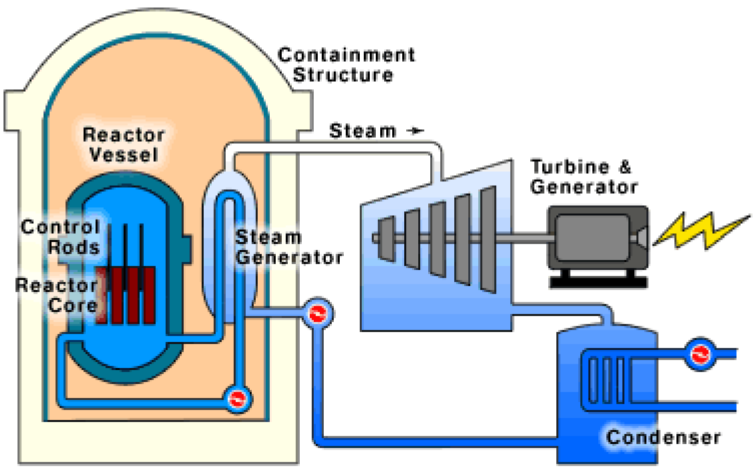
NUCLEAR REACTORS

- Pressurized Water Reactors (PWR)
- Boiling Water Reactor (BWR)
- Pressurized Heavy Water Reactor (CANDU) or (PHWR)
- Gas Cooled reactor (AGR, Magnox)
- Light Water graphite Reactor (RBMK)
- Fast neutron Reactor (FBR) " Breeder Reactors"

Details: PWR



Coolant: Light water

Moderator: water   Cladding: Zirconium alloy

Efficiency: 32%   Outlet temperature: 317^0 C

Fuel: After enrichment, the **uranium dioxide (UO_2)** powder is fired in a high-temperature, sintering furnace to create hard, ceramic pellets of enriched uranium dioxide.

Control: Boron and control rods are used to maintain primary system temperature at the desired point. In order to decrease power, the operator throttles shut turbine inlet valves. This would result in less steam being drawn from the steam generators.

PWR is the most common type of reactor. Powerful pumps circulate the water through pipes, transferring heat that boils water in a separate, secondary loop. The resulting steam drives the electricity producing turbine generators.

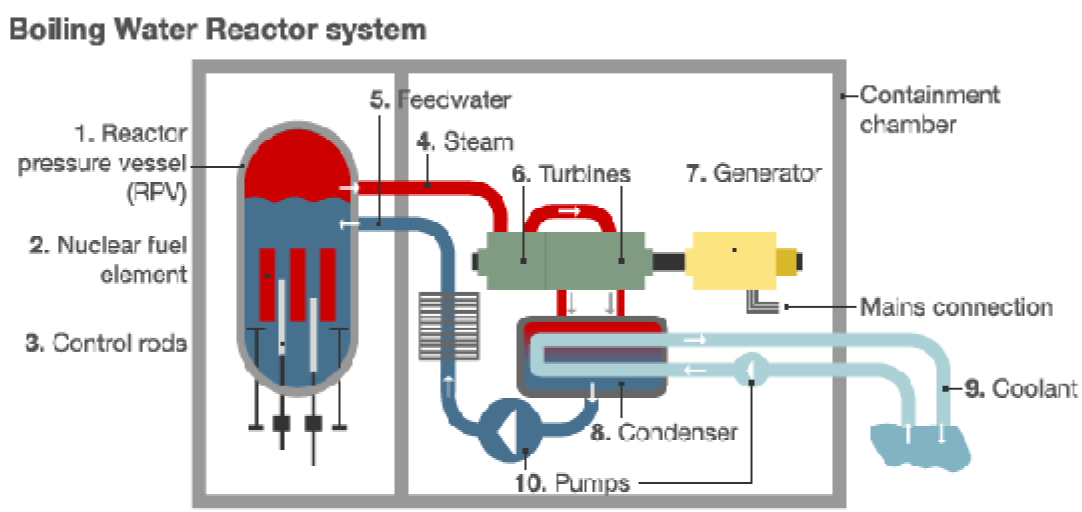
Advantage:

- PWR turbines cycle loop is separate from the primary loop, so the water in the secondary loop is not contaminated by radioactive materials.
- PWR technology is favored by nations seeking to develop a nuclear navy, the compact reactors fit well in nuclear submarines & other nuclear ships.

Disadvantage:

- Additional high pressure components such as reactor coolant pumps, pressurizer, steam generators, etc. are also needed. This also increases the capital cost and complexity of a PWR power plant.
- The coolant water must be highly pressurized to remain liquid at high temperatures.
- Because water acts as a neutron moderator, it is not possible to build a fast neutron reactor with a PWR design. A reduced moderation water reactor may however achieve a breeding ratio greater than unity, though this reactor design has disadvantages of its own.

BWR



Reactor power is controlled via two methods:

- By inserting or withdrawing control rods
- By changing the water flow through the reactor core.

Fuel: Enriched **Uranium dioxide (UO2)**

Coolant & Moderator: Water

- A modern BWR fuel assembly comprises 74 to 100 fuel rods.
- Reactor water level is controlled by the main feed water system. From about 0.5% power to 100% power, feed water will automatically control the water level in the reactor.
- The cooling water is maintained at about 75 atm (7.6 MPa, 1000–1100 psi) so that it boils in the core at about 285 °C (550 °F).
- Efficiency: 32%
- The core damage frequency of the reactor was estimated to be between 10^{-4} and 10^{-7} (i.e., one core damage accident per every 10,000 to 10,000,000 reactor years)

Advantage:

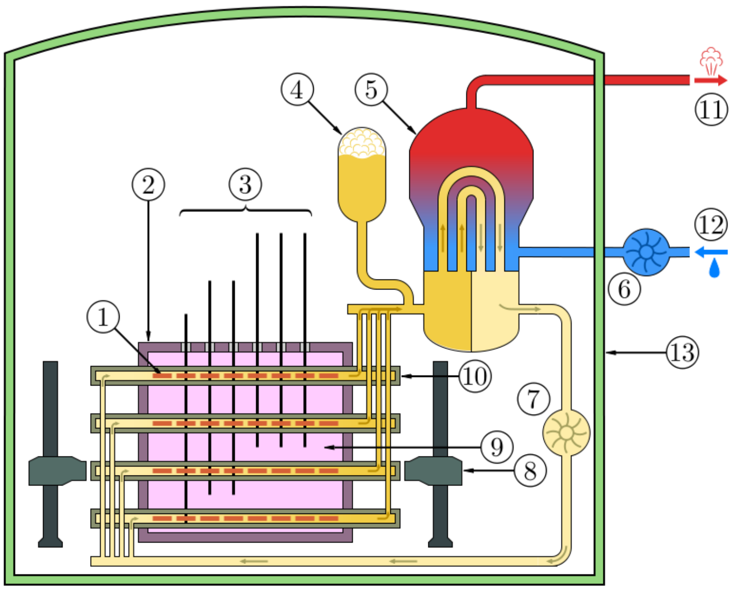
- Pressure vessel is subject to significantly less irradiation compared to a PWR, and so does not become as brittle with age.
- Operates at a lower nuclear fuel temperature.
- Fewer components due to no steam generators and no pressurizer vessel. (Older BWRs have external recirculation loops, but even this piping is eliminated in modern BWRs, such as the ABWR.)
- Lower risk (probability) of a rupture causing loss of coolant compared to a PWR, and lower risk of core damage should such a rupture occur. This is due to fewer pipes, fewer large diameter pipes, fewer welds and no steam generator tubes.

