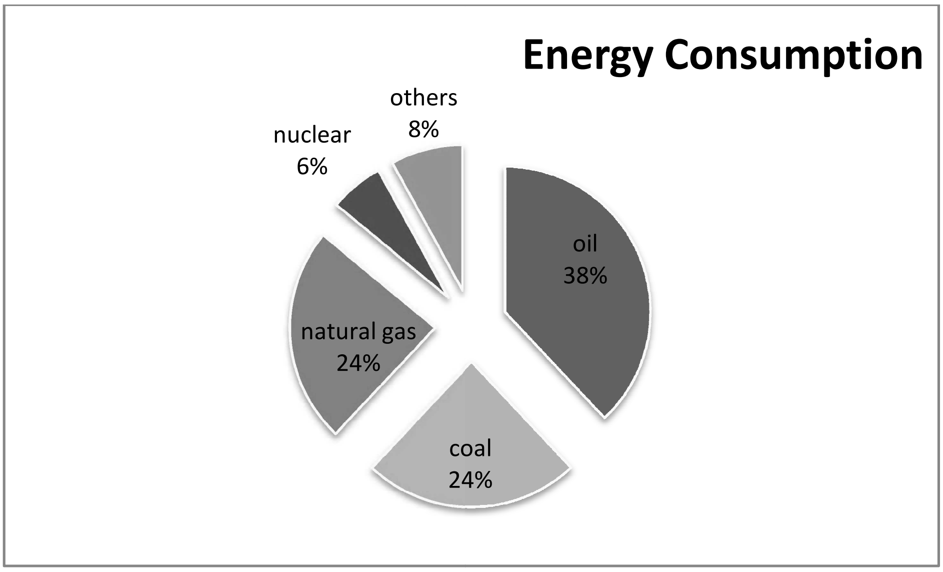
CHAPTER 3 RENEWABLE AND NON-RENEWABLE ENERGY SOURCES

1 Energy Sources

- Renewable energy: An energy source is said to be renewable if it can be naturally regenerated at a rate larger than or comparable to the rate of consumption.
- Energy density is the energy can be release per unit mass of energy source.
- Nuclear energy has the largest energy density.
- Common renewable energy sources:
  Solar energy, tidal energy, hydroelectricity, wind energy, geothermal energy
- Common non-renewable energy sources:
  Coal, oil and natural gases, nuclear energy.

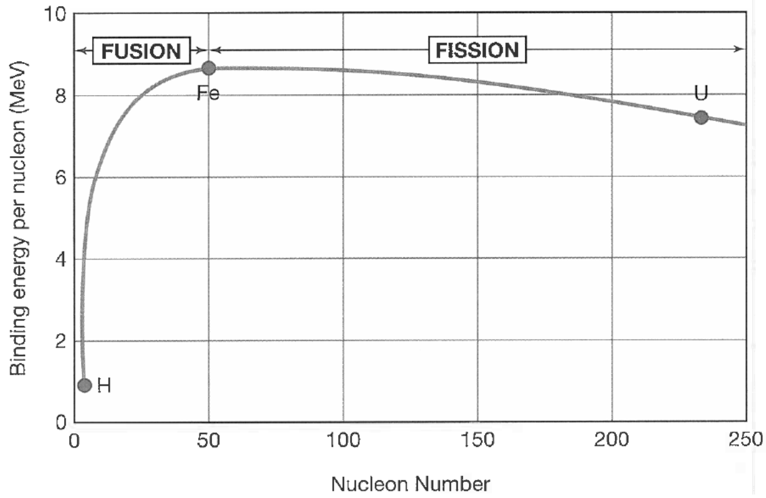


- Advantages of nuclear energy over fossil fuel:
  - Very high energy density
  - Large reserve

2 Nuclear Power

2.1 Binding Energy

- It is observed that the mass of a nucleus is less than the total mass of the constituting. Such difference is called mass defect (Δm).
- By Einstein's mass energy equivalence principle, this is the energy released when nucleons are bounded together. This energy is called the binding energy, reflecting the stability of a nucleus.



- A bigger nucleus will have a greater binding energy. To have a fair comparison of nuclei stability, we use binding energy per nucleon.
- A large binding energy per nucleon means the nucleus is very stable.

- Binding energy per nucleon is usually expressed in eV.

  1 eV = energy gained by an electron across a potential difference of 1V.

