Sustainable Engineering

Module 4

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Energy Sources

Basic concepts

- Energy is defined as the ability to do work

- Everyone of us need energy in some form or another, which powers society, industry and eventually our day to day life.

Forms of energy

1. **Kinetic energy :-** It is the energy of an object in motion. If an object of mass "m" is moving with a velocity, "v", then its kinetic energy is given by, $KE=\frac{1}{2}\, mv^2$.

2. **Potential energy :-** It is the energy of a body by virtue of its position, in the earth's gravitational field, given by PE=mgh, where, "m" is the mass, "g" is the acceleration due to gravity and "h" is the height in metre from the ground level.

3. **Thermal (or heat) energy :-** It is the form of energy resulting from kinetic energy of molecules, given by, $E=Cm\,\Delta t$. Here, "C" is the specific heat capacity in J/kg ^{0}C, "*m*" is the mass in kg and Δt is the difference in temperature in ^{0}C.

4. **Chemical energy :-** It is the energy stored in chemical bonds of atoms and molecules, which is released during chemical reactions. Chemical energy tied up in fossil fuels are released during combustion which are used to generate electricity.

5. **Electromagnetic and radiant energy :-** It is the form of energy from electromagnetic waves. Sun is the most important source of electromagnetic energy The energy associated with electromagnetic radiation of wavelength (λ) and frequency (f) is given by $E=hc/\lambda$, where "h" is the Plank's constant.

6. **Electrical energy :-** It is the energy resulting from the movement of electrons in a conductor. This form of energy can be converted to other forms of energy, for satisfying our daily needs.

7. **Nuclear energy :-** It is the energy associated with atomic fission (large atoms split into smaller ones) and atomic fusion (smaller atoms are combined to form larger ones). Energy associated with nuclear reaction is $E=mc^2$.

❖ Law of conservation of energy states that, "energy can neither be created nor destroyed, but it can be converted from one form to other".

Renewable and Non-Renewable Energy Sources

- **Renewable energy sources :-** These are energy sources, that are directly available, immediately accessed and can be replenished in a short period of time. Eg: solar energy, wind energy, geothermal, hydropower, Tidal energy (energy from ocean waves), biomass etc.

- **Non-Renewable energy sources :-** These are energies that cannot be replenished in short period of time. Eg: petroleum (crude oil), natural gas, firewood, Uranium etc. Coal, oil and gas are called "fossil fuels" because they have been formed from the organic remains buried under ground millions of year back. Over 85% of the energy consumed in the world is fossil non-renewable resources.

  a. Coal
  b. Crude oil
  c. Natural Gas
  d. Firewood
  e. Nuclear energy

Contribution of various energy sources to India's Energy production

Type of Energy Source	Contribution (%)
Coal Power	57
Hydro Power	18.5
Renewable sources other than Hydro power	12.3
Gas	9.3
Nuclear Power	2.3
Power from Diesel	0.6

- Our earth has a fixed or finite amount of non-renewable energy resources and if they are once run out, we will not be able to use this energy again.

Conventional & Non-Conventional Energy Sources

Conventional Sources of Energy

- Conventional sources of energy are generally **non-renewable** sources of energy, which are being used for a long time (ancient time onwards). Coal, Oil (petroleum), natural gas and firewood are examples. Energy is defined as the ability to do work

Non-Conventional Sources of Energy

- Non-Conventional sources of energy are generally **renewable** sources of energy, which are in the process of development over past few years. Few examples are listed below:-

1) Solar energy
2) Fuel Cells
3) Hydro-electric power
4) Wind power
5) Tidal Power
6) Wave power
7) Ocean thermal power
8) Geothermal power
9) Biomass
10) Bio-fuel

1. Solar Energy

- Solar is the Latin word for "sun" and solar power is the energy from the sun. It can be considered as a fusion reactor at a distance of about 150 x 10^6 km from earth. It is free, renewable and totally inexhaustible.

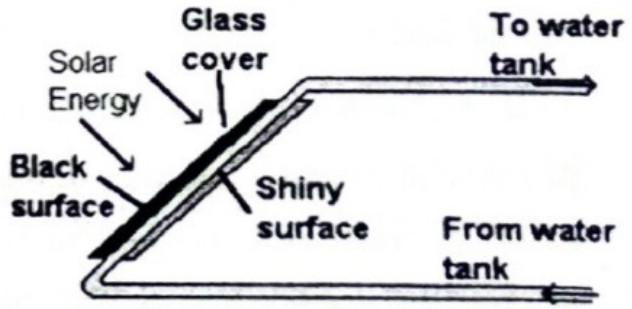
- Heat and electricity are other forms of energy that can be made from solar energy.

- Sun rays takes 8 minutes to reach earth's atmospheric region.

- Unfortunately sun is not available in the night and also in some cloudy/rainy days.