Disadvantage:

- BWRs require more complex calculations for managing consumption of nuclear fuel during operation due to "two phase (water and steam) fluid flow" in the upper part of the core. This also requires more instrumentation in the reactor core.
- Larger pressure vessel than for a PWR of similar power, with correspondingly higher cost, in particular for older models that still use a main steam generator and associated piping.
- Contamination of the turbine by short-lived activation product

CANDU

The **CANDU** (short for **Canada Deuterium Uranium**) reactor is a Canadian-invented, PWR used for generating electric power. The acronym refers to its deuterium-oxide (heavy water) moderator and its use of (originally, natural) uranium fuel.



1	Fuel bundle	8	Fueling machines
2	Calandria (reactor core)	9	Heavy water moderator
3	Adjuster rods	10	Pressure tube
4	Heavy water pressure reservoir	11	Steam going to steam turbine
5	Steam generator	12	Cold water returning from turbine
6	Light water pump	13	Containment building made of reinforced
7	Heavy water pump		

Core – The core of a CANDU reactor is kept in a horizontal, cylindrical tank called a calandria. Fuel channels run from one end of the calandria to the other. Each channel within the calandria has two concentric tubes. The outer one is called the calandria tube & the inner one is called the pressure tube.

CANDU reactors use non-enriched (natural) uranium oxide as fuel and heavy water as a moderator [deuterium oxide (D_2O)]

Coolant: Heavy water or light water **Outlet Temperature**: 305^0 C

Advantage: No Enriched uranium fuel

Heavy water as moderator which has low Fuel consumption

Disadvantage: cost of heavy water is very high.

Leakage problems.

Fuel: CANDU can also Breed Fuel from the more abundant Thorium. CANDU can burn a mix of uranium and plutonium oxides (MOX Fuel).

Pressure: 1285psia **Efficiency**: 30%

MIXED OXIDE FUEL

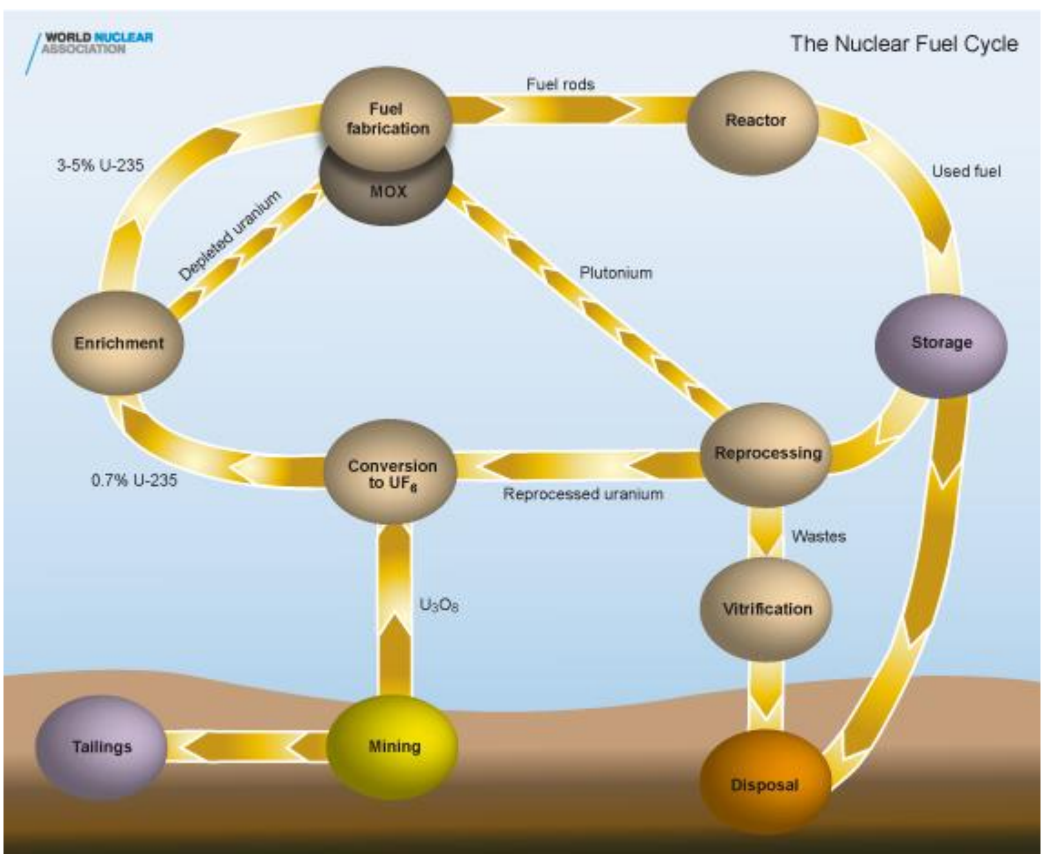
Commonly referred to as **MOX fuel**, is nuclear fuel that contains more than one oxide of fissile material, usually consisting of plutonium blended with natural Uranium, reprocessed uranium, or depleted uranium. MOX fuel is an alternative to the low-enriched uranium (LEU) fuel used in the light water reactors that predominate nuclear power generation.

Licensing and safety issues of using MOX fuel include:

- As plutonium isotopes absorb more neutrons than uranium fuels, reactor control systems may need modification.
- MOX fuel tends to run hotter because of lower thermal conductivity, which may be an issue in some reactor designs.
- Fission gas release in MOX fuel assemblies may limit the maximum burn-up time of MOX fuel.

Note: MOX fuel containing thorium and plutonium oxides.

