices of biomass, sequestered carbon and liquid fuel prices. One gets very deep into the cost structure of refineries, cost structure of sequestration and long-term sustainable agricultural economics before this begins to come out of the woodwork. Unlike burning biomass with CCS, this system enables nutrients recycle that has serious long-term sustainability and economic benefits.

4. It's interesting for the organizers because this has to be one of the most diverse set of experts in different fields that have every shown up at a technical workshop. We probably will also have one of the more diverse audiences of any workshop. The organizers have the presentations in advance so running ahead of the audience.

I am working on a slightly different strategy: Shell, Exxon, BP, Chevron, ENI, Cargill, ADM, etc.

Oil companies have three groups—retail/market, refinery, and oil field. That implies that if the oil companies see a way to keep 2/3 of the business going, they will move. Like all big organizations, real stovepipe problems. I have worked for MIT, ORNL, Exxon and Bechtel—all have the stovepipe problem that makes it hard to see around corners.

The key policy requirement is a carbon tax on carbon emissions that includes payments for sequestered carbon. Costs $50/ton if emit carbon and get an equal or larger payment if sequester *carbon. Then let the market sort out the winning technologies. The problem with the mandate strategy is nobody has sufficient knowledge to know the low-cost routes.* "

Charles W Forsberg 8/7/2021

[1] Can a Nuclear Biofuels System Enable Liquid Biofuels as the Economic Low-carbon Replacement for All Liquid Fossil Fuels and Hydrocarbon Feedstocks and Enable Negative Carbon Emissions? Three Wednesday Webinars (No Registration Fee): 10:00 am-1:30 pm EST; August 4, 11 and 18, C. Forsberg*, B. Dale, D. Jones, and L. M. Wendt.

APPENDIX XL. Nuclear and other biofueling scenarios

Electricity rapidly becomes uneconomic if its application is far from the grid. The following spreadsheet's calculations deal only with that fraction of the USA's energy demand currently satisfied by petroleum most of which is used for transporting people and things.

Its peer-reviewed references were written by genuine agricultural experts who've spent a good deal of time determining just how much biomass we're apt to be able to produce if the USA were to go balls to the walls in that direction* – not overly optimistic extrapolations like the ones that have sold too many people on the notion that solar panels will continue to become radically cheaper . Our farmers are also unlikely to ever become able to raise 2000 bu of corn/acre.

We will probably also need to make something to replace today's jet plane, chainsaw, and farm tractor engine fuels but that's only a small fraction of today's petroleum demand. That's where nuclear biofuels make the most sense. Synthetic fuels will likely be required for:

a) Backing up nuclear heating systems;
b) Aircraft, ships, long distance trains, heavy equipment, off road trucks, agricultural equipment.
c) Easily attaining high temperatures;
d) Portable equipment;(e.g., Chain saws, water pumps, standby electricity generators)

We will also need to implement some form of large-scale energy storage that's more efficient and cheaper than batteries, the amount of which will be determined by whether we choose to build enough reactors to satisfy maximum, not average, energy demand. For that purpose, Terrapower/GEHitachi/Bechtel's LMFBRs close-coupled to/molten salt tanks or giant rock piles concept makes sense. Close-coupling sustainable molten salt reactors to molten salt storage tanks or giant rock piles would make even more sense.

The fact that many of Europe's people are apt to be "freezing in the dark" this coming winter (2022-2023) due to natural gas shortages should be getting our decision makers' attention too. The USA doesn't have infinite reserves of frackable natural gas & windmills/solar panels/gas transport systems often don't work during our winters either. Texas's poorer citizens got a reminder of that fact a few months ago but of course because poor people aren't any US state's decision makers, not much is being done to prevent it from happening again during the next polar vortex.

The following spread sheet suggests that if we here in the USA were to 1) eat totally "vegan" with our most productive food crops wheat, soybeans, & corn , 2) devote 100% of the ag land thusly freed up to raising the most productive biomass-producer yet discovered (Miscanthus) 3) convert its carbon to hydrocarbonaceous ($CH_{2.5}$) synfuels 100% efficiently with hydrogen generated by ~1200 one GWe breeder reactors, we could indeed replace our current petroleum demand in a “renewable” fashion.