Solar Energy Technologies :- It comprises of two categories – solar thermal conversion & solar photovoltaic conversion. Some of them are listed below:

i. **Solar Water Heating :-** Water is pumped through the pipes in the panel. Using the heat from the sun, water pipes, which are painted black, will gets hot and thereby heating up the water flowing inside the pipe.



ii. **Solar space heating of buildings :-** This includes orientation of building and providing large south-facing windows. A heavy dark colored south-facing wall behind a layer of glass which provide air circulation through convection between glass and wall.

iii. **Solar air-conditioning :-** Photovoltaic powered cooling system is one method which can be used. Open cycle absorption desiccant cooling systems offer best prospects, in which the air is adiabatically cooled, de-humidified and ducted to living area.

iv. **Solar refrigeration :-** Solar powered batteries can be used for refrigeration. Solar powered refrigerator also uses phase change material for heating/cooling process. The technology has been used for storing food products and vaccines

v. **Solar drying :-** Regions having abundant sunshine uses solar drying as the cheapest method for drying agricultural products including grains, hay, fruits and vegetables.

vi. **Solar cooking :-** A typical solar cooker is a well furnished shallow rectangular / square metal box which is blackened from the inner side and filled with a flat glass cover. When placed in sunlight, the solar radiation penetrates the glass cover and are absorbed by the blackened surface, thereby resulting an increased temperature inside the box so that the food inside the box gets cooked.

vii. **Solar green houses :-** A green house is a closed structure covered with transparent material (glass or plastic) which acts as a solar collector and utilizes solar radiant energy for the growth of plants. The incoming short-wave solar radiations can pass through the green house glazing, but long-wave thermal radiations emitted by the objects with in the green house cannot escape through the glazed surface, resulting in an increase in temperature inside. Also the air inside the green house get enriched with carbon dioxide since it will not get mixed with outside air.

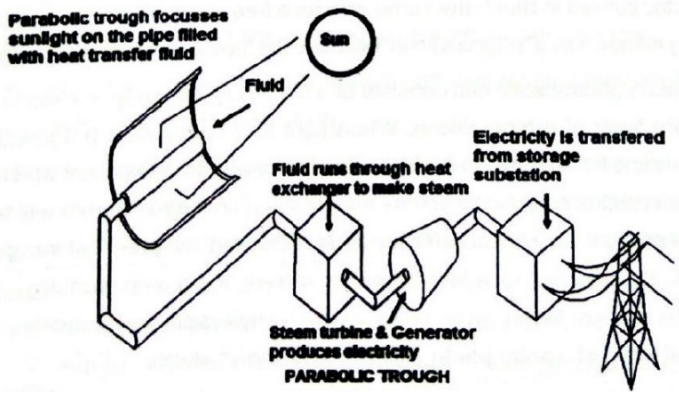
vii. **Solar furnaces :-** It uses a huge array of mirrors to concentrate the suns energy into a small space and produce very high temperature, even up to 3500 ^{o}C, which can be used to melt refractory (very strong) materials.

vii. **Solar desalination :-** This is used to desalting sea-water and brackish (salty) well water. In this method solar radiation is admitted through a transparent air tight cover of sloping sheets of glass into a shallow blackened basin / pool containing saline water. The water gets heated and evaporated. The vapors produced, get condensed to form purified water an collected to a storage tank. The salt that is not evaporated is run to waste.

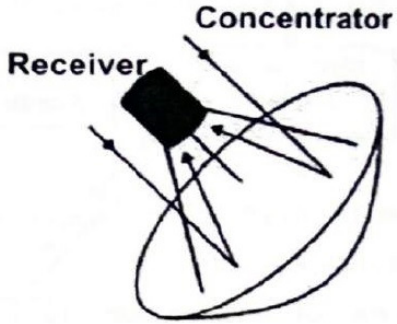
vii. **Salt production :-** The method, "solar desalination" of sea-water is use to obtain salt.

viii. **Solar electricity-thermal :-** Instead of using fossil fuels, solar thermal power plants, uses sun's rays to heat a fluid to high temperature and circulated through pipes so that it can transfer its heat to water and produce steam to run the turbine for the production of electricity. The three main types of solar thermal power system, is given below:

a. Parabolic trough :- It has long parabolic shaped reflector that focusses the sun's rays on a receiver pipe located at the focus of the parabola.

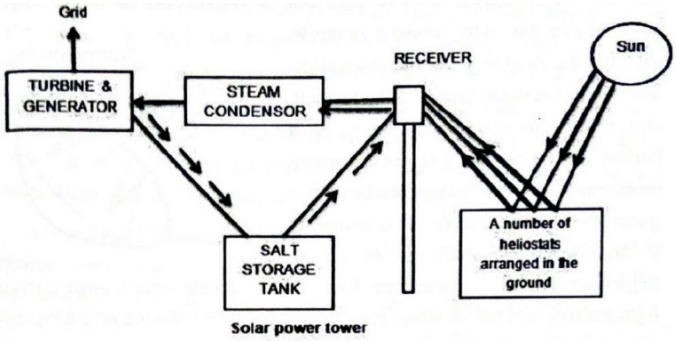


b. Solar dish :- A reflective parabolic dish focusses all the sunlight that strikes the dish, onto a single point above the dish, where a receiver captures the heat and transfer it to water to produce steam for running steam turbines to produce electricity.

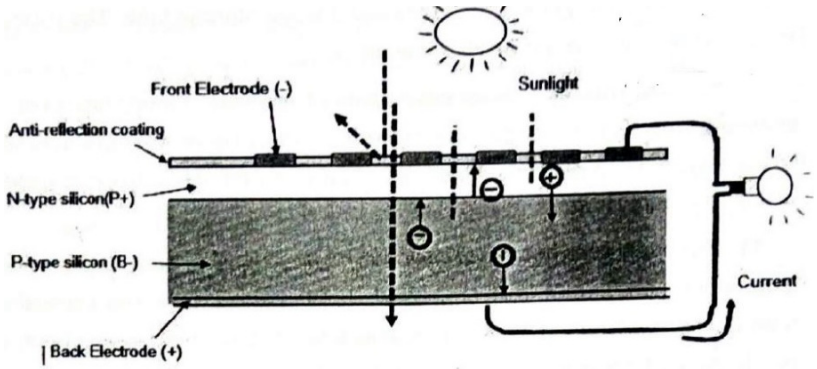


c. Solar power tower :- It generates electric power from sunlight by focusing the radiation (from thousands of tracking mirrors called "heliostats") to a tower mounted heat exchanger (receiver).