NUCLEAR FUEL CYCLE:

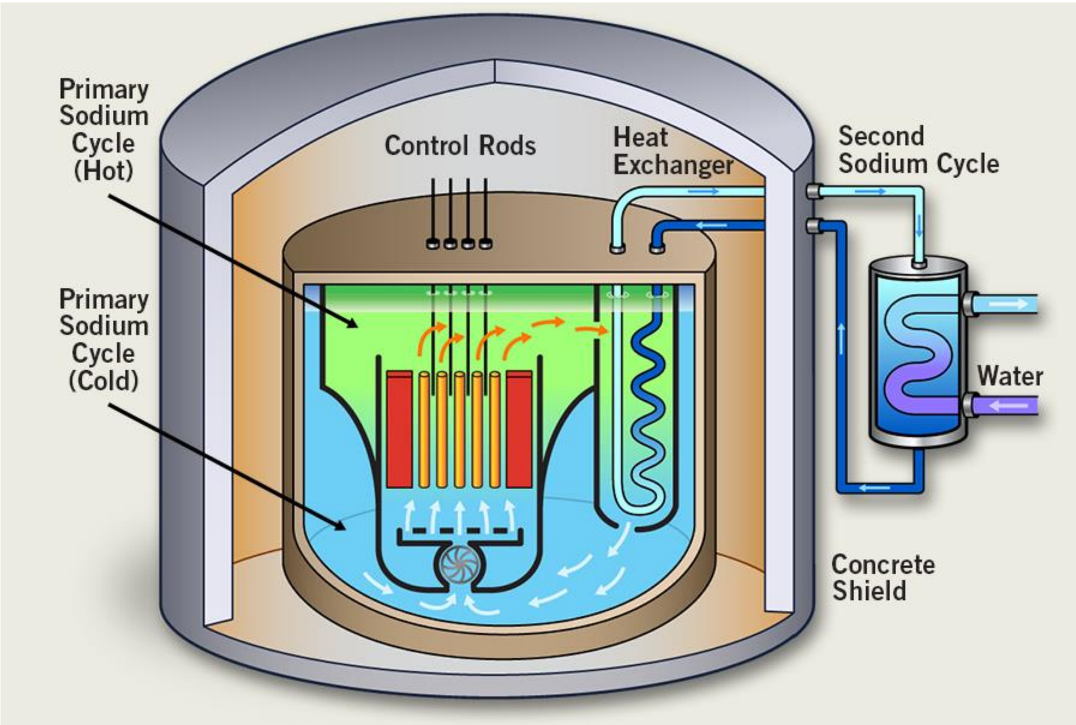


FAST BREEDER REACTORS:

In 2006 all large-scale fast breeder reactor (FBR) power stations were **liquid metal fast breeder reactors (LMFBR)**cooled by liquid sodium. These have been of one of two designs:

Loop type: In this primary coolant is circulated through primary heat exchangers outside the reactor tank

Pool type: the primary heat exchangers and pumps are immersed in the reactor tank



Fuel used: PuO_2 & UO_2

Moderator: None

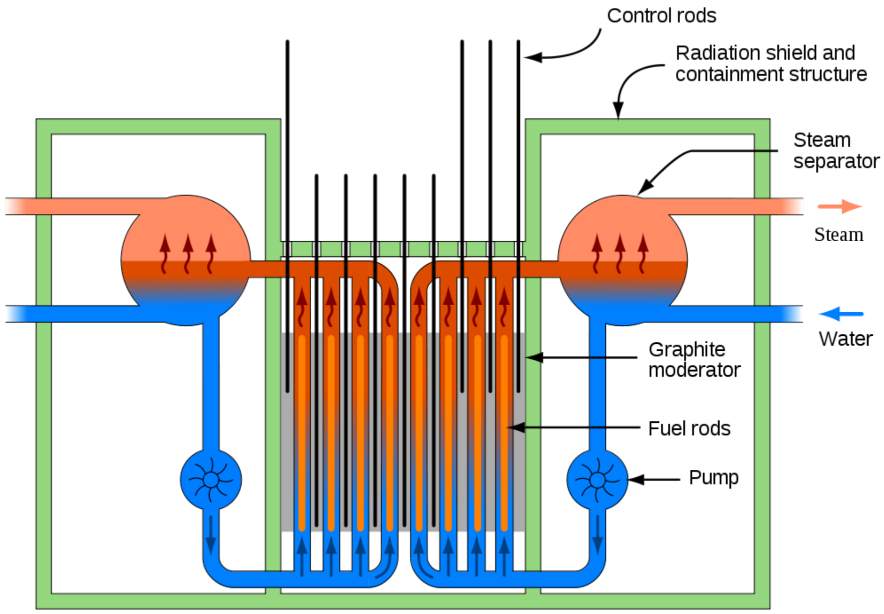
Coolant: Liquid sodium (Metal)

FBR use fast neutrons to convert materials such as U-238 & Th-232 into fissile materials, which then fuel the reactor. This process combined with recycling, has the potential to increase available nuclear fuel resources in the very long term.

A breeder reactor creates 30% more fuel than it consume.

Working temperature of Liquid metals are higher. (Sodium is a solid at room temp. but liquefies at 98^0 C. It has a wide working temp. Since it doesn't boil until 892^0 C)

LIGHT WATER GRAPHITE MODERATED REACTOR (RBMK)



Moderator: Graphite

Coolant: Light Water

Nuclear fuel: Uranium Oxide (UO_2) enriched to 1.8% natural Uranium.

Cladding: Zirconium alloy

Outlet temperature: 284^0C Pressure: 1000psia

Efficiency: 31%

ADVANCE GAS COOLED REACTOR: (AGR)

Uranium Oxide (UO_2) enriched to 2.3% natural Uranium

Cladding: Stainless Steel

Moderator: graphite Coolant: CO_2

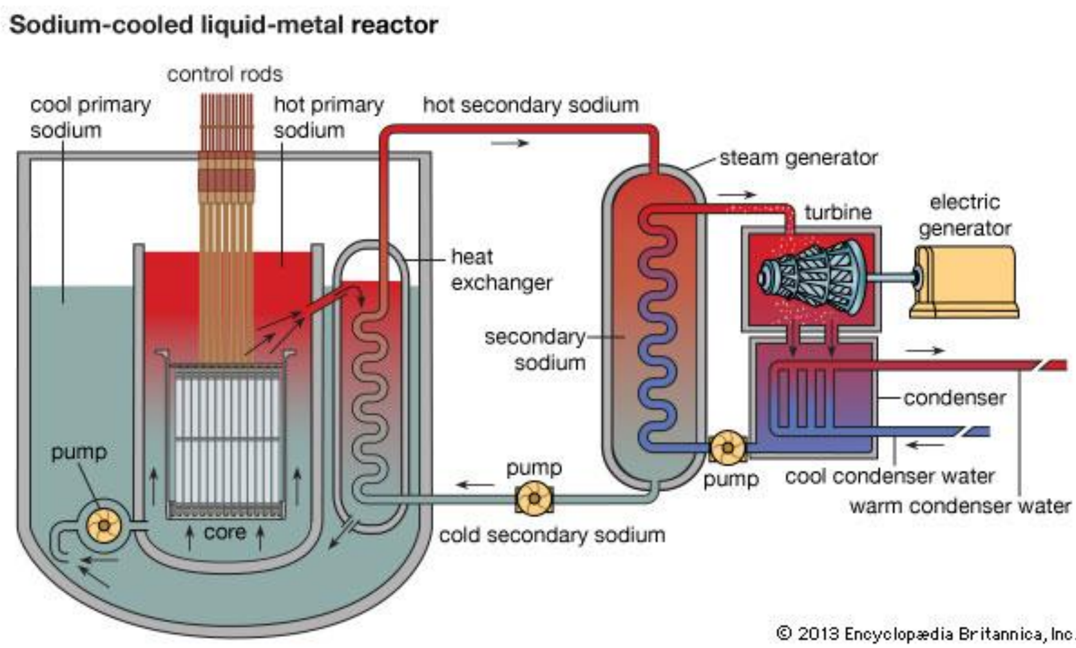
Outlet temperature: 650^0 C Pressure: 600psia