Nuclear biofuel ballparking update d.siemer 17sep21											
Reference											
(99+) (PDF) Impacts of land use change due to biofuel crops on carbon balance, bioenergy production, and agricultural yield, in the conterminous United States | Min Chen - Academia.edu											
ZHANGCAI QIN, QIANLAI ZHUANG† and MIN CHEN," Impacts of...." GCB Bioenergy (2012) 4, 277–288, doi: 10.1111/j.1757-1707.2011.01129.x											
first & third rows of the following table are from above ref. The rest of the numerical input data is from GOOGLING											
	corn	soy	wheat	miscanthsus	switchgrass						
NPP g C/m2/a	690	27	320	1700	590						
Yield Bu/acre	170	55	52							438.6667	
area Mha	30.9	31.2	23.8								
wt grain/m2	1066.609019	345.0794	326.2569								
tot wt USA/a	3.29582E+14	1.08E+14	7.76E+13								
at 4 kcal/g in all grains tot kcal=	1.31833E+15	4.31E+14	3.11E+14				tot k Cal worth of grain/d/person US is now about			17099.08	
average kcal/day/330M	10945	3575	2579				lets assume				
Mha land required to feed everyone	9.035573038	9.123297	6.959438	Mha			2500 kCal/day necessary with an equal amount wasteds so need 5kcal/d/each of ~330 million				
land for miscanthus	21.86442696	22.0767	16.84056	Mha							
tot land for miscanthus if we raise only enough corn to provide everyone with 5000 kcal/d =						60.78169178	Mha possible are devoted to miscanthus				
at 1700 g C/m2 that'd be	1.03329E+15	g biocarbon									
if converted to SpG 0.9											
hydrocarbon with $CH_{2.25}$ that's	8.58E+09	42 gallon barrels of nuclear biofuel - US average petroleum consumption is about 18 million bbl/day or								6.57E+09	bbl/a
assuming that all of the hydrogen required to hydrogenate that biocarbon is from water electrolysis , how many 1 GWE reactors would we need?											
we'd need	1.93742E+14	g hydrogen									
"producing 1 kg of **hydrogen** (which has a specific energy of 143 MJ/kg) requires 50–55 kW·h (180–200 MJ) of **electricity"** , **WIKIPEDIA**											
assuming 190 MJ/kg we'd need	3.68109E+19	J's worth of electricity to make the H_2									
requiring	1167.266365	one GWe nuclear reactors running 100% of the time									
please note that battery powered cars (BEVs) are 5-7 times more efficient than are those powered with internal combusion engines meaning that far fewer new reactors would be needed											
what about miscanthus to ethanol - no hydrogenation											
factors - need cheap cellulose (carbohydrate) to ethanol process - still doesn't exist , lose 1/3 of the carbon to CO2 during brewing, & lots of energy inputs to raise crop, make,& purify product											
ref. Lask J, Wagner M, Trindade LM, Lewandowski I. Life cycle assessment of ethanol production from miscanthus: A comparison of production pathways at two											
European sites. GCB Bioenergy. 2019;11:269–288. https://doi.org/10.1111/gcbb.12551											
its table 5 says get about 240 kg ETOH/tonne dry miscanthus											
assuming that its carbon is present as carbohydrate (CH2O FW=30) 1700 g C/m2=						42500	kg dry miscanthis /ha				
so expect to get	10200	kg ETOH/ha									
so from	60.78169178	Mha expect to get		6.19973E+11	kg ETOH	which at 29.9 MJ/kg energy wise =			1.85372E+19	joules	
	one 42 gal bbl, SpG 0.9. 46 MJ/kg petroleum has					6581358000	Joules worth of heat energy				
	so that much miscanthus turned into alcohohl would be					2.816622399	billion bbls oil equivalent per year				
please note that the same amount of miscanthus turned into alcohol would produce only about one third as much fuel energy as it would if hydrogenated - much less than the USA currently consumes											
note too that the miscanthus to ethanol bifuel scenario is generally recognized to be much more efficient than is today's corn-to-ethanol route											

APPENDIX XLI. Another Modest Proposal

A half bottle of too old and terrible-tasting red wine helped me come up with this late-night suggestion (below) to my ZOOM buddies some time ago (1/23/2020) which was subsequently updated a bit and recently sent off to the ATLANTIC’s opinion-page editor.

Suggested title “How Mr. Biden could save the world”

The key to understanding the Kremlin’s actions (declaring war) on its relatively impoverished neighbor, Ukraine, is that Russia is an oligarch-managed petrostate relying upon oil and natural gas sales for about 40% of its total budget. Russia supplies about one half of Europe’s heating fuel — natural gas – and any crimp upon its ability to access that market represents a threat to its economic security.