In another type, molten salt is heated by sunlight and is used to produce steam, which is used for producing electricity. (**Rankine cycle**)



ix. **Solar electricity-photovoltaic (Solar cells) :-** Photovoltaic systems are made up of semiconductor materials that converts light energy into electricity. Basically it is a semiconductor diode. When light falls on PN junction, electrons and holes moves in opposite direction across junction. If a load is connected, electric current will flow.



Advantages of solar Energy

a. Solar energy is free
b. Solar energy does not cause pollution
c. It can be used in remote areas where it is expensive to extend electricity power grid
d. Calculators and other low power devices can be powered
e. Since it is renewable, solar energy is infinite.

Disadvantages of solar Energy

a. Solar energy can be harnessed only at day time
b. Solar panels are relatively expensive
c. Large area of land is required
d. Power output of solar power station do not match with the similar sized conventional power stations.

2. Fuel Cells

- A fuel cell is an electro-chemical device that converts chemical energy of fuels directly into electrical energy.
- Each fuel cells consists of 2 electrodes, anode and cathode, separated by an electrolyte.
- Electrolyte carries electrically charged ions from one electrode to another. Depending on the type of electrolyte, different types of fuel cells are shown below:

  i. Alkaline Fuel Cell
  ii. Solid oxide Fuel Cell
  iii. Direct alcohol Cell
  iv. Molten carbonate Fuel Cell
  v. Phosphoric acid Fuel Cell
  vi. Proton Exchange Membrane Fuel Cell

  Basic operation of all fuel are the same. Working of a fuel cell with an aqueous electrolyte is shown below:

Working

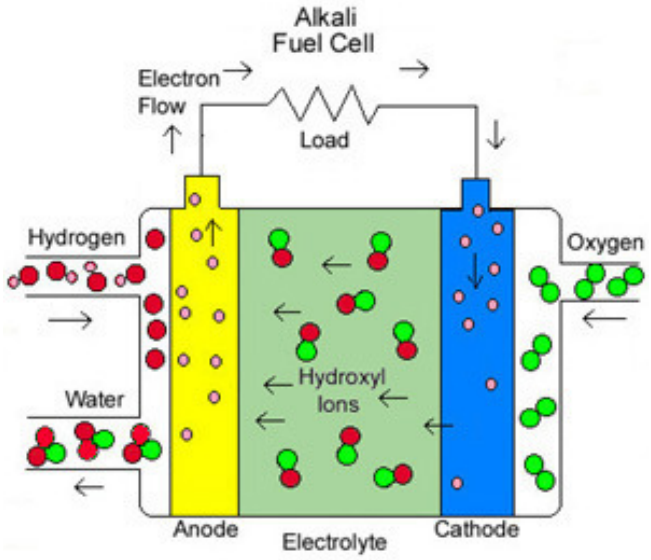
- At the anode, hydrogen gas is diffused through a porous carbon electrode, where it get adsorbed on the electrode surface in the form of hydrogen atoms. Hydrogen atoms react with hydroxyl (**OH^-**) ions (of electrolyte) to form water and release electrons which can pass through external circuit to the cathode to form the current.

- Electrolyte used is concentrated solution of Potassium Hydroxide (KOH).
- At the cathode, the oxygen diffused through the cathode is adsorbed on to the electrode surface, where it is reduced to hydroxyl ($\mathbf{OH^-}$) ions.
- The ($\mathbf{OH^-}$) ions thus formed migrates through the electrolyte from the cathode to anode. Thus electrolyte remains invariant.

Anode Reaction: $\mathbf{2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-}$

Cathode Reaction: $\mathbf{O_2 + 2H_2O + 4e^- \rightarrow 4OH^-}$

Net Cell Reaction: $\mathbf{2H_2 + O_2 \rightarrow 2H_2O}$



- The ($\mathbf{OH^-}$) ions thus formed migrates through the electrolyte from the cathode to anode. Thus electrolyte remains invariant
- Single fuel cell produces only around 0.6 to 0.8 volts under load. The desired amount of voltages can be produced by combining fuel cells in series.

Advantages

- Energy conversion efficiency is high (70 to 80 %)
- It is eco-friendly since water is the only by-product
- Fuel cells can be stacked in series to get required voltage

Limitations

- High initial cost for fabrication
- High cost for the electricity generated
- If gas is used as fuel, they have to be stored in big tanks under high pressure

Applications

- Can be used in remote areas
- Can be used to provide off-grid power supplies
- Can be applicable in both hybrid and electric vehicles

3. Wind Energy

- The origin of wind energy is from sun. When sun rays fall on earth, its surface gets heated unevenly, which causes blowing of air from region of high pressure to low pressure.
- During the day, the air above the land heats faster than air over water. This warm air over the land expands and rises, and the cooler air, which is heavier takes its place, creating wind
- Windmill farms have been erected in areas where the wind speeds are high enough to produce viable amount of energy

Wind energy and wind power

- The total wind energy flowing with a velocity (V) m/s, through an imaginary surface area (A) in m^2, during time t seconds is given by,

$$E = \frac{1}{2}mV^2 = \frac{1}{2}(AVt\rho)V^2 = \frac{1}{2}At\rho V^3$$

Where m is the mass of air hitting the wind turbine (kg)