Efficiency: 42%

LIQUID METAL COOLED REACTOR:

Sodium graphite reactor (SGR)
Sodium as coolant
Graphite as moderator
Liquid sodium= Boiling point: 880^0 C   freezing point: 95^0C

Mixed oxide fuel core of up to 20% plutonium dioxide (PuO_2) and at least 80% uranium dioxide (UO_2).
Particularly uranium-238 and thorium-232- plutonium-239
Stainless steel is used as canning material



Because the metal coolants have much higher density than the water used in most reactor designs, they remove heat more rapidly and allow much higher power density. This makes them attractive in situations where size and weight are at a premium, like on ships and submarines. To improve cooling with water, most reactor designs are highly pressurized to raise the boiling point, which presents safety and maintenance issues that liquid metal designs lack.

Liquid metals, being electrically highly conductive, can be moved by electromagnetic pumps.

Applications of Nuclear Reactor:

- Military uses , Nuclear weapons
- in making plastics and sterilization of single-use products
- as a prerequisite for the full automation of high speed production lines
- Nuclear medicine
- Agriculture (fertilizer etc.)
- food preservation
- Hydrology, mining or the space industry.
- Solving problems such as the "greenhouse effect" and acid rain.

Future of Nuclear energy:

Thorium power is the safe future of nuclear energy. (Th-232)

In accepting a neutron from the beam, Th-232 becomes Th-233, but this heavier isotope doesn't last very long. The Th-233 decays to protactinium-233, which further decays into U-233. The U-233 remains in the reactor and, similar to current nuclear power plants, the fission of the uranium generates intense heat that can be converted to electricity.

Germany will shut down all his Nuclear reactors till 2022.

Components of Nuclear Waste:

Hydro carbons

Radio isotopes

Uranium

Mercury

Cyanide

High Level waste (By products) are: 3% Volume of Waste

Plutonium (238, 239, 240, 241, 242)

Neptunium-237

Uranium-236

Other: Xenon-133, iodine, Tritium

VAPOUR POWER CYCLE

- Carnot cycle
- Rankine cycle
- Reheat Rankine cycle
- Regenerative Rankine cycle

Carnot cycle:

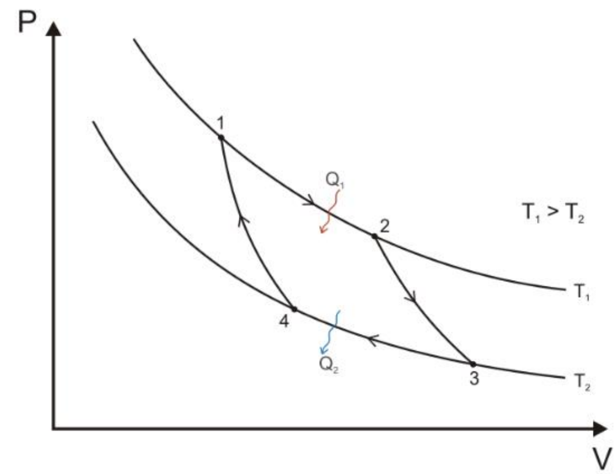
Process:

1-**Reversible isothermal expansion**

2-**Isentropic** (Reversible adiabatic)

3-**Reversible isothermal compression**

4-**Isentropic compression**



Evaluation of the above integral is particularly simple for the Carnot cycle. The amount of energy transferred as work is

$$W = \oint PdV = \oint Tds = (T_H - T_C)(S_B - S_A)$$

The total amount of thermal energy transferred from the hot reservoir to the system will be

$$Q_H = T_H(S_B - S_A)$$

and the total amount of thermal energy transferred from the system to the cold reservoir will be

$$Q_C = T_C(S_B - S_A)$$

The efficiency η is defined to be:

$$\eta = \frac{W}{Q_H} = 1 - \frac{T_C}{T_H} \qquad (3)$$

where

W is the work done by the system (energy exiting the system as work),
Q_C is the heat taken from the system (heat energy leaving the system),
Q_H is the heat put into the system (heat energy entering the system),
T_C is the absolute temperature of the cold reservoir, and
T_H is the absolute temperature of the hot reservoir.
S_B is the maximum system entropy
S_A is the minimum system entropy

RANKINE CYCLE:

The Rankine cycle is a model that is used to predict the performance of steam turbine systems. The Rankine cycle is an idealized thermodynamic cycle of a heat engine that converts heat into mechanical work.

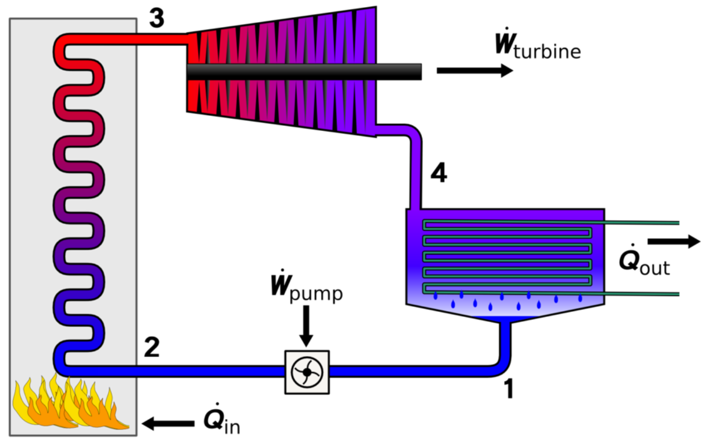
Process:

1-2 isentropic compression in water pump

2-3 constant pressure heat addition

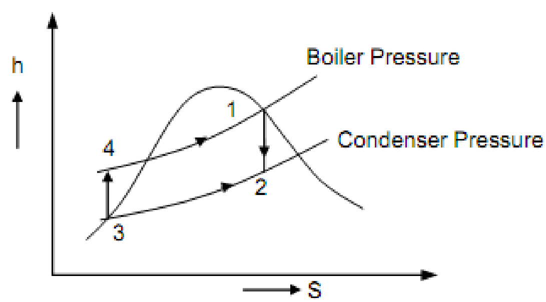
3-4 isentropic expansion in turbine

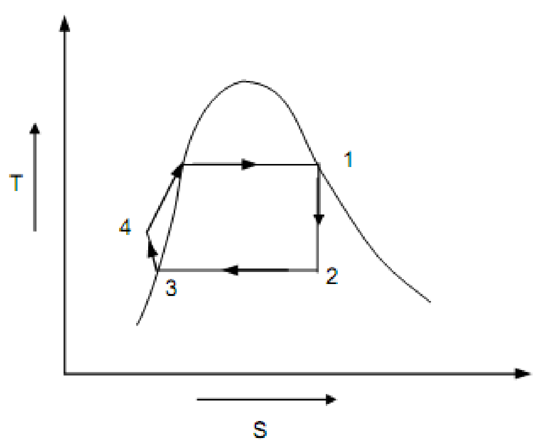
4-1 constant pressure heat rejection in condenser