To get its chief commodity to the EU, Russia mostly relies upon two old pipelines, one of which runs through Belarus and the other through Ukraine. For this, Russia had been paying Ukraine around $2 billion a year in transit fees.

In Russia's topmost oligarch's (Putin's) opinion, a switch of allegiance by Ukraine to the West — be it an economic association agreement with the EU like it was on the verge of signing in 2014, or even a hint of joining NATO — constitutes an act of war.

Putin views the fall of the Soviet Union as the "greatest geopolitical tragedy" of the past century and the rush of former-Eastern Bloc countries into the embrace of the European Union and even NATO, as a humiliation. Consequently, he has drawn a line in the sand through the ex-USSR countries bordering Russia, invading Georgia in 2008 when it hinted at joining NATO, annexing Crimea in 2014, and moving to further destabilize the rest of Ukraine when it moved to establish closer economic ties with Europe.

Domestically, Putin has sold his incursions into Ukraine on purely nationalistic grounds — even dismissing Ukraine's history as an independent country.

Since returning for his third term as Russia's president, his country has withdrawn further into itself no longer even trying to intertwine its economy into the global system or encourage foreign investment. As Putin and his oligarch buddies were building skyscrapers in Moscow with their petro cash, his government became more backwards-looking with his only important foreign admirers being other "real man" wannabes like the USA's Donald Trump and Brazil's Jair Bolsonaro. When Trump was replaced with someone that Putin couldn't rely upon and the EU, especially Germany, was facing a self-imposed home heating energy crisis*, he decided that it was time to "kick some butts". It's since become apparent that he's willing to risk starting another world war to prove that he's still a real man & that he's just up against a bunch of gutless western-world wimps[12].

So, what should our Mr. Biden do now?

He could "save the world"!!

---

[12] He may have been right about that. His policy of using natural gas as a weapon against Ukraine's supporters has raised its price as much as ten times previous levels and supplies are running out. Many look to Germany – the EU's largest economy – as the test case for continued European commitment to Ukraine. However, public opinion surveys suggest that energy prices are not the key issue to Germany's people. While they support Ukraine many of them also believe that they've done enough already. Two factors -- their memory of German aggression in World War II and concern about the costs of hosting refugees – seem to matter more than energy prices in German public opinion about helping Ukraine.

First, let's discuss his personal situation. Mr. .Biden is another old timey cold warrior who's also in deep doo doo at home politically & has also gotta prove that he's a real man capable of solving big problems including un/under employment here at home, ~40 million still-crazy Trump-worshipping constituents, COVID 19's interminable issues, global warming's consequences, & the inevitable economic consequences of the world's reaching peak oil/gas/coal etc. to his and everyone else's grandkids by the end of this century. He's also at least nominally** the leader of another nuclearly-armed-to-the teeth country that's a shadow of what it used be in several respects including the ability to either develop or implement anything as controversial as a "sustainable nuclear renaissance" would be.

Moreover, he, Putin, Macron, Scholz, etc. must come out of this thing looking like they & their countries have won/done something that's really great.

It'd be tough for Mr. Biden to pull off, but a way for him to end up being remembered as a great President would be for him to secretly ask for Putin's "help" in jointly saving the world before the yellow peril (Trump's "Chyna") totally dominates it & them both. Of course, that'd involve his declaring that it'd be OK for Germany to import its natural gas via Russia's already-built Nord Stream 2 pipeline and offering to "help" Russia build enough clean, reliable, & genuinely sustainable nuclear power plants by paying him & his oligarchs with enough freshly printed, genuine American paper dollars to replace the whole world's evil, finite resource guzzling, atmosphere polluting coal/oil/gas burning power plants, starting off, of course, here in the USA with Russia's already developed, fully demonstrated, & ready-to-go "cheap" (~$4/watt) fast breeder reactors.

He could even help a bit more by volunteering to <u>not</u> permit the USA's nuclear experts & regulators to supervise ROSATOM's construction crews and promise to put the glass made from its new closed fuel cycle's radwastes into another brand-new "Waste Isolation Pilot Plant" for free.

Of course, if he/we were to do that, most of the rest of the free world would likely decide that maybe they should get on the sustainable nuclear bandwagon too as they've done with just about everything else the USA has decided to do good or bad, smart or stupid, ever since the end of WWII.