ρ is the density of air (1.23 kg/m^3 at sea level)

E is the kinetic energy in Joules

The power (P) in the wind hitting the wind turbine per unit time is given by the following equation :

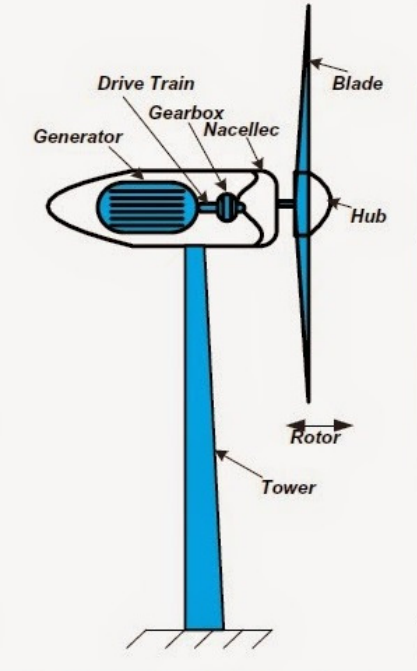
$$P = \frac{E}{t} = \frac{1}{2}\rho AV^3$$

Where, P is the power in watts (1 watt = 1 Joule / second)

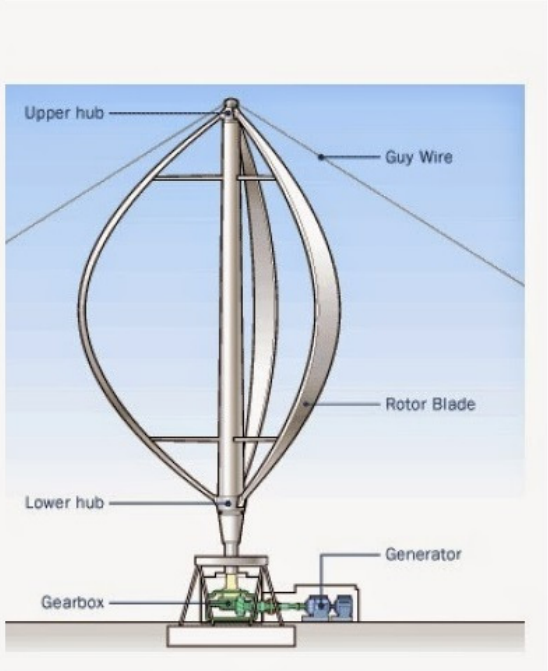
- Wind power is proportional to its 3rd power of wind velocity. As wind velocity increases, the energy increases. This is the reason why wind turbines are erected at high altitudes where wind velocity is high.

- Kinetic energy of wind, turns the propeller blades, which in turn spins a generator to produce electricity. Wind turbines are classified into two:

  i. Horizontal Axis Wind Turbine (HAWT) – Most common design
  ii. Vertical Axis Wind Turbine (VAWT)



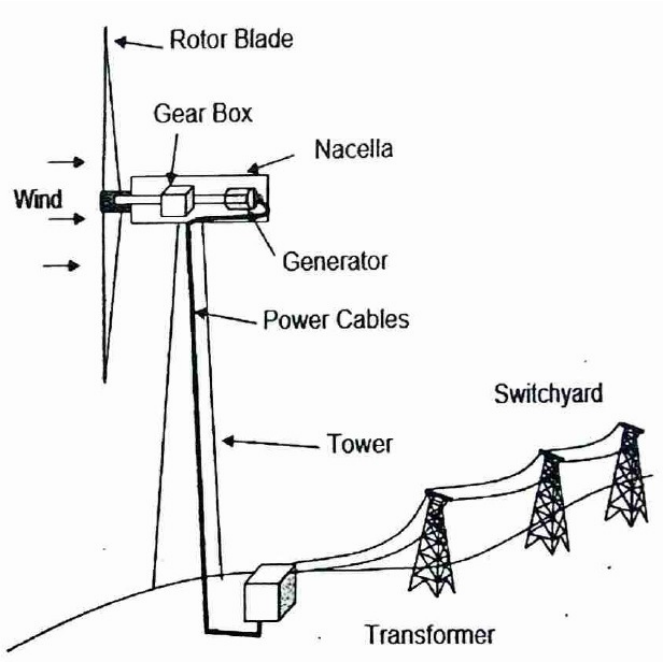
Horizontal Axis Wind Turbine (HAWT)



Vertical Axis Wind Turbine (VAWT)

Advantages

- Wind is free, hence no fuel needed
- Produce no waste or greenhouse gases
- The land between the wind mill can be used for farming
- A good method for supplying energy to remote areas