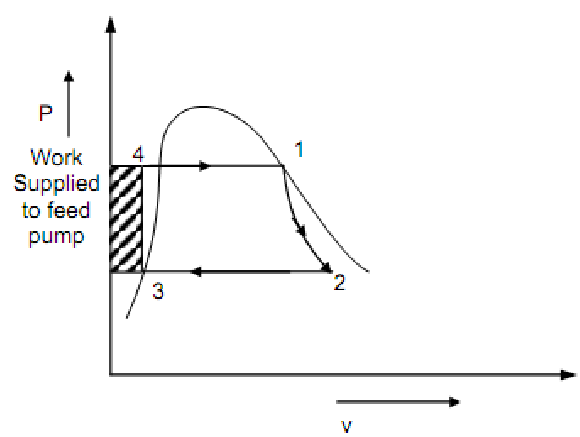


Diagrams:

P-V, T-S, H-S

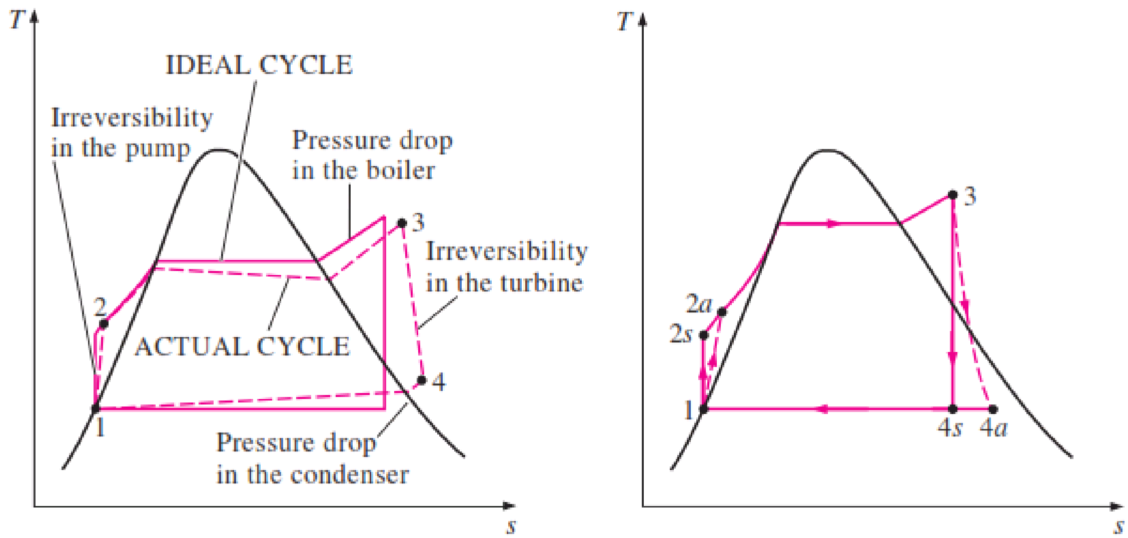






Irreversibility's and losses in Rankine cycle:

(a) Deviation of actual VPC from rankine cycle
(b) The effect of pumps and turbine irreversibility's on rankine cycle



(a) (b)

The actual VPC differs from the ideal Rankine cycle as a result of irreversibility's in various components.

Fluid friction & heat losses to the surroundings are the two common sources of irrerversibilties.

Thermal efficiency:

The thermal efficiency of the Rankine cycle is given by,

$$\eta = \frac{Net\ workdone}{Heat\ supplied} = \frac{w_{net}}{q_{in}} = \frac{q_{in} - q_{out}}{q_{in}} = 1 - \frac{q_{out}}{q_{in}}$$

Or

$$\eta = \frac{w_{turb,out} - w_{pump,in}}{q_{in}} = \frac{(h_3 - h_4) - h_2 - h_1}{(h_3 - h_2)}$$

The pump work is usually very small compared to turbine work.

Hence, sometimes, it is neglected. In that case,

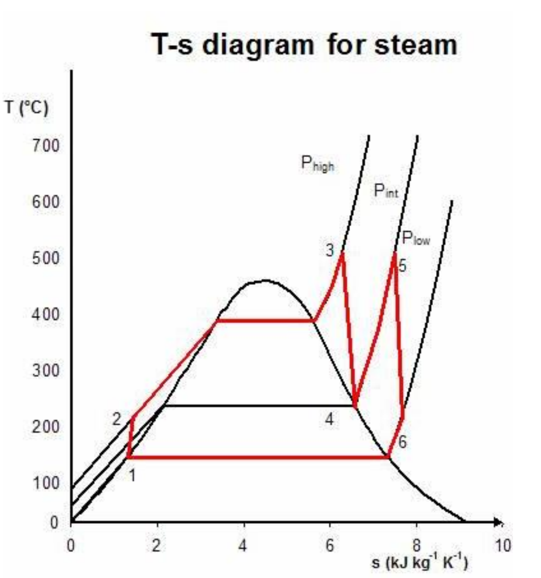
$$\eta = \frac{(h_3 - h_4)}{(h_3 - h_2)}$$

<u>Reheat Rankine cycle:</u> (a)

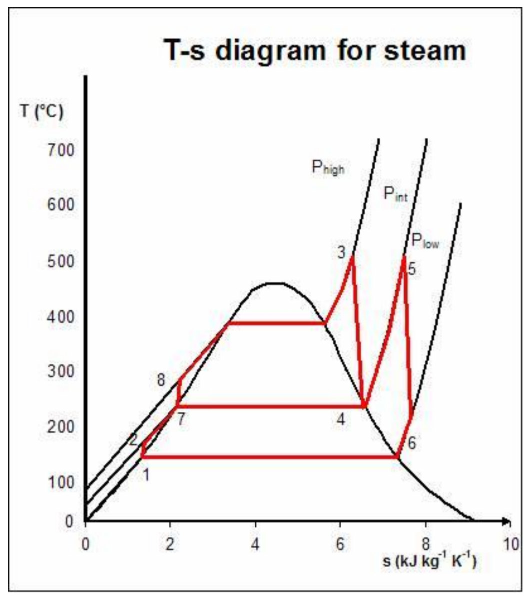
The purpose of a reheating cycle is to remove the moisture carried by the steam at the final stages of the expansion process.. The reheat temperatures are very close or equal to the inlet temperatures, whereas the optimum reheat pressure needed is only one fourth of the original boiler pressure., this prevents the vapor from condensing during its expansion and damaging the turbine blades, and improves the efficiency of the cycle