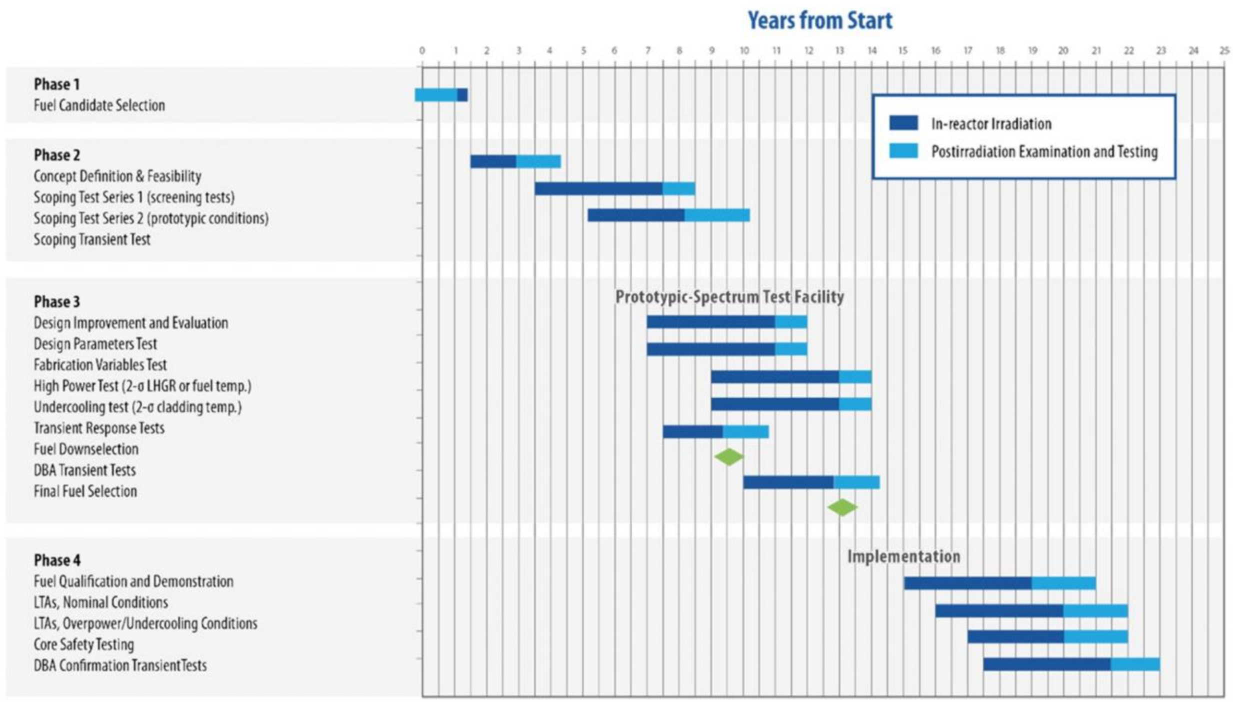
Meanwhile China's President Xi will probably just continue to wait and see what happens.

*As has also happened here in the USA, the EU's nations adopted policies that didn't maintain their nuclear power capability thereby rendering them more dependent upon natural gas whenever Mother Nature is being niggardly with her non-nuclear "renewables".

**Nominally" because until Congress officially declares war, a US President is just a figure head with an especially bully pulpit along with an especially big target printed on his back.

APPENDIX XLII. Up to date DOE road mapping example

Here's a hot-off-the-Press (Feb2022) example of the sorts of schedules that DOE NE and its business partners set for themselves when finally forced to admit that something "new" must be developed (below) – in this case it's a timeline for developing a "new" US reactor fuel. The "unique" thing about it is that its fuel "meat"(the actinide stuff inside the cladding) is to be metallic, not oxide-based. A detail not mentioned in Nuclear Newswire's parroted rationalization for this taxpayer-supported, quarter century-long, R&D boondoggle is that there's nothing 'new" about metallic fuels – the US and world's first breeder reactor - "EBR I" - first fired up in 1951 -utilized metallic fuels as did its successor, EBR II



The need for a metallic nuclear fuels qualification plan -- ANS / Nuclear Newswire (February 2022)

If General Groves had let his contractors and R&D experts do things this way, his successor would probably still be agonizing how we'd go about testing the world's first atom bomb 76 years after both of his program's quite different from-scratch creations helped to end WW II.