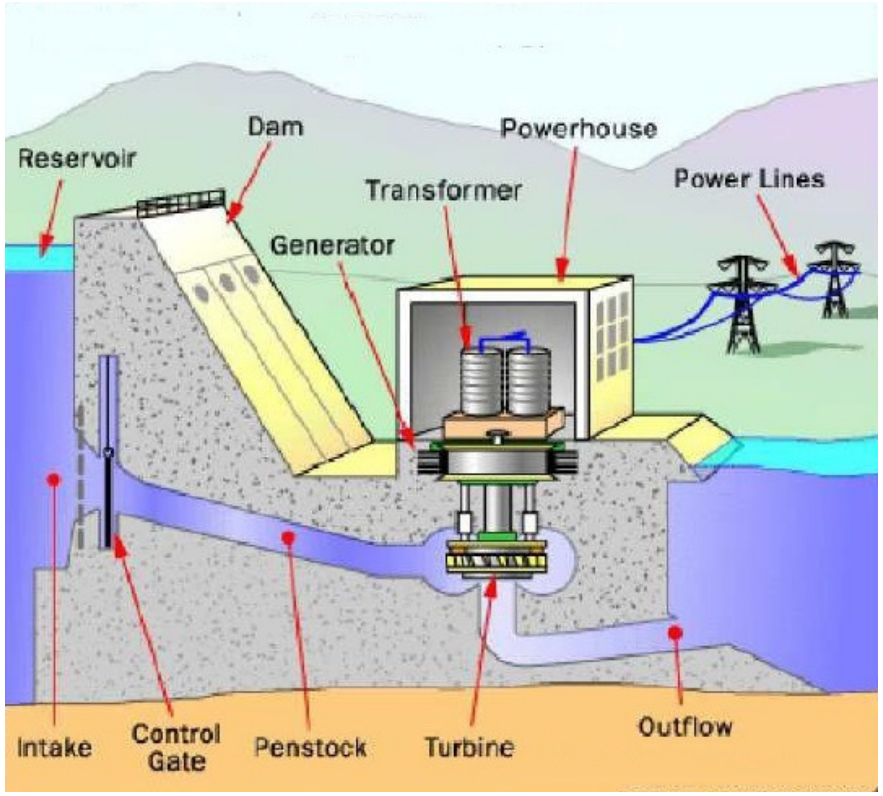
Disadvantages

- High initial investment required
- Wind is not always predictable, hence variation in energy production
- Can kill birds – hence wind mills are to be avoided in migratory routes of bird folks
- Noise produced by rotor blades is concern for local people

- India is the 4th largest wind power generator in the world, after Germany, USA and Denmark. The leaders in wind power generation in India are Tamilnadu, Maharashtra, Rajasthan and Gujarat.

4. Hydro Electric Power

- It is the electricity generated by hydropower. ie; electricity is produced by gravitational force of running water.
- Dam is a hydraulic structure constructed across flowing river to store water on its upstream side.
- Water flows from higher elevation to lower elevation through tunnels called “penstock” turns the turbines.
- The kinetic energy of running water is used to turn turbines to generate electricity



Types of hydro electric power plants

- Hydro power plants are classified based on the installed capacity

Types of hydro power	Installed Capacity
Micro hydro power	< 100 kW
Mini hydro power	101 kW – 2000 kW
Small hydro power (SHP)	2001 kW – 25000 kW
Medium hydro power	25001 – 100 MW
Large hydro power	> 100 MW

- Idukki Hydro Electric Project is the largest hydro electric project in Kerala. Installed capacity of this project is 780 MW. The powerhouse has six generators of 130 MW capacity each.

- In India and China, Small Hydro Power (SHP) refer to station capacity up to 25MW. Hydro electric projects in Kallada, Peppara, lower Meenmutti, Peechi etc. are some of the small hydro electric projects in Kerala.

- Unlike large hydroelectric projects, SHP does not necessitate a reservoir and can be constructed in any location where there is enough water flow.

Advantages of SHP

- Produce minimal impact on environment
- Clean, pollution less renewable energy source
- Relatively short time for construction and operation
- It has number of benefits such as flood control irrigation and water supply
- Long useful life (50 to 100 years)
- Low running cost

Disadvantages of SHP

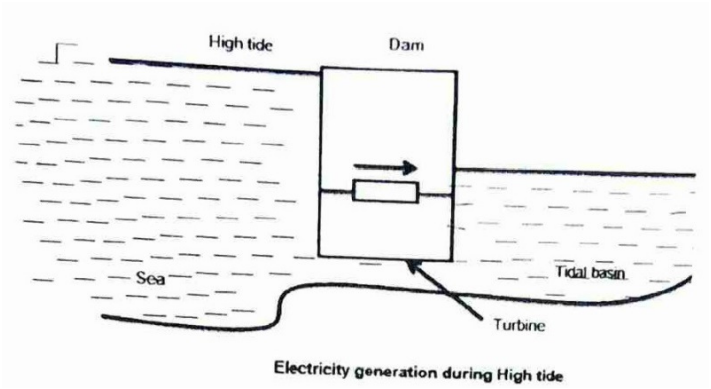
- For SHP to be economical, energy consumers needed to be located near to the hydro power scheme, thus limiting the benefit of project to stream side communities.
- Seasonal variation in stream flow causes variation in energy supply
- Fish population may be affected

5. Energy derived from oceans

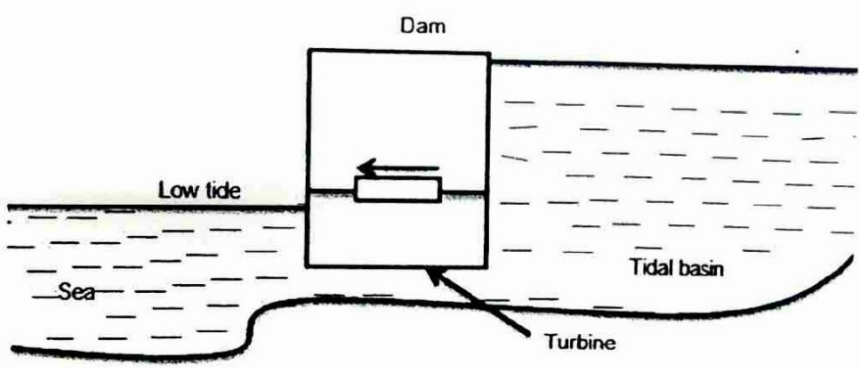
❖ Ocean energy can be captured in three ways:

i. Tidal Energy :-

- Tides are formed due to the gravitational attraction of ocean water by the sun and the moon and due to earth's rotation. When the ocean water level is above the mean sea level, it is called high tide (flood tide) and otherwise called low tide (ebb tide).
- To tap tidal power, a dam is constructed, separating the tidal basin from the ocean to create a difference in water level.
- During high tide water flows from ocean into the tidal basin through the opening (called sluice way), rotating the turbine, thereby producing electricity.
- During low tide, water from tidal basin flows to the ocean through sluice way, rotating the turbine.
- Generation of power stops only when the ocean water level and tidal basin water level are equal.