  1eV= 1.6×10^{-19} J
- Iron is at the peak of the curve and it is most stable.
- Light nuclei can fuse together to release energy, this is called nuclear fusion.
- Heavy nuclei can split into lighter nuclei and release energy, this is called nuclear fission.

- Sometimes we also use the atomic mass unit (u) as energy unit.

  $1u = 1.6606 \times 10^{-27}$ kg, which is equivalent to 1.49×10^{-10} J = 931.5 MeV.

- Sometimes we also use MeV/c^2 as mass unit.

Example:

Using the data, calculate the binding energy per nucleon for a helium-3 nucleus.

	Neutron	Proton	${}^{3}_{2}He$
Mass in MeV/c^2	939.6	938.8	2808.5

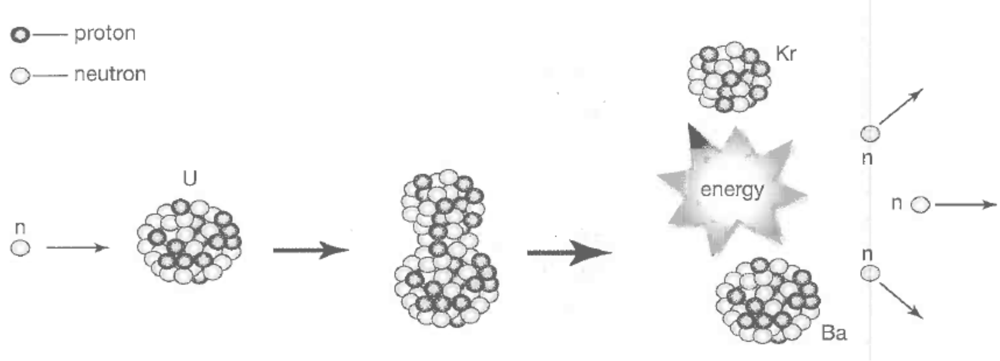
$\Delta m = 2 \times 938.8 + 1 \times 939.6 - 2808.5$

$= 8.7 MeV/c^2$

$\therefore$ Binding energy per nucleon $= \frac{8.7}{3} = 2.9 MeV$

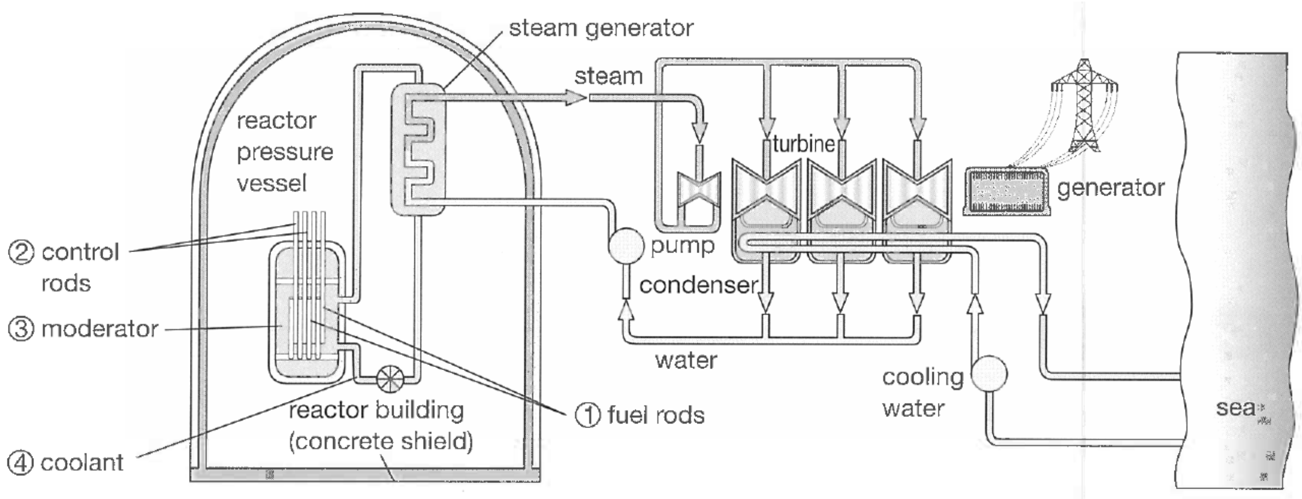
2.2 Nuclear Fission Reactor

- Fuel: Uranium-235
- Nuclear fission happens when uranium-235 bombarded by neutron, it will then split into two smaller nuclei with liberation of some neutron. A large amount of energy is released in this process.