APPENDIX XLIII. Technical nerd Solar Power

Based upon what EBAY recently told me, if I were going to "go solar" it'd be with a homemade "plug & play" system. Such systems consist of solar panels connected to a grid-tied-type inverter (DC to 120 VAC converter) that's plugged into one of your home's existing electrical outlets. Since your home likely has 240 volt service that's split down the middle to make two 120 VAC circuits 180 degrees out of phase with each other, I'd be purchasing 2 separate 1000 watt, grid tie converters for ~$100 each, six nominally 327 watt solar panels at $100 each from one of EBAY's sellers, two $144/each racks each capable of supporting 3 panels, a coil of three conductor 14 gauge solid strand insulated copper wire, two heavy duty 120 V plugs, and about 25 dollars-worth of MP 4 connectors. Its total cost adds up to about $1200 depending upon how much wire is needed.

Table 18 A cheapskate technical nerd's solar power system

input your current cost /kWh-	0.11			
irradiance data Solar Energy & Solar Power in Texas | Solar Energy Local				
	AUSTIN TX assuming 6, 20% efficient panels			
	kWh/m2/da	kwh/day	kwh/mo	$/month savings
Jan	4.29	8.4	256	$28.16
Feb	4.93	9.7	294	$32.36
Tx	5.24	10.3	313	$34.40
Apr	5.54	10.9	331	$36.37
May	5.37	10.5	320	$35.25
Jun	5.45	10.7	325	$35.78
Jul	5.43	10.7	324	$35.65
Aug	5.67	11.1	338	$37.22
Sep	5.93	11.6	354	$38.93
Oct	5.85	11.5	349	$38.40
Nov	5.01	9.8	299	$32.89
Dec	4.56	8.9	272	$29.93
annual sums→		124.1357	3775.795	$415.34

Table 18 is a little spreadsheet I've put together for Austin TX resident, Gene Preston, that combines, 1) what NREL tells me that his hometown's solar irradiance is throughout an average year, 2) the above-proposed system's likely efficiency (about 20%), and 3) the assumption that he, his wife, or a servant (oops, I meant to say, their “essential worker”) shifts the panels sideways two or three times per day to roughly follow the sun.

If his regional “service provider’s” electricity were to cost 11 cents per kwh (Des Moines IA’s current rate), it would pay for itself within about three years.

This system’s great “weakness” is that it generates power when the sun is shining regardless of whether it’s needed then and won’t run your electricity meter backwards. However, it would be cheap, simple to put together, able to satisfy a hefty fraction of your electricity demand & could be rendered even more useful if you also had a few kWh’s worth of battery storage. The “obvious” way to implement that would be with a properly designed BEV or hybrid battery powered automobile which I’m hoping that Mr. Biden’s policy setters will incentivize that industry to provide us with.

What that battery might be is still unknown The USA’s premier electrical engineering news magazine recently announced that EVs had seized a record 5.8 percent of the United States’ new car market in 2022 and could get 11 percent of the global market by the end of 2023 https://spectrum.ieee.org/ev-battery-wish-list.

Battery “fueled“ cars barely existed when the Tesla Model S was still just a glint in Elon Musk’s eye thirteen years ago. The world now (March 2023) has over 20 million BEVs and that total is expected to nearly quadruple by 2025.

EV demand was anticipated for several years, but China was the only country that acted on it and is now roughly a decade ahead of the rest of the world in both cell production and the sourcing, refining, and processing of battery materials.

The battery comprising the heart of each of those cars remains by far its most expensive component, which fact has set off a worldwide race to “ethically” source battery materials and crank up production to meet demand. The industry’s experts are projected to spend $1.2 trillion to develop and produce EVs through 2030 and most of them believe that more and better batteries remain key to their products reaching a market tipping point.

In recent decades, it wouldn’t have made sense for a US automaker to also become a processing or mining company, but with today’s world-wide supply chain and political issues, the winner of its EV sweepstakes will likely have to take the same sort of “drastic” measures that Henry Ford did make his model T cheap enough for his era’s “middle” class to purchase.

Tesla’s CEO Mr. Musk also got out in front of the world’s legacy automakers by thinking in terms of vertical integration, the need to control the entire supply chain, from lithium brine mines to final production and recycling.

There are many possibilities that are not currently being given much press here in the US.

More sophisticated chassis and battery design along with a national commitment to implementing charging infrastructure would help a lot. Tesla’s Superchargers aside, the industry’s experts cite the USA’s patchwork, notoriously unreliable charging network as a leading roadblock to EV adoption. 2021’s U.S. Infrastructure Law is providing $7.5 billion to build a network of 500,000 EV chargers by 2030. But rather than own and operate their own chargers like Tesla is doing, GM, Ford and others in my opinion rightly argue that standardized, open-source chargers are critical to convincing more Americans to kick their ICE habit. Those refueling systems must be available everywhere that people live and work and open to drivers of any car brand. It would also help if those chargers were more reliable than today’s: A 2022 study concluded that nearly 25 percent of the San Francisco Bay area’s public chargers —a mecca for EV ownership—weren’t functioning properly. To fill those gaps in public networks, GM is also establishing “uptime guarantees” with its charging collaborators which would allow drivers to see in advance if a charger is operational and to hold them a spot.

Automakers and battery manufacturers are coming up with lots of possible solutions including more efficient chassis and battery designs that could give renewed life to “lesser” but good-enough battery chemistries that would otherwise be uncompetitive and obsolete —especially the relatively cheap lithium iron phosphate system that has become the hottest thing in batteries around the world.

Most of today’s electric vehicles (EVs) use lithium-ion batteries whose cathodes include nickel, manganese, and cobalt (i.e., NMC batteries). They provide an energy density of around 270 Wh/kg, which allows an EV to travel upwards of 300 miles (480 km) on a charge but come with some serious baggage. First, nickel and cobalt are mined primarily in Russia and the Congo, respectively. Sanctions against Russia and the Congo's questionable labor practices are causing the industry to seek out alternatives. Second, NMC batteries are susceptible to thermal runaway, potentially leading to catastrophic fires. Finally, with a lifespan of around 1000 cycles, they will need to be replaced every decade or so—roughly half of an EV's expected lifetime. Lithium-ion batteries employing iron phosphates as their cathodes (LFP batteries) are an attractive alternative but their higher weight (i.e., lower energy density) lessens EV range. That drawback has relegated LFPs to stationary applications (where weight isn't an issue) and entry-level EVs, where price outweighs range. However, greater nickel market volatility due to the war in Ukraine, the U.S. Inflation Reduction Act's emphasis of domestically sourced materials, the shorter lifespan of NMC batteries, and recent improvements in LFP energy densities means that they are poised to take over as the standard EV battery.

Two things that still don't seem to be getting much attention here at home are Thomas Edison's "battery switching station" car refueling concept and the far East's adoption of smaller/lighter/cheaper commuter-type BEVS.

Frankly I'm convinced that it's too early to buy an EV for myself yet because it's likely that today's offerings aren't nearly as efficient or affordable as 2030 AD's will be and neither I nor my wife really needs anything "better" than our already-paid-for gas-powered cars yet.

APPENDIX XLIV. US BN-800 build-out scenario

BN 800 reactor build-out modeling

(it's another demonstration of the "miracle" of compound interest)

here's a detailed description of russia's BN 800 breeder reactor

https://inis.iaea.org/collection/NCLCollectionStore/_Public/33/011/33011298.pdf

TABLE 1. Principle characteristics of the BN-800 reactor with MOX and uranium fuel

800MV 2.1 GW thermal, 565 fuel assemblies each with 127 pins

880 mm length 6.6 mm wall thickness 0.4 mm

that's 5.8 mm fuel meat diame | 25105381821.pdf (ia | 10.3 g/cc is realistic fuel meat density

vol UO2= | 1667479 | cm2 if density= 10.3 | 15.147 | tonnes total actinide

if 20% of it is fissile that's | 3.029398 | tonnes | (this is its startup fissile - mostly Pu- requirement)

Let's do some modeling

1) calc fissile burn from the reactor's output;

2) calculate extra new fissile generated by the breeder based uon its CR

3) add new reactors that that amount of fissile corresponds to

energy generated by one actinide fission=200MEV=3.2E-11 J

one gram mole of anything =6.023E+23 of them; one gram mole of ^{238}U is 238 grams of ^{238}U

we'll assume that new reactors can be cranked out as fast as fissile becomes available with a six year delay at the beginning

& that we'll start with 34 tonnes of Pu | 34/3.028= | 11.22335 | reactors 6 years after deciding to start building

the amount of fissile "burned" by a 2.1 GWt/0.8 Ge reactor is | 0.817787 | tonnes/annum that's 1.02 tonnes fissile/Gwe/year

fissile burn per reactor year =2.1e9 J/sec*#sec/year*3.2e-11 J/fission /6.023e23 atoms/g mole*238 g.mole/1e6 grams.tonne=

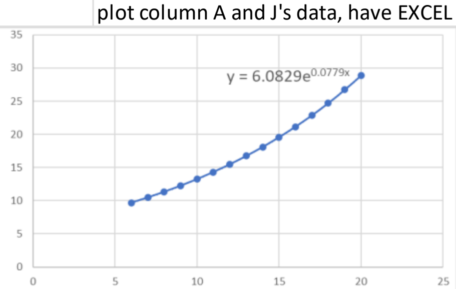
let's do it in a way that permits some variation (the amount of startup fissile & CF | input CR | 1.3

input tonnes starting fissile in y | 34 | input MW | 2100

year	fissile consumed	extra fissile made	new reactors	total number	tot. GWe
				12.13228	9.705821
6	9.178308	2.753492	0.908924	13.11481	10.49185
7	9.921614	2.976484	0.982533	14.17691	11.34153
8	10.72512	3.217535	1.062104	15.32503	12.26003
9	11.59369	3.478107	1.148118	16.56613	13.2529
10	12.53261	3.759782	1.241099	17.90774	14.32619
11	13.54756	4.064268	1.341609	19.358	15.4864
12	14.64471	4.393413	1.45026	20.92571	16.74057
13	15.83071	4.749214	1.567709	22.62038	18.0963
14	17.11276	5.133829	1.69467	24.45229	19.56183
15	18.49864	5.549593	1.831913	26.43256	21.14605
16	19.99676	5.999027	1.98027	28.5732	22.85856
17	21.6162	6.484859	2.140643	30.88721	24.70977
18	23.36679	7.010036	2.314003	33.38861	26.71089
19	25.25915	7.577744	2.501403	36.09259	28.87407
20	27.30476	8.191428	2.703979		

etc

plot column A and J's data, have EXCEL print out its exponential relationship



use the plot's equation to extrapolate to future years

eg by 2100 AD (77 years from now) starting with 34 tonnes fissile &

building 1.3 CR BN-800's as fast as we could fue them

we'd have | 2448.326 | GWe's worth of reactors

GLOSSARY/ACRONYMS

(If you can't find what you're looking for, try GOOGLE)

ABoVE (NASA's) Arctic Boreal Vulnerability Experiment

ABWR advanced boiling water reactor

AECL Atomic Energy of Canada Limited

AGR advanced gas-cooled reactor

ALARA As Low As Reasonably Achievable (a fine sounding slogan)

AP Advanced Plant (USA)

APR Advanced Pressurized-Water Reactor (South Korea)ARIS Advanced Reactors Information System

ASME American Society of Mechanical Engineers

ABWR advanced boiling water reactor

AECL Atomic Energy of Canada Limited

AGR advanced gas-cooled reactor

APR Advanced Pressurized-Water Reactor (South Korea)

ARIS Advanced Reactors Information System

ASME American Society of Mechanical Engineers

BEV battery electric vehicle (100% electric, no gas/diesel)

BOE (42-gallon) Barrels of Oil Equivalent (energy unit =6.12E+9 J)

BOL beginning of life (refers to the compostion of "fresh" nuclear fuel)

BN fast sodium (reactor) (Russian abbreviation

BWR boiling (light) water reactor

CANDU Canada Deuterium Uranium (reactor)

CARES Clean and Renewable Energy Standard (CARES) (Maryland's plan to provide 100% green electricity by 2040)

CHP Combined Heat & Power

CSS Carbon Sequestration and Storage

CO2e Carbon Dioxide Equivalent

COE cost of energy

DME dimethyl ether

EIS Environmental Impact Statement

EPA Environmental Protection Agency (US)

EPR European Pressurized-Water Reactor (France)

ERCOT – Electric Reliability Council of Texas: ISO. Texas's stand-alone ISO (not connected to the USA's two other major "interconnections") managed as an unregulated "energy", not "reliability"   market.

FAQ Frequently Asked Questions (web sites that nominally answer common questions posed by people seeking information about things or proposals)

FERC Federal Energy Regulatory Commission

FFTF Fast flux test facilty (400 MW sodium cooled test reactor built at the Hanford site circa 1978, shut down in 1993 , and maintained in standby condition ever since)

FHR Fluoride-salt cooled, High temperature pebble bed Reactor

FIMA Fraction Initial heavy Metal (actinides) Fissioned

FIT feed-in-tariff

GCR gas-cooled reactor

GCV grid-connected (electric) vehicle

GE General Electric (USA)

GWe Giga watts electric (power- 1E+9 J/s)

GWh Giga watt hour (energy - 3.6E+12 J)

GWe-year =3.15e+16 J   = 0.0299 quad= 5.15E+6 BOE

GWP Global Warming Potential

GWt Giga watts thermal

HDI human development index

HLW high level waste (the USA's definition of "high" in that context makes sense to lawyers, not scientists & engineers)

HM heavy metal – all actinides (Th, U, Np, Pu…..)

HTGR high temperature graphite (moderated) reactor

HTR high temperature pebble-bed graphite moderated/modular (reactor)

IAEA International Atomic Energy Agency

ID inside diameter

INEL Idaho national engineering laboratory (Idaho's national laboratory's second name)

INEEL Idaho national engineering and Environmental laboratory (third name of Idaho's national laboratory

INL Idaho national laboratory (4th name of Idaho's national laboratory

ISO "Independent System Operator" (US)

IWTU INL's "Integrated waste treatment unit" (a "steam reformer")

*J Joule (energy) one J = one volt *(times) one coulomb = 6.25E+18 Ev (1/1.6E-19 J/Ev) = 3.13E+10 actinide atom fission energies (1/3.2E-11 J/fission)*

LCOE levelized cost of energy or electricity

LFTR Liquid fluoride thermal reactor (Flibe Energy's reincarnation of ORNL's two-fluid/salt MSBR)

LGR light-water-cooled, graphite-moderated, reactor

LMFBR liquid-metal fast-breeder reactor

LMR liquid-metal(usually sodium or lead)-cooled reactor

LNG liquefied natural gas

LOLE Loss Of Load Expectation

MCFR molten salt fast reactor (Terrapower)

MCSFR molten chloride salt fast reactor (Elysium)

MHI Mitsubishi Heavy Industries (Japan)

M&O Management & Operating –the title accorded the contractor that's temporarily responsible for running one of DOE's national laboratories

MSBR molten salt breeder reactor (ORNL's last breeding capable MSR concept)

NAS National Academy of Science (USA)

NE the (US) DOE organization responsible for nuclear reactor related R&D

NEM Net Energy Metering

NE R&D Nuclear Energy Research & Development

NERC North American Electric Reliability Corporation

NOAA National Oceanic and Atmospheric Administration

NREL – National Renewable Energy Laboratory

NSAGR not so advanced gas-cooled reactor

NPP nuclear power plant

NRC. nuclear regulatory commission

NRTS national reactor testing station (1st name of Idaho's national laboratory

NTS Nevada Test Site (the site of most of the USA's "small" (up to ~100 kilotonnes) nuclear weapons tests

OECD Organization for Economic Co-operation andDevelopment

PBMR   pebble-bed modular reactor

PHWR pressurized heavy-water reactor

POTUS President Of The United States (aka "Leader of the Free World"- a colloquialism sometimes used to describe that country itself)

PV photovoltaic (solar panels or cells)

POV privately owned vehicle

PWR pressurized water reactor

RBMK Reactor of Large Capacity Channel Type Reactor (see RPRBR)

R&D research and development

RPS Renewable Portfolio Standard

RPV reactor pressure vessel

RPGMWCRBLWR really primitive graphite moderated water cooled Russian-built LWR- see Chernobyl

RTO regional transmission organization (US see also ISO)

SFR sodium fast reactor (a "burner/converter")

SMR small modular reactor (also, small and medium sized reactor)

SSCAB site specific citizens advisory board

TRW Traveling Wave (Liquid metal fast breed and burn (aka :candle") Reactor

TWh (a medium-sized energy unit). Terra Watt-hour, one trillion Watt-hours =1E+9 kWh = 3.6E+15 J = 0.00341 quad

UAE United Arab Emirates

UK United Kingdom

VPP Virtual Power Plant

VTR Versatile Test Reactor (DOE's currently proposed 300 MWt sodium cooled fast spectrum test reactor)

VVER   "Water-water energy reactor' *in Russian abbreviations – another name for PWR*

*W   Watt (power) = Joules (energy) per second = one volt*one coulombs/second (amp) =1/747 horsepower =one kg accelerated at a rate of 1 m/second^2*

WNA World Nuclear Association

YM   DOE's long-proposed & much-studied Yucca Mountain HLW repository site. It is a low mountain ridge situated in the USA's continental nuclear weapons test site (NTS) through which several miles of still-empty, three decade-old, 25 ft diameter tunnels have been bored.

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