Electricity generation during High tide



Electricity generation during low tide

Advantages

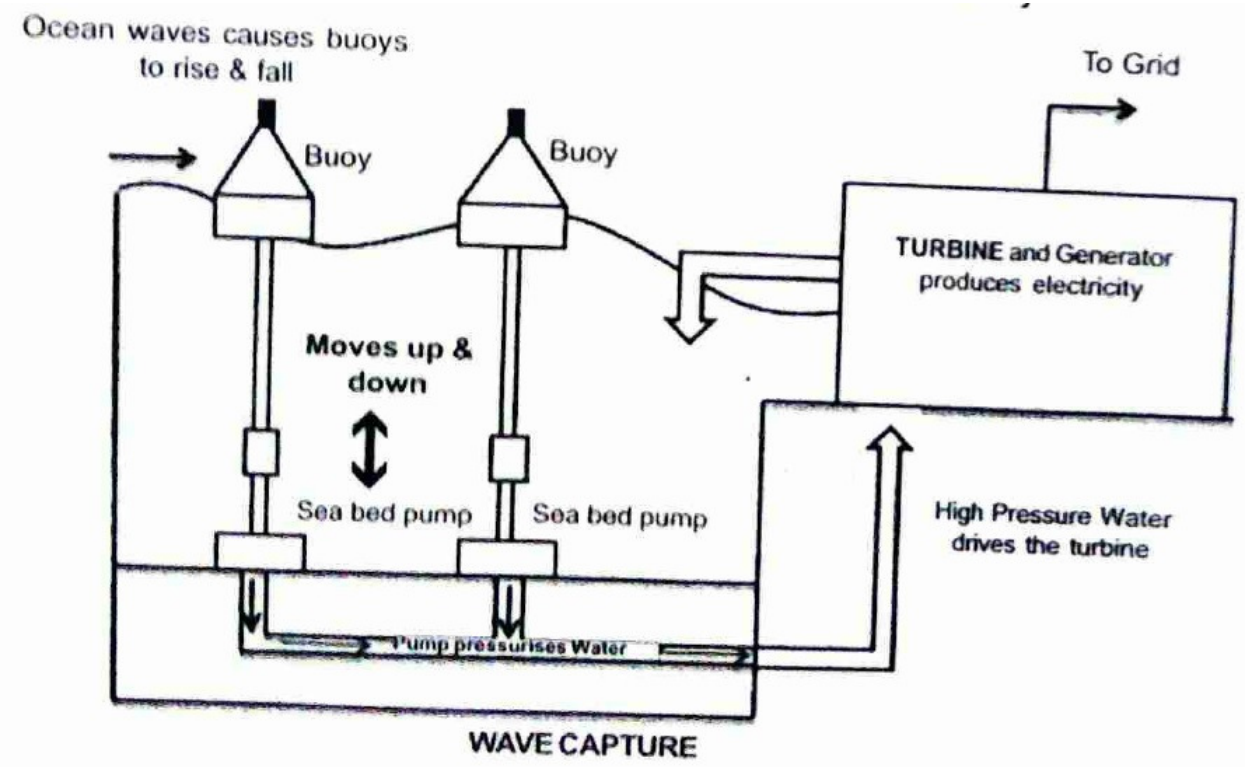
- Tidal power is free from pollution
- Cleanest source of renewable energy
- It can provide recreational facilities to tourists
- Low noise pollution

Disadvantages

- Construction of dam across a bay is very expensive and affect fish and marine eco-system.
- There are only a suitable sites for generating tidal power
- Tidal power is not continuous since it depend on timing of tides.

ii. Wave energy

- Ocean waves are caused by the wind as it blows across the sea.
- At a wave power station, the waves causes buoys (floating signals) to rise and fall.
- As the buoy moves up and down, the sea bed pump pushes the water under the pressure through a pipe, to the power station. As a result the moving water under pressure spins the turbine connected to a generator which generates electricity.



Advantages

- The energy generated is free and eco-friendly
- Abundant and widely available
- No expense to operate and maintain