- With sufficient amount of U^{235} nuclei, the neutrons released can trigger fission of other nuclei, initiating a chain reaction.
- If the chain reaction is allowed to proceed freely, the result will be an uncontrolled nuclear reaction, which is in the case of an atomic bomb.
- In nuclear reactor, control rods are used to control the rate of reaction by absorbing excess neutron.

- Structure:



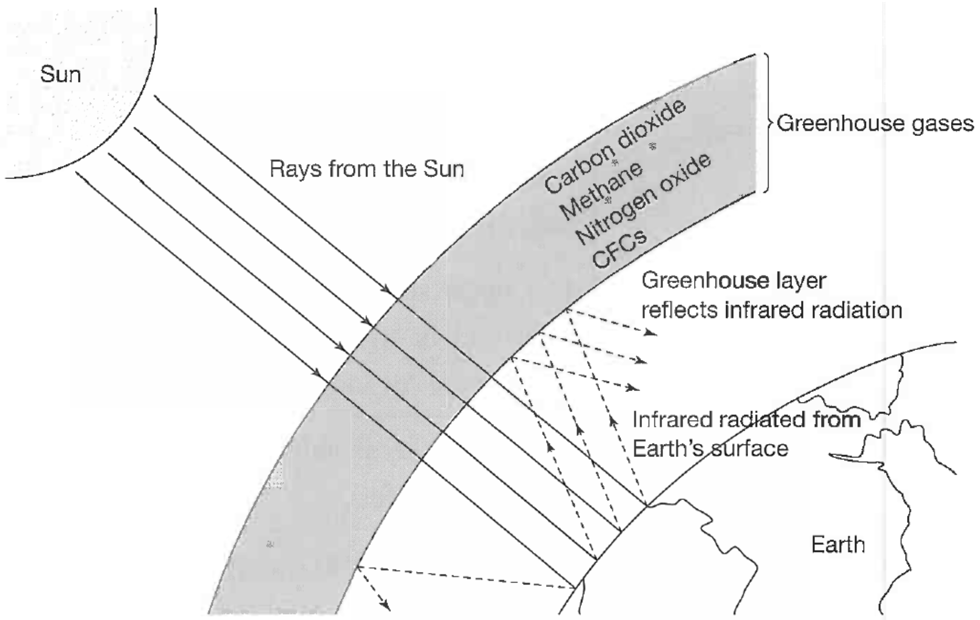
- Fuel elements:
  - Made from enriched uranium oxide, containing 3% ^{235}U and 97% ^{238}U.
    (Natural occurrence of ^{235}U : 0.72%)
- Control rods:
  - Made of boron that can absorb excess neutrons to control the rate of chain reaction.
  - They can be inserted into or removed from the reaction chamber.
- Moderator:
  - The fuel elements are submerged in water under high pressure, which serves to slow down the fast fission neutrons for them to react with the nuclear fuels. The chain reaction will stop if the neutrons move too fast.
- Coolant:
  - The pressurized water also acts as a coolant to absorb heat from the reaction and transfer this heat to the electrical generator. This heat will drive a steam turbine which generates electricity by generators.

3 Environmental Impact of Energy Consumption

- Energy sources need to go through the following stages before the energy is made available for use: extraction, conversion, and distribution. Each step can produce environmental impact on society.
- Irrespective of the starting form of energy, the end of any energy conversion process is heat. Such waste heat contributes to the heat island effect causing higher temperatures in urban areas.

4 Greenhouse Effect

- Short wavelength IR is received from the Sun and warm up Earth surface.
- The Earth will emit IR of longer wavelength as its surface is much cooler.
- The Earth's atmosphere is transparent to short wavelength IR but not for longer IR. Therefore the long IR emitted by the Earth's surface will be absorbed and re-emitted in all directions. The gases in the atmosphere that absorbs IR radiation are called greenhouse gases.



- The net effect is that the upper atmosphere and the surface will be __heated__.
- It should be noted that the greenhouse effect is a __natural__ process, which maintains the surface temperature __higher__ than planets without atmosphere. This makes the Earth __habitable__ for living organisms.
- The main greenhouse gases are usually naturally occurring, but their amounts and proportions can be changed as a result of human activities.