<u>Regenerative Rankine cycle:</u> (b)

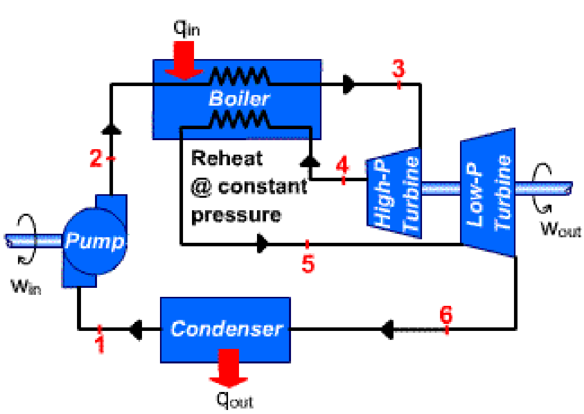
Regeneration increases the cycle heat input temperature by eliminating the addition of heat from the boiler/fuel source at the relatively low feed water temperatures that would exist without regenerative feed water heating. This improves the efficiency of the cycle, as more of the heat flow into the cycle occurs at higher temperature.

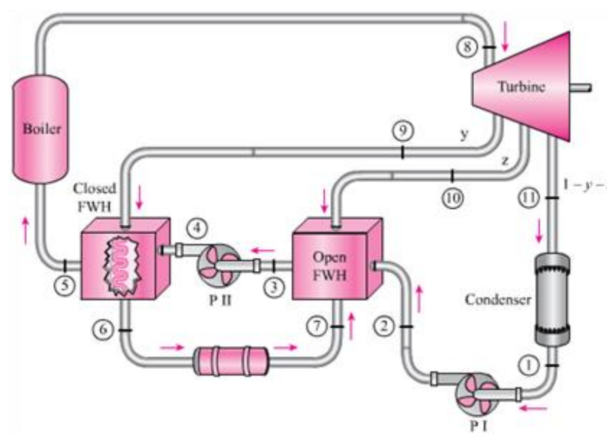


(a)



(b)





TUTORIAL PROBLEMS

1. A generating station has an overall efficiency of 15% and 0·75 kg of coal is burnt per kWh by the station. Determine the calorific value of coal in kilocalories per kilogram. **[7644 kcal/kg]**
2. A 75 MW steam power station uses coal of calorific value of 6400 kcal/kg. Thermal efficiency of the station is 30% while electrical efficiency is 80%. Calculate the coal consumption per hour when the station is delivering its full output. **[42 tons]**
3. A 65,000 kW steam power station uses coal of calorific value 15,000 kcal per kg. If the coal consumption per kWh is 0·5 kg and the load factor of the station is 40%, calculate (*i*) the overall efficiency (*ii*) coal consumption per day. **[(*i*) 28·7% (*ii*) 312 tons]**
4. A 60 MW steam power station has a thermal efficiency of 30%. If the coal burnt has a calorific value of 6950 kcal/kg, calculate :
   (*i*) the coal consumption per kWh,
   (*ii*)the coal consumption per day. **[(*i*) 0·413 kg (*ii*) 238 tons]**
5. A 25 MVA turbo-alternator is working on full load at a power factor of 0·8 and efficiency of 97%. Find the quantity of cooling air required per minute at full load, assuming that 90% of the total losses are dissipated by the internally circulating air. The inlet air temperature is 20º C and the temperature rise is 30º C. Given that specific heat of air is 0·24 and that 1 kg of air occupies 0·8 m^3. **[890 m^3/minute]**
6. A thermal station has an efficiency of 15% and 1·0 kg of coal burnt for every kWh generated. Determine the calorific value of coal. **[5733 kcal/kg]**

Example 2.1. A steam power station has an overall efficiency of 20% and 0·6 kg of coal is burnt Per kWh of electrical energy generated. Calculate the calorific value of fuel?

Solution.

Let x kcal/kg be the calorific value of fuel.

Heat produced by 0·6 kg of coal = 0·6 x kcal

Heat equivalent of 1 kWh = 860 kcal

$$\text{Now,}\quad \eta_{overall} = \frac{\text{Electrical output in heat units}}{\text{Heat of combustion}}$$

$$\text{or}\quad 0{\cdot}2 = \frac{860}{0\cdot 6x}$$

$$\therefore\quad x = \frac{860}{0\cdot 6 \times 0\cdot 2} = \mathbf{7166{\cdot}67\ kcal/kg}$$

Example 2.2. *A thermal station has the following data :*

Max. demand	=	*20,000 kW*	;	*Load factor*	=	*40%*
Boiler efficiency	=	*85%*	;	*Turbine efficiency*	=	*90%*
Coal consumption	=	*0·9 kg/kWh*	;	*Cost of 1 ton of coal*	=	*Rs. 300*

Determine (i) thermal efficiency and (ii) coal bill per annum.

Solution.

(*i*) Thermal efficiency $= \eta_{boiler} \times \eta_{turbine} = 0{\cdot}85 \times {\cdot}9 =$ **0·765** or **76·5 %**

(*ii*) Units generated/annum = Max. demand × L.F. × Hours in a year

$= 20{,}000 \times 0{\cdot}4 \times 8760 = 7008 \times 10^4$ kWh

$$\text{Coal consumption/annum} = \frac{(0\cdot 9)\left(7008 \times 10^4\right)}{1000} = 63{,}072 \text{ tons}$$

∴ Annual coal bill = Rs 300 × 63072 = **Rs 1,89,21,600**

Example 2.3. *A steam power station spends Rs. 30 lakhs per annum for coal used in the station. The coal has a calorific value of 5000 kcal/kg and costs Rs. 300 per ton. If the station has thermal efficiency of 33% and electrical efficiency of 90%, find the average load on the station.*

Solution.

Overall efficiency, $\eta_{overall} = 0{\cdot}33 \times 0{\cdot}9 = 0{\cdot}297$

Coal used/annum $= 30 \times 10^5/300 = 10^4$ tons $= 10^7$ kg

Heat of combustion = Coal used/annum × Calorific value

$= 10^7 \times 5000 = 5 \times 10^{10}$ kcal

Heat output $= \eta_{overall} \times$ Heat of combustion

$= (0{\cdot}297) \times (5 \times 10^{10}) = 1485 \times 10^7$ kcal

Units generated/annum $= 1485 \times 10^7/860$ kWh

$$\therefore \text{Average load on station} = \frac{\text{Units generated / annum}}{\text{Hours in a year}} = \frac{1485 \times 10^7}{860 \times 8760} = \mathbf{1971\ kW}$$

Example 2.5. *A 100 MW steam station uses coal of calorific value 6400 kcal/kg. Thermal efficiency of the station is 30% and electrical efficiency is 92%. Calculate the coal consumption per hour when the station is delivering its full rated output.*

Solution.