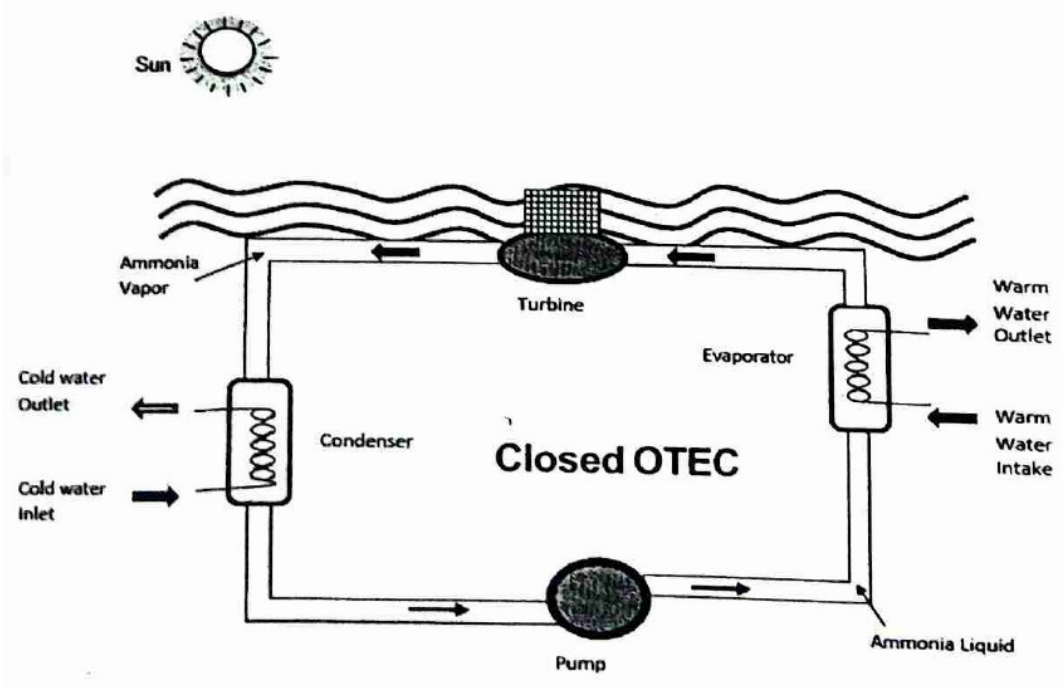
Disadvantages

- Energy output depends on the availability of waves, ie; energy is varying
- Needs a suitable site, where waves are consistently strong
- Components of a wave power station should withstand rough water

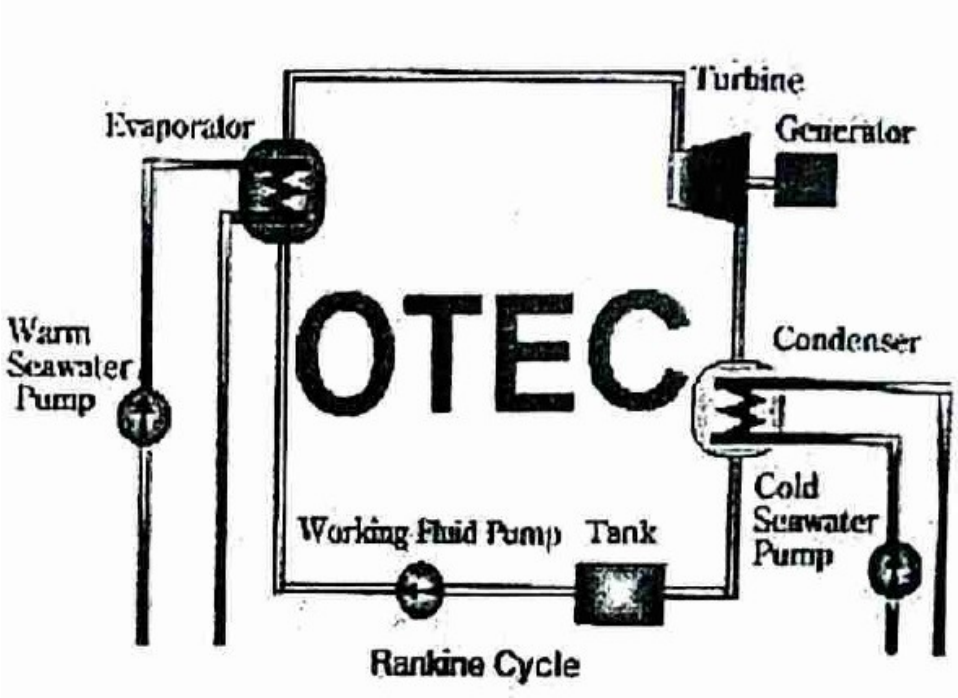
iii. Ocean Thermal Energy Conversion (OTEC)

- OTEC is a process that produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface water. Two types of OTEC are :-

  i. **<u>Closed-cycle OTEC</u> :-** The surface warm ocean water (25 to 30 ^{0}C) flowing through pipes making ammonia (or any fluid having low boiling point), boil and vaporize. This heated ammonia vapor expands and turns the turbine to produce electricity. Thereafter the heated ammonia is passed through a second heat exchanger, where deep ocean cold water (5 to 9 ^{0}C) condenses ammonia to liquid form so that it can be realized again.



i. **<u>Open-cycle OTEC</u> :-** Surface warm sea water (25 to $^{0}30$) itself is turned into steam, (by reducing its pressure) and its steam drives a turbine which generates electricity. This steam is condensed again using deep sea cold water (5 to $^{0}9$). Since in this case, sea water is used for heating and condensing, the by-product is salt free water. Hence OETC also acts as a desalination plant also.



<u>Advantages</u>

- Clean and renewable energy source.
- Power from OTEC is continuous

<u>Disadvantages</u>

- This technology is relatively inefficient
- Suitable only for tropical areas with relatively large temperature gradients

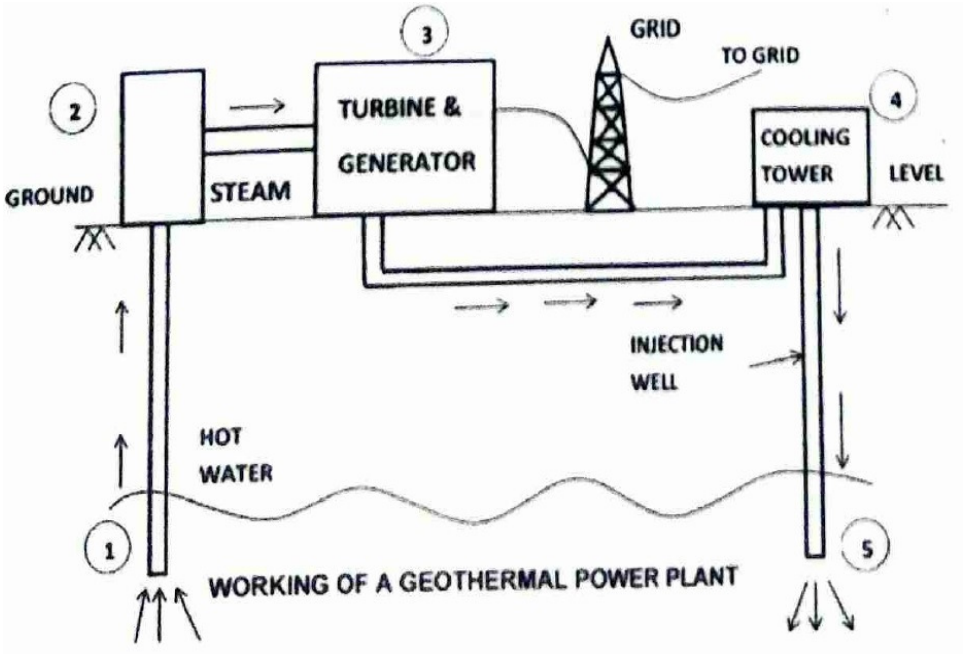
6. Geothermal Energy

- "Geothermal" comes from two Greek words : "geo" means "earth" and thermal means "heat"
- It is the energy stored in the form of heat below the earth's surface.
- Center of earth is around 5000 ^{0}C, hot enough to melt rock easily.
- In general the temperature rises 1 ^{0}C for every 30 to 50 meters we go down
- In volcanically active areas, such as Iceland, New Zealand etc; molten rock can be very close to surface.
- Geothermal energy can be captured using two methods:

i. Geothermal power plants:-

Steps

1) Injection wells are driven deep into the earth and hot water is pumped up to the surface.
2) At the surface, pressure gets reduced, which converts hot water to steam.
3) This steam is used to spin the turbine to generate electricity.
4) Steam cools off in a cooling tower and condense back to water.
5) Thereafter cooled water is pumped down into the injection well and the cycle is repeated.

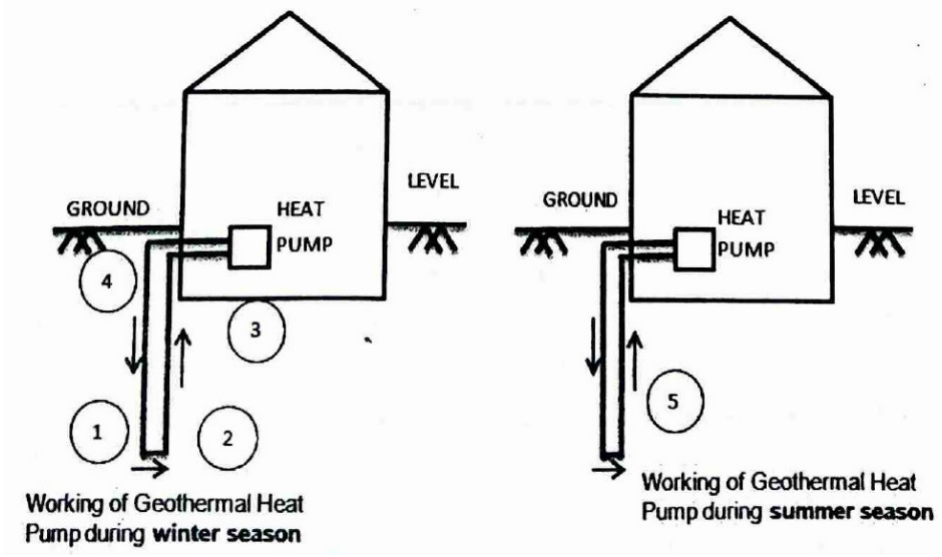


i. Geothermal heat pumps:-

- Geothermal heat pumps tap heat from the shallow reservoirs (close to the earth's surface) either to heat water or to provide heat for the buildings.

Steps

1) Water or refrigerants moves through a loop of pipes
2) When the water is cold, the water or refrigerant heats up as it travels through part of loop that is buried underground
3) Once it gets back above ground, the warmed water or refrigerant transfers heat into the building
4) The water/refrigerant cools down after its heat is transferred. It is pumped back to the underground, where it heats up once more, starting the process again
5) On a hot day, the system can run reverse, the water/refrigerant cools the building and then is pumped to underground where extra heat is transferred to the ground around the pipes.



Advantages

- Inexhaustible and renewable energy source
- Non polluting and ecofriendly source
- An excellent supplement to other renewable source
- Geothermal energy is not affected by seasonal changes

Disadvantages

- Not available in many locations
- Overall efficiency of power production is quite low (10 to 20%).

Assignment

1. **Explain biomass. What are the different methods for converting biomass to energy?**
2. **Explain biofuel? What are the biofuels that can be made from biomass?**
3. **What is biogas? How is it produced?**


THANK
YOU!