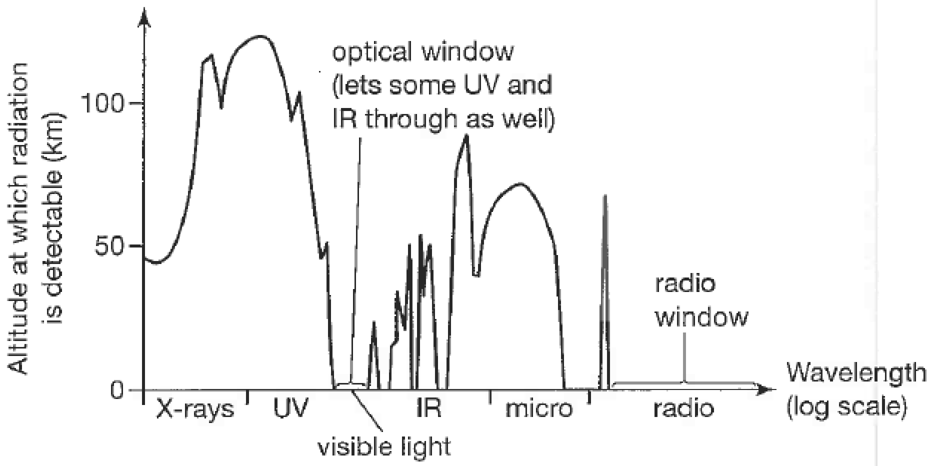
Greenhouse Gases	Sources
Methane	Livestock and plants. Product from decay, decomposition or fermentation.
Water	From water cycle, has a significant effect.
Carbon dioxide	Burning, but plants help to remove this.
Nitrogen oxides	Industry and livestock. (Livestock feeding and waste decomposition)
Ozone	Naturally occurring. Absorbs UV but also adds to greenhouse effect.
Chlorofluorocarbons	Refrigerants, propellants, cleansing solvents. They can deplete the ozone layer.

- Global warming: The __acceleration__ of greenhouse effect due to rapid expansion of industrial and economical activities.
- Impact of global warming:
  - __Rise__ of sea level which will __flood__ a lot of lowlands.
    - It should be noted that the largest contribution for rise in water level is __thermal expansion__ of water, while the __melting__ of ice comes next.
  - Change in __climate__ and more __extreme__ weathers may occur.
  - Spread of disease. A warmer temperature is favorable for bacterial growth.

- Factors account for increasing amount of greenhouse gases:
  - Burning of fossil fuels for increasing energy requirements.
  - Clearing of forests.
  - Population growth causing increase on energy requirements.

5 Solar Power

- Astronomical unit (AU): The average distance from the Sun to the Earth.
  - 1 AU = 1.496×10^8 km
- Solar constant: the incoming power of EM radiation from the sun, at a distance 1 AU from sun, per 1 square-meter of area.
  - Due to variation of solar activity, the solar constant actually varies slowly with time. The mean value of solar constant is about 1366 $W m^{-2}$.
  - The solar constant includes all types of solar radiations, not just the visible light. Also, it does not include the absorption by the atmosphere.



- To harness solar energy arrives the Earth's surface, we usually use solar cells and solar heater.

Example:

The mean distance of the Earth from the Sun is 1.496×10^8 km. The solar constant is 1366 Wm^{-2}.

(a) Calculate the total radiation power of the Sun.

(b) The Earth may be treated as a sphere of radius 6400 km. Find the total solar power radiation towards the Earth.