Overall efficiency of the power station is

$$\eta_{overall} = \eta_{thermal} \times \eta_{elect} = 0{\cdot}30 \times 0{\cdot}92 = 0{\cdot}276$$

Units generated/hour $= (100 \times 10^3) \times 1 = 10^5$ kWh

$$\text{Heat produced/hour, } H = \frac{\text{Electrical output in heat units}}{\eta_{overall}}$$

$$= \frac{10^5 \times 860}{0\cdot 276} = 311\cdot 6 \times 10^6 \text{ kcal} \qquad (\because\ 1 \text{ kWh} = 860 \text{ kcal})$$

$$\therefore \text{Coal consumption/hour} = \frac{H}{\text{Calorific value}} = \frac{311\cdot 6 \times 10^6}{6400} = \mathbf{48687\ kg}$$

Example 2.14. A diesel power station has fuel consumption of 0·28 kg per kWh, the calorific value of fuel being 10,000 kcal/kg. Determine (i) the overall efficiency, and (ii) efficiency of the engine if alternator efficiency is 95%.

Solution.

Heat produced by 0·28 kg of oil = 10,000 . 0·28 = 2800 kcal
Heat equivalent of 1 kWh = 860 kcal

(*i*) $$\text{Overall efficiency} = \frac{\text{Electrical output in heat units}}{\text{Heat of combustion}} = 860/2800 = 0{\cdot}307 = \mathbf{30{\cdot}7\%}$$

(*ii*) $$\text{Engine efficiency} = \frac{\text{Overall efficiency}}{\text{Alternator efficiency}} = \frac{30{\cdot}7}{0{\cdot}95} = \mathbf{32{\cdot}3\%}$$

Example 2.15. *A diesel power station has the following data :*

Fuel consumption/day = 1000 kg

Units generated/day = 4000 kWh

Calorific value of fuel = 10,000 kcal/kg

Alternator efficiency = 96%

Engine mech. efficiency = 95%

Estimate (i) specific fuel consumption, (ii) overall efficiency, and (iii) thermal efficiency of engine.

Solution.

(*i*) Specific fuel consumption = 1000/4000 = **0·25 kg/kWh**

(*ii*) Heat produced by fuel per day

= Coal consumption/day × calorific value

$= 1000 \times 10{,}000 = 10^7$ kcal

Electrical output in heat units per day

$= 4000 \times 860 = 344 \times 10^4$ kcal

$$\text{Overall efficiency} = \frac{344 \times 10^4}{10^7} \times 100 = \mathbf{34{\cdot}4\%}$$

(*iii*) $$\text{Engine efficiency, } \eta_{engine} = \frac{\eta_{overall}}{\eta_{alt.}} = \frac{34{\cdot}4}{0{\cdot}96} = 35{\cdot}83\%$$

$$\text{Thermal efficiency, } \eta_{ther} = \frac{\eta_{engine}}{\text{Mech. } \eta \text{ of engine}} = \frac{35{\cdot}83}{0{\cdot}95} = \mathbf{37{\cdot}71\%}$$

Example 2.16. *A diesel engine power plant has one 700 kW and two 500 kW generating units. The fuel consumption is 0·28 kg per kWh and the calorific value of fuel oil is 10200 kcal/kg. Estimate (i) the fuel oil required for a month of 30 days and (ii) overall efficiency. Plant capacity factor = 40%.*

Solution.

(*i*) Maximum energy that can be produced in a month

= Plant capacity × Hours in a month

$= (700 + 2 \times 500) \times (30 \times 24) = 1700 \times 720$ kWh

$$\text{Plant capacity factor} = \frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$$

or $$0{\cdot}4 = \frac{\text{Actual energy produced}}{1700 \times 720}$$

$\therefore$ Actual energy produced in a month

$$= 0{\cdot}4 \times 1700 \times 720 = 489600 \text{ kWh}$$

Fuel oil consumption in a month

$$= 489600 \times 0{\cdot}28 = \mathbf{137088 \text{ kg}}$$

(*ii*)

$$\text{Output} = 489600 \text{ kWh} = 489600 \times 860 \text{ kcal}$$

$$\text{Input} = 137088 \times 10200 \text{ kcal}$$

$$\therefore \quad \text{Overall efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{489600 \times 860}{137088 \times 10200} = \mathbf{0{\cdot}3 \text{ or } 30\%}$$

Example 2.17. An atomic power reactor can deliver 300 MW. If due to fission of each atom of U-235 , the energy released is 200 MeV, calculate the mass of uranium fissioned per hour?

Solution:

Energy received from the reactor

$$= 300 \text{ MW} = 3 \times 10^8 \text{ W (or Js}^{-1})$$

$$\text{Energy received/hour} = (3 \times 10^8) \times 3600 = 108 \times 10^{10} \text{ J}$$

$$\text{Energy released/fission} = 200 \text{ MeV} = 200 \times 10^6 \times 1{\cdot}6 \times 10^{-19} \text{ J} = 3{\cdot}2 \times 10^{-11} \text{J}$$

Number of atoms fissioned per hour

$$= \frac{108 \times 10^{10}}{3 \cdot 2 \times 10^{-11}} = 33{\cdot}75 \times 10^{21}$$

Now 1 gram-atom (*i.e.*, 235g) has $6{\cdot}023 \times 10^{23}$ atoms.

$\therefore$ Mass of Uranium fissioned per hour

$$= \frac{235}{6 \cdot 023 \times 10^{23}} \times 33{\cdot}75 \times 10^{21} = \mathbf{13{\cdot}17 g}$$

Example 2.18. *What is the power ouput of a* ${}_{92}U^{235}$ *reactor if it takes 30 days to use up 2 kg of fuel? Given that energy released per fission is 200 MeV and Avogadro's number =* $6{\cdot}023 \times 10^{26}$ *per kilomole.*

Solution.

$$\text{Number of atoms in 2 kg fuel} = \frac{2}{235} \times 6{\cdot}023 \times 10^{26} = 5{\cdot}12 \times 10^{24}$$

These atoms fission in 30 days. Therefore, the fission rate (*i.e.*, number of fissions per second)

$$= \frac{5{\cdot}12 \times 10^{24}}{30 \times 24 \times 60 \times 60} = 1{\cdot}975 \times 10^{18}$$

$$\text{Energy released per fission} = 200 \text{ MeV} = (200 \times 10^6) \times 1{\cdot}6 \times 10^{-19} = 3{\cdot}2 \times 10^{-11} \text{J}$$

$\therefore$ Energy released per second *i.e.*, power output *P* is

$$P = (3{\cdot}2 \times 10^{-11}) \times (1{\cdot}975 \times 10^{18}) \text{ W}$$

$$= 63{\cdot}2 \times 10^6 \text{ W} = \mathbf{63{\cdot}2 \text{ MW}}$$

INTRODUCTION TO THERMODYNAMICS:

Enthalpy: Amount of energy in a system capable of doing mechanical work.
Entropy: Amount of energy in a system no longer available for doing mechanical work.

