CLIMATE CHANGE MITIGATION LOGIC January 5, 2021

Xylene Power Ltd. Is focused on identification of the energy technologies that are required for arresting CO_2 driven climate change. There is no public benefit in committing public resources to technologies that are physically incapable of providing significant climate change mitigation. The interim conclusions are summarized below:

1) Carbon dioxide (CO_2) formed by combustion of fossil fuels is accumulating in the atmosphere and oceans.
2) Excess fossil CO_2 in the atmosphere is causing global warming.
3) Global warming is melting near polar permafrost, which is releasing large quantities of the green house gas methane, which is causing further global warming.
4) Global warming is reducing the average annual circumpolar snow and ice cover which is reducing the fraction of incident solar radiation reflected back into space (planetary albedo).
5) The consequent increased absorption of solar energy is causing further warming which is melting land borne glaciers, causing an ongoing increase in sea level.
6) Excess CO_2 dissolved in the ocean is reducing the ocean surface pH which is causing destruction of plankton and hence the entire marine food chain.
7) The best that we can do to mitigate these problems is to completely stop burning fossil fuels.
8) Simple energy conservation will not arrest global warming. World wide consumption of fossil fuels is increasing in spite of widespread energy conservation efforts.
9) The time frame for natural processes to cause the carbon contained in the excess fossil CO_2 to revert into a fossil fuel is many millions of years.
10) Our descendants will have to live with the excess CO_2 that has already been produced plus whatever excess fossil CO_2 is produced until there is sufficient non-fossil energy to fully displace fossil fuels.
11) Even if we could completely stop burning fossil fuels today global warming would continue to increase due to progressive near polar snow and ice melting, which is further reducing the planetary albedo.
12) It is essential to recognize that fossil fuels presently supply about 85% of human world energy requirements.
13) In order to fully displace fossil fuels we need to continuously supply an at least equal amount of non-fossil energy from new non-fossil energy sources.
14) Due to lack of suitable geography for seasonal energy storage and to energy transmission constraints renewable energy can supply at most 30% of the required non-fossil energy. The balance of the non-fossil energy requirement must be met with nuclear reactors operating with sustainable fuel cycles.
15) In order to displace present fossil fuel consumption we require about 20,000 GW of new non-fossil thermal power, which is about 50X the present total world wide installed nuclear electric power supply capacity.

16) This new reactor power capacity requirement can be reduced by about 50% if the new reactors are sited in major urban areas, so that nuclear electricity generation waste heat can be delivered directly to thermal loads by piped fluids.

17) There is complete failure by western politicians and their lackeys to face the extent of this required nuclear new build, the rate at which these new reactors must be built to arrest climate change, the reactor fuel requirements and the related energy transmission and distribution infrastructure requirements.

18) The potential for CO2 capture and long term storage is orders of magnitude too small to significantly reduce the excess fossil CO2 accumulation.

19) To be effective at climate change mitigation the technologies for supplying and distributing new non-fossil power must be suitable for world wide deployment.

20) The nuclear reactor technology must be conceptually simple and reliable, must not rely on scarce resources and must not require large numbers of highly educated personnel for deployment and future support.

21) The major raw materials used must be abundant, low in cost and readily available world wide.

22) Nuclear reactors are of two types, fast neutron reactors and thermal neutron reactors. As compared to thermal neutron reactors fast neutron reactors are potentially about 100X more fuel efficient and produce about 1000X less long lived nuclear waste per unit of energy output.

23) Fast neutron reactors have the disadvantage that in order to operate they require a larger initial fissile fuel inventory than thermal neutron reactors. However, from fuel sustainability and waste disposal perspectives fast neutron reactors are the only practical choice.

24) Over time high energy fast neutrons will damage almost any solid material that they impinge upon. Hence for a fast neutron reactor to be durable its replaceable fuel assembly needs to be surrounded by a thick liquid coolant guard band that can safely and continuously absorb the fast neutrons that escape from the fuel assembly. This guard band makes the reactor linear dimensions too large for truck or rail transport in the fully assembled state.

25) Nuclear reactors must be fabricated from materials and material combinations that are well understood and characterized from chemical, physical and nuclear engineering perspectives.

26) Fabrication of major reactor components must not require large capital equipment that is only available in a few countries.

27) For public safety reasons urban sited nuclear reactors should have low pressure primary coolants.

28) Liquid sodium cooled nuclear reactors and molten salt cooled nuclear reactors both feature low pressure primary coolants.

29) Liquid sodium cooled reactors and molten salt cooled reactors can both be engineered as fast neutron reactors to provide potential fuel sustainability.

30) Liquid sodium cooled nuclear reactors running a sustainable U-238 – Pu-239 fuel cycle are presently favored over molten salt cooled nuclear reactors running a sustainable Th-232 – U-233 fuel cycle in part due to much greater technology maturity and in part due to much lower educational requirements for field personnel. Molten salt cooled reactors have unresolved material problems. Liquid sodium cooled reactors have added costs related to sodium-water incompatibility and fire prevention.

31) At present the corrosion control and radio chemistry issues in molten salt reactors that are designed to support sustainable fuel cycles are unproven, too immature and too complex for large scale deployment.

32) The excess neutrons from the U-238 - Pu-239 fuel cycle used by liquid sodium cooled reactors will be required to support the Th-232 - U-233 molten salt reactor fuel cycle.

33) A sustainable nuclear fuel cycle that maximizes energy recovery from the available nuclear fuel inherently minimizes the long term nuclear waste disposal issues.

34) There must be isolated dry storage of nuclear fuel fission products for three centuries to allow safe natural decay of shot lived radio isotopes.

35) There must be a comparatively small amount of isolated long term dry storage for disposal of long lived low atomic weight radio isotopes.

36) Any non-fossil electricity system with sufficient output capacity to ensure meeting the annual peak electricity load has surplus electricity generation and delivery capacity at most other times.

37) In order for the surplus intermittently available non-fossil electrical energy to be sold for fossil fuel displacement there must be peak demand based retail electricity pricing. The marginal cost of a unit of surplus electrical energy, when it is available, must be lower than the marginal cost of the same amount of fossil fuel supplied heat.

38) Surplus non-fossil electricity will remain economically unavailable to consumers for fossil fuel displacement until Canadian provincial and US state politicians approve appropriate restructure of retail electricity rates.

39) In urban areas the least expensive non-fossil heat source will be nuclear heat produced by distributed Small Modular Reactors (SMRs) that is delivered to consumers via a piped fluid district heating system. Presently almost all waste heat from nuclear reactors is discarded.

40) To achieve economy a SMR nuclear power plant should be assembled from truck portable modules of common design that have standardized lifting points and external connections.

41) For public safety liquid reactors with sodium bonded solid metallic fuel are favored over other reactor types due to the protection from prompt neutron criticality provided by rapid core fuel disassembly within the reactor's sealed metal fuel tubes.

42) Provincial energy regulators must enable district heating municipal utilities. These district heating utilities will likely also supply electricity intended for powering circulation pumps, heat pumps and fan coil heat rejection units located on or adjacent to consumer premises.

43) Municipal planners and building code regulators must do all necessary to enable retrofitting of district heating systems, including provision of energy supply corridors, pipe easements and space for terminal heat exchange units and related pumps.

44) The choice of potential distributed reactor locations available to municipal planners is constrained by both the reactor elevation requirement with respect to the local water table and by the district heating system's pipe network and elevation requirements with respect to the thermal loads.

45) Nuclear power plant modules must be truck transportable along existing city streets and must comply with existing truck load height, weight and length constraints.

46) With suitable module replacements urban nuclear power plants should have an almost

unlimited operating life.

47) Siting nuclear reactors in cities requires a different perspective on public safety than is currently the norm for power reactors.

48) The urban nuclear power plants must have no requirement for a perimeter exclusion zone for public safety.

49) The nuclear reactors must be capable of safe autonomous operation.

50) Anything that can go wrong sooner or later will go wrong. When a technical problem occurs a reactor or its affected heat transport system(s) must automatically shut down and there must be no credible threat to public safety.

51) Every reactor must be walk-away safe.

52) In order to be durable and to realize a sustainable fuel cycle the reactors must be physically large enough to capture the entire radial neutron flux within the primary coolant enclosure.

53) To enable eventual safe removal of the primary coolant enclosure and the intermediate heat exchange bundles these components must not be neutron activated during normal reactor operation.

54) This constraint effectively sets linear size minimums on both the diameter and height of the reactor coolant enclosure.

55) Hence a fully assembled reactor primary coolant enclosure will be too large for truck transport and must be assembled on the reactor site.

56) The reactors and accompanying power plant components should be easy to maintain and should have a minimum number of moving parts.

57) To minimize fuel reprocessing costs the fuel cycle time for each fuel bundle should be 10 to 30 years. On average one or two fuel bundles should be exchanged per week.

58) To minimize fuel reprocessing costs used fuel bundles should be truck and/or railway transported between the reactor site and a shared remote fuel reprocessing facility.

59) A local fuel bundle warehouse should be used to minimize the frequency of reactor shutdowns for refueling.

60) During truck or rail transport each fuel bundle must be surrounded by a neutron absorbing material such that it will remain sub-critical if its transport container is accidentally immersed in water.

61) The fuel bundle transportation container must remain intact and the contained fuel bundle must remain sub-critical after it is involved in a high speed transportation crash.

62) All radioactive fuel should be contained in sealed metal fuel tubes.

63) The reactor must be able to safely withstand a horizontal earthquake induced acceleration of 0.5 g without damage and must tolerate a 3 g horizontal earthquake induced acceleration without causing a hazard to the public.

64) A major advantage of sodium bonded metallic nuclear fuel in fuel tubes is that reactors can be made with two different temperature ratings.

Medium Temperature > 330 C to 480 C at the thermal load, Fe-Cr fuel tubes, stainless steel primary sodium pool enclosure, U-Pu-Zr Na bonded fuel;

High Temperature > 600 C to 750 C at the thermal load, Mo fuel tubes depleted in Mo-25, 617 alloy primary sodium pool enclosure, U-Pu Na bonded fuel;

SUMMARY:

The main means of displacing energy obtained from combustion of fossil fuels with non-fossil energy must be widespread deployment of fast neutron reactors that consist of a pool of low pressure primary liquid coolant and a central assembly of vertical fuel tubes. Heat is removed from the primary coolant via immersed intermediate heat exchange bundles that are located around the perimeter of the coolant pool. Each reactor must have a liquid coolant guard band surrounding the fuel tube assembly to prevent neutrons that escape from the fuel assembly from impinging on the intermediate heat exchange tube bundles, the coolant enclosure and overhead equipment. The top of pool temperature is about 500 degrees C for a medium temperature rated reactor or at about 800 degrees C for a high temperature rated reactor.

This type of reactor is intrinsically safe because it acts as a constant temperature heat source. During normal operation the reactor thermal power is controlled by adjusting the pumped secondary coolant flow rate. Natural circulation of the secondary coolant is sufficient to remove fission product decay heat when the chain reaction is shut down.

To achieve the neutron conservation necessary for fuel sustainability the reactor does not use neutron absorbing control rods. Instead the reactor operating temperature set point is set by using hydraulic piston lifters to change the relative vertical positions of the mobile core fuel bundles. The vertical position, temperature and gamma ray emissions of each mobile core fuel bundle are continuously monitored. On loss of control power gravity causes a reactor cold shutdown.

For practical reactors rated for 1000 MW thermal power with natural primary coolant circulation the primary coolant pool size will likely be about 20 m diameter X 15 m deep.

To arrest climate change the nuclear reactor fleet must provide sufficient energy to displace at least 70% of the thermal energy presently provided by fossil fuels.

IMPLEMENTATION:

1) Large liquid sodium cooled fast neutron power reactors have been built and are safely operating today. The relevant material and safety issues are well understood.

2) In nuclear power plant design sodium related fire safety issues must take precedence over almost all other considerations. This requirement is particularly important with respect to locating the reactor primary sodium pool above the maximum elevation of the local water table.

3) We are concerned about the unrealistic claims presently being circulated by parties promoting molten salt cooled reactors. The reality is that there is little practical experience with molten salt cooled reactors, and even with an unlimited budget likely 20 years of additional development may be required before a credible molten salt power reactor design can be considered. The major known issues with molten salt reactor technology include corrosion control, isotope separations of Li-7 and Cl-37, Mo-95 selective isotope extraction, moderator durability and chemical process control. There are also many practical issues related to the high melting points of the salts and maintenance of salt purity.

4) The continuous radio chemistry required for autonomous operation of a molten salt reactor running a sustainable Th-232 – U-233 fuel cycle has never been demonstrated. Making molten salt reactors

operate with a sustainable Th-232 – U-233 fuel cycle will likely require more billions of R & D dollars and decades of effort before this technology can significantly mitigate climate change. There are many difficult material issues and there is presently an unwillingness of electricity utilities to invest in the expensive and protracted R & D necessary to address these issues.

5) Hence, if we are serious about mitigation of climate change we should be deploying liquid sodium cooled reactors now. The climate change situation is too urgent for further delay. Molten salt cooled reactors can be deployed when they are ready.

6) Converting existing North American cities to district heating will be a massive task requiring 50 to 100 year future municipal planning. The present practice of infrastructure planning only to the next political election must change.

7) A major issue is easements and right-of-way for future energy transmission and public transit corridors. A related issue is site expropriation for nuclear power plants in existing cities. There will have to be major changes in municipal utility related legislation.

8) Another related issue is modification of building codes to enable connection to district heating systems.

9) There will also have to be major enabling changes in condominium related legislation.

10) Our concern is that both politicians and green energy proponents have put little or no thought into these practical matters. Worse yet, there is reluctance to learn from parties who do have relevant practical experience. The Russians have lots of real life experience with both large sodium cooled reactors and with district heating systems.

11) Why has OPG failed to send a delegation to Russia to learn about these matters? In Toronto there has been a representative of European district heating equipment suppliers for over 35 years. However, that knowledge base has not been utilized by either the City of Toronto or the government of Ontario. There is a "not invented here" mentality.