(a) $4\pi r^2 \cdot P$

$= 4\pi(1.496\times10^{11})^2(1366)$

$= 3.84\times10^{26}$ W

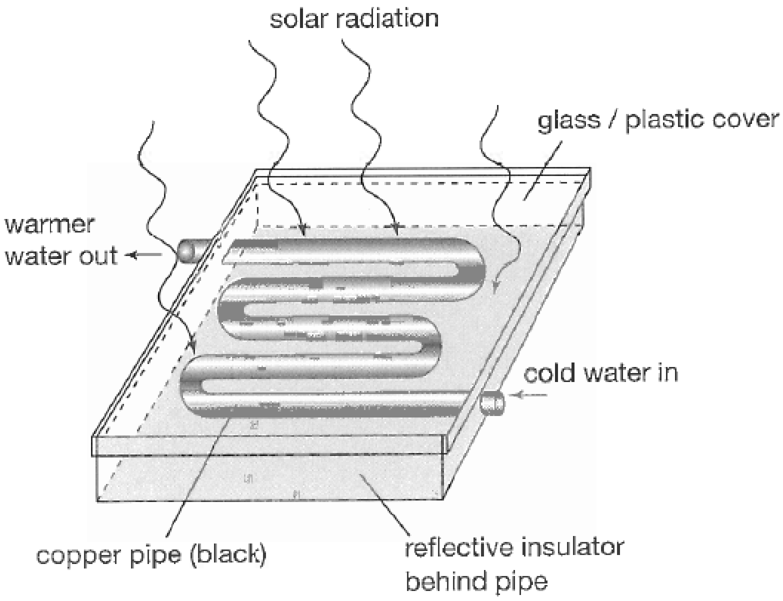
(b) $\pi r^2 I$

$= \pi(6.4\times10^6)^2(1366)$

$= 1.76\times10^{17}$ W

5.1 Solar Heater

- Solar heater converts solar energy into thermal energy in water.



Active solar heater

- The copper pipe is blackened since a dull surface is a good absorber of radiation.
- The glass cover allows radiation to pass through and prevent heat loss by convection.
- The reflective insulator prevents heat loss by conduction and radiation.

5.2 Solar Cell

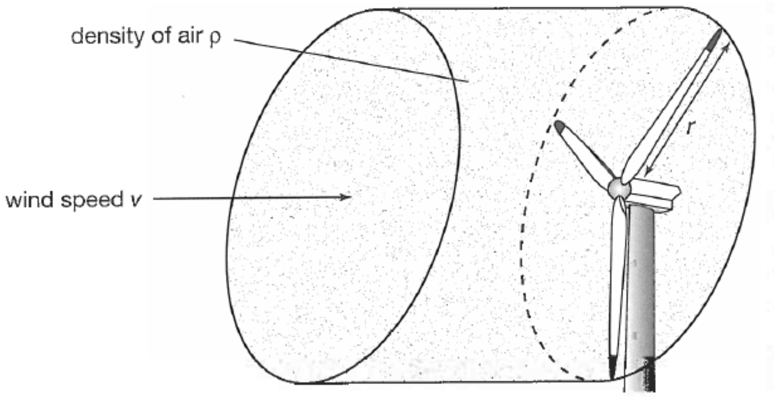
- Solar cell converts light energy into electrical energy. A solar cell is usually prepared in the form of a panel.
- A solar cell consists of two layers of semiconductors placed in contact, one in n-type and one in p-type.
- n-type: charge carriers are electrons.

  p-type: charge carriers are electron holes.
- Before light is shined onto the cell:
  - In the p-n junction, negative electrons diffuse from n to p, positive electron holes diffuses from p to n.
  - Such separation of charges makes n-type side positive, and the p-type side negative, around the p-n junction. Therefore an electric field from n to p is set up. Such region is called the depletion region.
  - Such field opposes further charge movements and the system is in equilibrium.
- When light is shined onto the cell:
  - Some electrons are knocked by the incident photon and becomes mobile electrons and electron holes, which are free to move in the materials.
  - Near the electric field, these mobile electrons will travels from p to n; and mobile electron holes will travels from n to p.

- Under connection to a complete external circuit, excess electrons on n-typed side may travel through the wire and power the load.
- These electrons finally reach the p-typed side and recombine with positive electron holes there.

6 Wind Power

- As different parts of the atmosphere are heated to different temperatures, such temperature differences cause pressure differences and wind blows.
- The kinetic energy of wind is extracted by wind turbines.
- Maximum power of a wind turbine:



- The area swept out by the blades of turbine $A =$ πr^2.
- In 1 second, the volume of air that passes the turbine $V =$ Av -.
- Mass of air passes the turbine in 1 second $m =$ $\rho V = \rho A v$.
- Maximum KE available per second = $\frac{1}{2} m v^2$

$= \frac{1}{2} \rho A v^3$

- Maximum power available :

$$P = \frac{1}{2}\rho A v^3$$

- It should be noted that the above expression is the theoretical maximum power available. Typically only 40% of the wind power can be converted to electrical power.
  - Reasons:
    - Wind is not stopped by the turbines.
    - Wind direction not always normal to turbines.

7 Hydroelectric Power

- The source of energy in a hydroelectric power station is the gravitational potential energy of water. This is extracted when water is allowed to flow downhill.
- The water can gain gravitational potential energy by
  - water cycle
  - tidal power