1st law of thermodynamics:

Energy can neither be created nor be destroyed but it can change from one form to another form.
Change in internal energy=total heat added and work done
+W work done on system & –W work done by the system

$$\Delta U = \Delta Q \pm \Delta W$$

2nd law of thermodynamics:

Indicates that in any complete cycle the gross heat supplied plus the W_{net} input must be greater than zero.
Adiabatic Process: Occurring without loss of heat or gain.

Adiabatic compression: Gain in internal energy (+U)
Adiabatic expansion: Loss of internal energy (-U)

Temperature is an objective comparative measure of hot or cold.
Pressure is the force applied perpendicular to the surface of an object per unit area over which that force is distributed.
Internal Energy: The total energy contained by the thermodynamic system.
Alternator: is an electrical generator that converts mechanical energy to electrical energy in the form of alternating current.

Cogeneration:

Combined heat and power (**CHP**) is the use of a heat engine or power station to generate electricity and useful at the same time.

Cogeneration is a thermodynamically efficient use of fuel.

Thermal efficiency in a trigeneration system is defined as:

$$\eta_{th} \equiv \frac{W_{out}}{Q_{in}} \equiv \frac{\text{Electrical Power Output} + \text{Heat Output} + \text{Cooling Output}}{\text{Total Heat Input}}$$

Where:

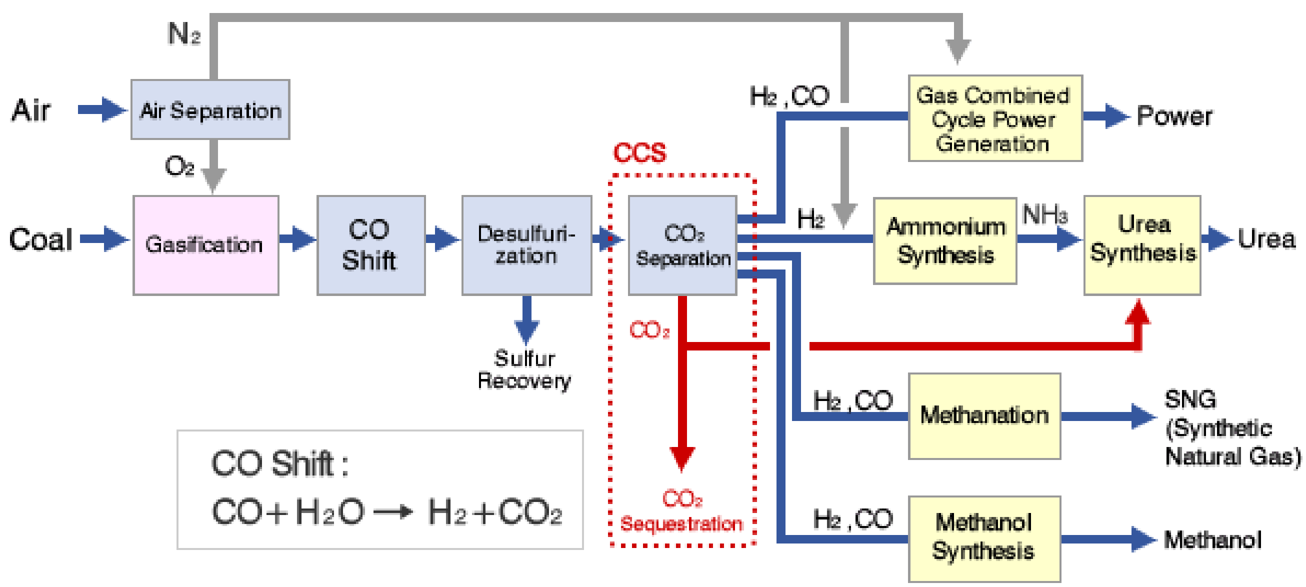
η_{th} = Thermal efficiency
W_{out} = Total work output by all systems
Q_{in} = Total heat input into the system

Total input energy: . Electricity = 45% Heat + Cooling = 40% Heat Losses = 13%
Electrical Line Losses = 2%

CLEAN COAL TECHNOLOGY:

"Clean" coal technology is a collection of technologies being developed to mitigate the environmental impact of coal energy generation. When coal is used as a fuel source, the gaseous emissions generated by the thermal decomposition of the coal include sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon dioxide (CO_2), mercury, and other chemical byproducts that vary depending on the type of the coal being used. These emissions have been established to have a negative impact on the environment and human health, contributing to acid rain, lung cancer and cardiovascular disease. As a result, clean coal technologies are being developed to remove or reduce pollutant emissions to the atmosphere.

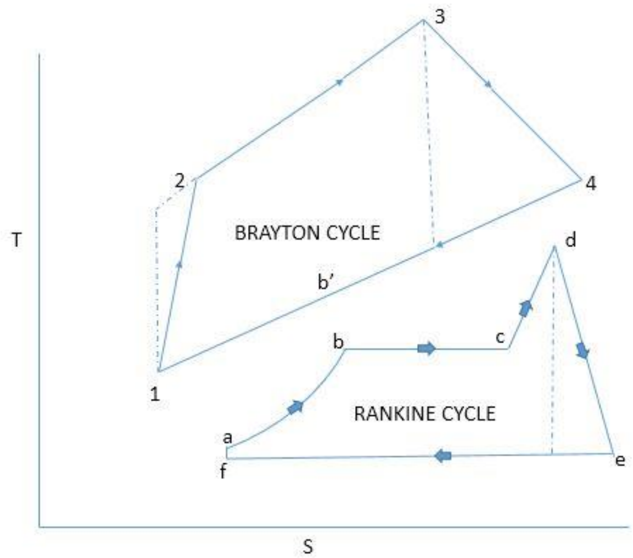
Clean coal technology usually addresses atmospheric problems resulting from burning coal.



COMBINED CYCLE:

The thermodynamic cycle of the basic combined cycle consists of two power plant cycles. One is the Joule or Brayton cycle which is a gas turbine cycle and the other is Rankine cycle which is a steam turbine cycle.[1] The cycle 1-2-3-4-1 which is the gas turbine power plant cycle is the topping cycle. It depicts the heat and work transfer process taking place in high temperature region.

The cycle a-b-c-d-e-f-a which is the Rankine steam cycle takes place at a low temperature and is known as the bottoming cycle. Transfer of heat energy from high temperature exhaust gas to water and steam takes place by a waste heat recovery boiler in the bottoming cycle. During the constant pressure process 4-1 the exhaust gases in the gas turbine reject heat. The feed water, wet and super-heated steam absorb some of this heat in the process a-b, b-c and c-d.



Classification of nuclear power plant by generation: