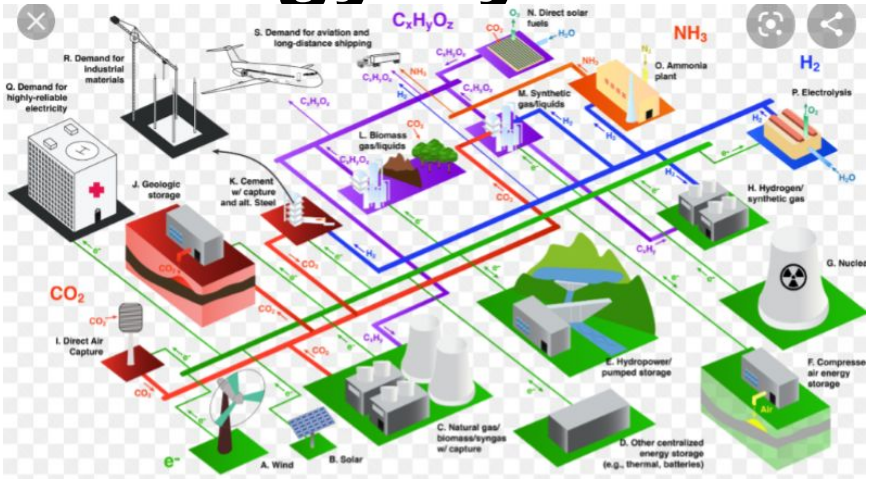
Module-3

Energy Systems



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Introduction:

- Energy is the fundamental aspect of human life. Energy is defined as the capacity to do work. Everything we do is connected to energy in one form or the other. Chemical fuels are used in transportation, communication and illumination etc,

Chemical fuel :

- It is is a naturally occurring or an artificially manufactured combustible carbonaceous material which serves particularly as a source of heat and light and in a few cases as a source of raw material.
  Ex: Wood, Coal, Crude oils, Natural gas etc.

Classification of Fuels:

- On the basis of origin, fuels are classified as primary and secondary fuels. These are sub divided into solid, liquid and gaseous fuels.

Primary Fuels:

- Is one which occurs naturally and requires no chemical processing before utilization are called primary fuels
  Ex: Wood, coal, peat, crude petroleum and natural gas.

Secondary Fuels:

- Is one which is derived from primary fuels are called secondary fuels. Secondary fuels required chemical processing before utilization. Ex: Charcoal, coke, petrol, gasoline.

Calorific value of a fuel:

- It is defined as the amount of heat liberated when unit mass of a fuel is completely burnt in excess of air or oxygen.
- Calorific value is normally expressed in joules per kg (j/kg) for solid and liquid fuels and joules per cubic meter (j/m3) for gaseous fuels in SI units.

Gross Calorific Value or Higher Calorific Value (GCV)

- It is defined as the amount of heat liberated when unit quantity of a fuel is burnt completely in air and product of combustion are cooled to room temperature.
- All fuels invariably contain carbon and hydrogen. On combustion carbon and hydrogen present in fuels are converted into carbon dioxide and steam respectively. On cooling the products of combustion, steam gets condensed to water and liberates it latent heat. The measured calorific value includes the latent heat of steam. Therefore it is always higher than net calorific value.

GCV = NCV + latent heat of condensation of water

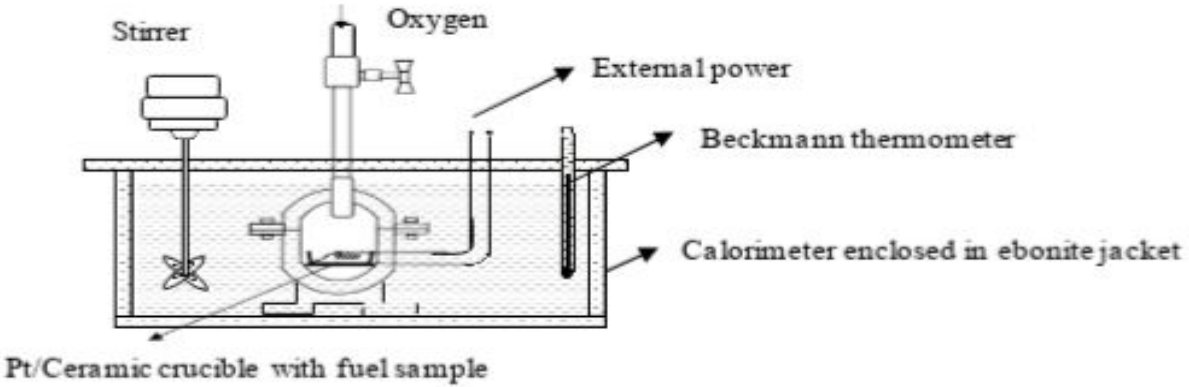
Net (lower) Calorific Value (NCV):

- It is defined as the amount of heat released when a unit quantity of a fuel is burnt completely in air and the products of combustion are allowed to escape.
- In actual practice, the combustion products are not cooled to room temperature, but simply allowed to escape into the atmosphere. Since this calorific value does not include the latent heat of steam, net calorific value is always lower than gross calorific value.

NCV = GCV - % of H_2 x 0.09 x latent heat of steam

Determination of Calorific Value of Solid or Liquid Fuel Using Bomb Calorimeter.

- It is the device used to determine the calorific value or heat content of a solid / liquid fuel under applied pressure
- It consists of a strong cylindrical steel vessel (bomb) with a capacity of 450-500 ml. It has airtight screw lid and a valve for pumping oxygen. A known mass of the fuel (about 1g) in the form of a pellet taken in a stainless Pt/Ceramic crucible with a loop of copper wire projecting out from it is placed in the bomb.
- The lid is closed tightly and oxygen is pumped in through a valve at s pressure of 25-30 atmospheres. The apparatus is placed in a known mass of water taken in the calorimeter.
- The calorimeter is exposed in a jacket to minimize heat exchange with the surroundings. The initial temperature of water is noted.
- The fuel is ignited by connecting the ends of the wires to a source of electric current. Rapid combustion of the fuel takes place, water in the calorimeter is continuously stirred using an electrical stirrer during heating. The maximum temperature attained by water is noted.



Observation and calculation

- Mass of the fuel =m kg
- Initial temperature of water = t1 0C
- Final temperature of water = t2 0C
- Rise in temperature of water = (t2-t1) 0C= Δt 0C
- Mass of water in the calorimeter =W kg
- Water equivalent of calorimeter =w kg
- Specific heat of water (s) =J/kg/0C
- If Q is the gross calorific value

Then,

Heat released by the m kg of fuel = Heat absorbed by water and apparatus

$$m\ Q_{gross} = W \times S \times \Delta t$$

$$Q_{gross} = (W + w) \times S \times \Delta t / m$$

$$= \ldots\ldots\ldots\ldots\ J/kg$$

Knocking of Petrol Engine:

- It is defined as the production of a shock wave in an IC engine as a result of explosives combustion of fuel air mixture due to an increase in the compression ratio, beyond a certain value, leading to a rattling sound.

Mechanism of Knocking

- Under ideal conditions there is a slow oxidation of the fuel during which oxygen combines with a few hydrocarbon molecules and activates them.
- The activated molecules combine with the hydrocarbon molecules and a chain reaction is set up resulting in a smooth combustion.

  $C_2H_6 + 3/2O_2 \longrightarrow 2CO_2 + 3H_2O$
- Knocking occurs because the chain reaction proceeds at a very fast rate.
- The hydrocarbon molecules combine with oxygen to form peroxides.
- The unstable peroxide decomposes readily to give a number of gaseous compounds. This gives rise to pressure waves which knock against the engine walls.

  $C_2H_6 + O_2 \longrightarrow H_3C\text{--}O\text{--}O\text{--}CH_3$

  $H_3C\text{--}O\text{--}O\text{--}CH_3 \longrightarrow H_3C\text{-}CHO + H_2O$

  $H_3C\text{-}CHO + 1/2O_2 \longrightarrow HCHO + CO_2 + H_2O$

  $HCHO + O_2 \longrightarrow CO_2 + H_2O$

ill Effect of Knocking

- Decreases the life of IC engine.
- Causes mechanical damage due to overheating to engine parts such as spark plug, piston and engine walls.
- Consumption of fuel is more, results in decreased power output.
- Due to undesirable rattling sound, driving becomes unpleasant.

Power Alcohol:

- This is alcohol-blended petrol.
- Gasohol is a blend of 10 – 85% of absolute ethanol and 90 – 15% of petrol by volume and is used as a fuel in the United States. Absolute alcohol is used in the preparation of Power alcohol to prevent phase separation.
- Alcohol contains higher percentage of oxygen than MTBE and hence brings about complete oxidation of petrol more effectively.
- Therefore power alcohol has better antiknocking characteristics than unleaded petrol.

Advantages of power alcohol

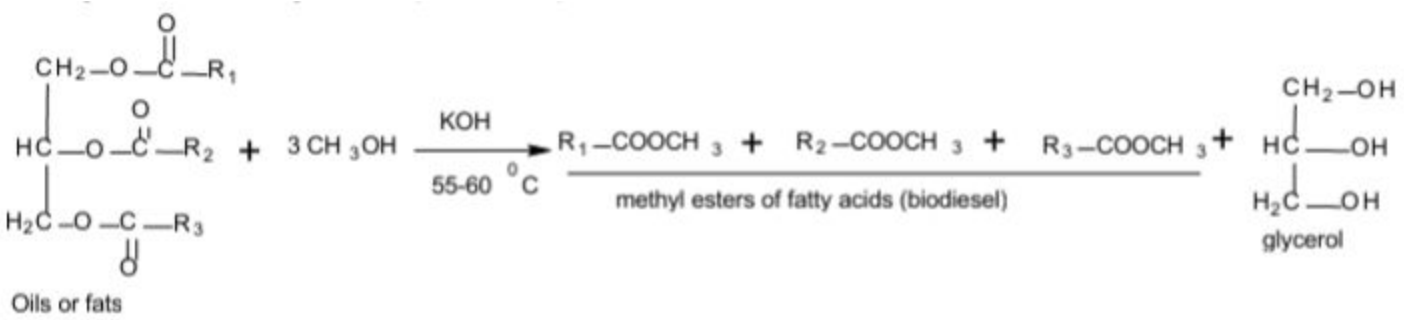
- Power output is high
- Does not release CO, causes less pollution.
- It is obtained from molasses, a agricultural product and hence readvantages of power alcohol.

Unleaded Petrol:

- The petrol is totally free from lead is known as unleaded petrol. The octane value may be increased by adding methyl tertiary butyl ether (MTBE).
- MTBE contains oxygen in the form of ether group and supplies oxygen for the complete combustion of the petrol in internal combustion engine thus reducing the formation of peroxy compounds.
- Petrol whose octane number is increased by the addition of substance other than lead compounds is referred to as unleaded petrol.

Biodiesel:

- It is alternative fuel to diesel. It is ecofriendly fuel obtained from renewable sources like vegetable oils and animal fats.
- Vegetable oils are triglycerides which have high viscosity, flash point and low heating value. Hence they cannot be used as such in diesel engine.
- The triglycerides are needed to be converted into biodiesel by a process called transesterification. During esterification, the triglyceride is treated with methanol or ethanol in the presence of a base like KOH forms methyl ester of fatty acids (biodiesel).



- R1 R2 & R3 are long chain fatty acids.
- The mixture of methyl esters are called biodiesel and have the desired characteristics of diesel fuel with cetane number in the range of 50-62 depending on the vegetable oil used for trans esterification.

Advantages of Biodiesel

- Trans-esterified biodiesel has much lesser viscosity and can replace petroleum diesel in the diesel engine.
- It is completely degradable, non-toxic and free from sulphur compounds.
- Non edible oils can be used.
- Eco friendly products are formed.
- Byproduct glycerol can be used for various purposes.

Fuel Cells

Introduction:

- A fuel cell is a galvanic cell in which the chemical energy contained in a readily available fuel oxidant system is converted directly into electrical energy by means of electrochemical process in which the fuel is oxidized at the anode.
- The fuel cell has two electrodes & an electrolyte. However, the fuel & the oxidizing agents are continuously & separately supplied to the two electrodes of the cell, at which they undergo reactions. These cells are capable of supplying current as long as they are supplied with the reactants.
- A fuel cell essentially consists of the following arrangement:

Fuel / Electrode / Electrolyte / Oxidant / Electrode

Anode : Fuel --------> Oxidation product + ne

Cathode : Oxidant + ne ---------> Reduction product

Difference between Conventional cell & Fuel cell

Conventional Cell (Battery)	Fuel Cell
1. Batteries are energy storage devices.	1. Fuel cells are energy conversion devices.
2. The electrodes are not assisted with catalyst.	2. The electrodes are impregnated with catalyst.
3. The active materials are mixture of complex chemical compositions.	3. The active materials are fuel & oxidant.
4. Active materials placed along with electrodes in the cell.	4. Active materials i.e., Fuel & oxidant are stored outside the cell & are supplied when ever required.
5. Recharging of the cell is required.	5. Recharging of the fuel cell is not required.

Limitations of fuel cell

- Electrodes & electrolytes are costly.
- Fuels in the form of gases & oxygen need to be stored in tanks under high pressure.
- Power output is moderate.

Advantages of fuel cells

- High efficiency of the energy conversion process.
- No moving parts & there is no wear & tear, high reliability in electricity generated.
- They operate very silently.
- Absence of harmful waste products and Recharging of the cell is not required.

Construction & Working of Methanol-Oxygen fuel cell

Construction

- In this cell the anode of the cell is made up of platinum & methanol along with 3.7 M sulphuric acid is continuously supplied into anodic compartment as a fuel.
- Cathode is made up of platinum & oxygen gas is circulated into cathodic compartment as an oxidant.A membrane is placed adjacent to cathode to prevent the diffusion of methanol to cathode.
- The electrolyte used is 3.7 M H_2SO_4.

Working

- At anode methanol undergoes oxidation to form carbon dioxide.

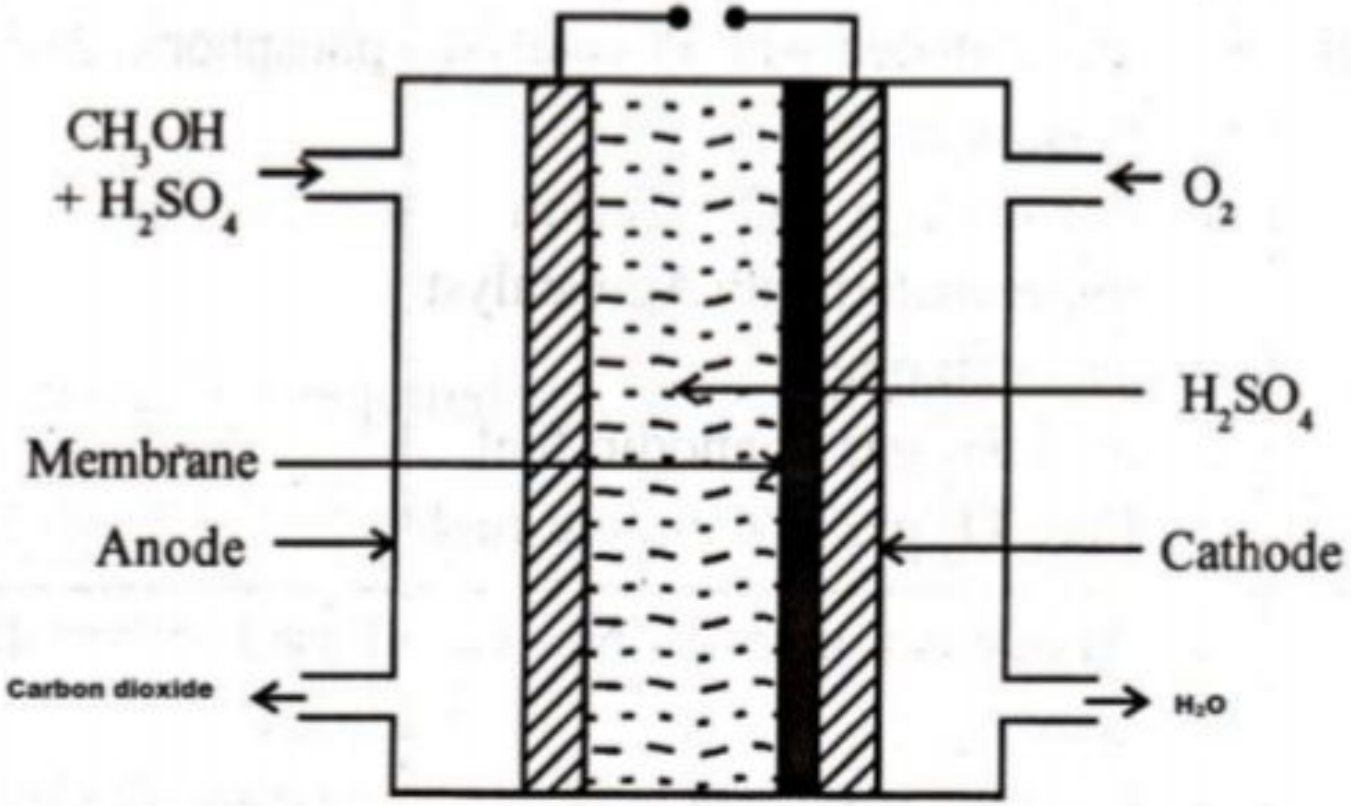
  $CH_3OH + H_2O \text{----------} > CO_2 + 6H^+ + 6e^-$
- At cathode, O_2 gets reduced in presence of H^+ ions.

  $3/2\ O_2 + 6H^+ + 6e \text{ ----------} > 3H_2O$

- The net fuel cell reaction is $CH_3OH + 3/2\ O_2 \text{ ----------} > CO_2 + 2H_2O$
- Fuel & air are fed to the electrodes. The cell potential is 1.21V at 250C.
- The acid electrolyte offers the advantage of easy removal of CO_2, a product of the cell reaction and sulphuric acid used to evacuate CO_2 from the cell.

Applications:

- In all kinds of portable, automotive & mobile applications like Powering laptop, computers, cellular phones & digital cameras.
- Fuel cell vehicles.
- Spacecraft applications
- Any consumables which require long lasting power compared to Li – ion batteries.



Methanol oxygen fuel cell

Solid oxide fuel cells (SOFC) :

- A solid oxide fuel cell (or SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel. Fuel cells are characterized by their electrolyte material; the SOFC has a solid oxide or ceramic electrolyte.
- In this cell the anode is made up of porous electrode coated with cobalt and Zirconium oxide (ZrO_2). Hydrogen & carbon monoxide fuel is continuously supplied into anodic compartment as a fuel. Cathode of the cell is made up of $LaMnO_3$ doped with strontium.
- Oxygen from the air is continuously supplied into cathodic compartment as an oxidant. At the cathode, a catalyst causes electrons from the electrical circuit to combine with oxygen to create negatively charged oxygen ions.
- The negatively charged oxygen ions flow through the electrolyte to the anode. At the anode, the catalyst causes the hydrogen to react with the oxygen ions forming water and free electrons.
- The negatively charged electrons cannot flow through the electrolyte to reach the positively charged cathode, so they must flow through an external circuit, forming an electrical current.
- At the cathode, the electrons combine with oxygen to create negatively charged oxygen ions, and the process repeats.

The cell reactions are

At the anode $H_2 + O^{(2-)} \rightarrow H_2O + 2e$, At the cathode : $1/2O_2 + 2e \rightarrow O^{(2-)}$

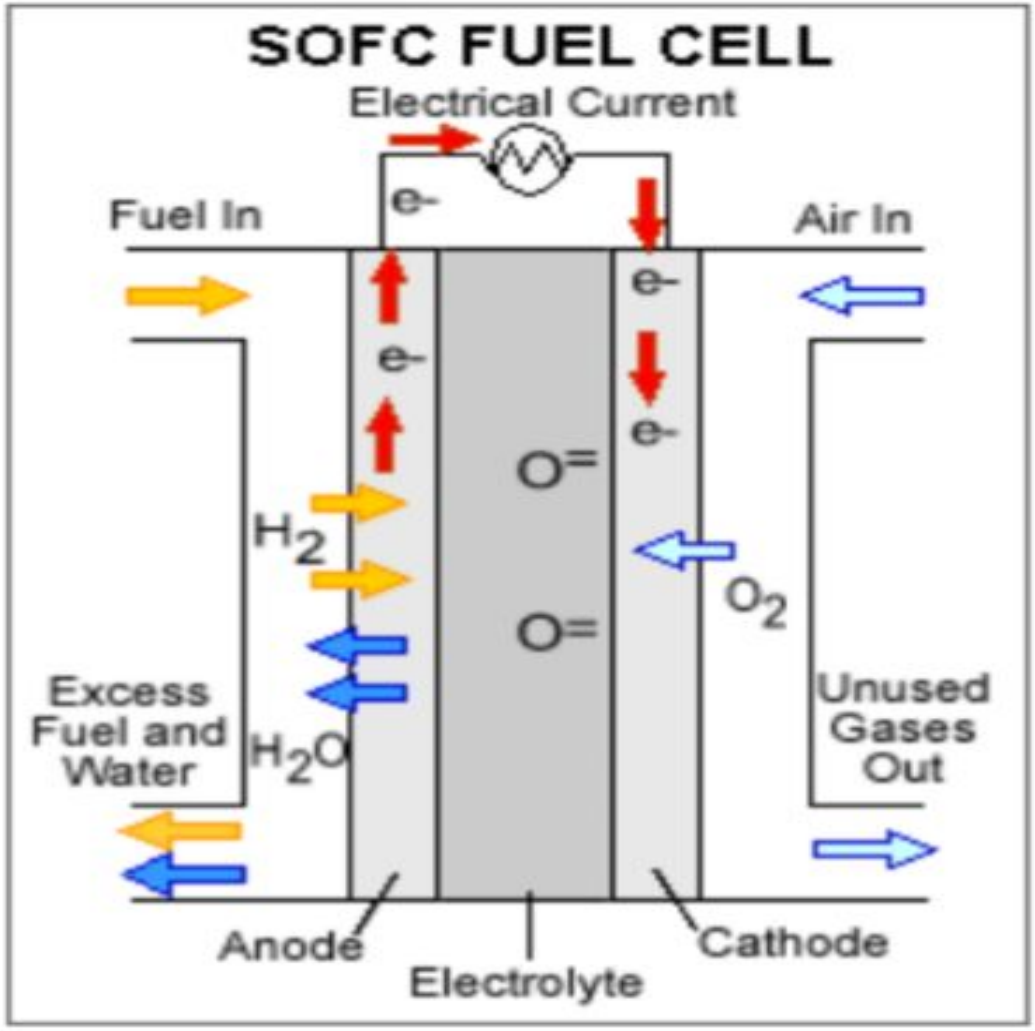
The overall cell reaction $H_2 + 1/2)\ O_2 \rightarrow H_2O$

Advantages of solid oxide fuel cell

- Solid oxide fuel cell includes high efficiency,Long-term stability, Low emissions, and relatively low cost.

Disadvantage Solid Oxide Fuel Cell

The largest disadvantage is the high operating temperature which results in longer start-up times and mechanical and chemical compatibility issues.


SOFC FUEL CELL
Electrical Current
Fuel In
Air In
e-
e-
e-
e-
O=
O=
H2
O2
Excess
Fuel and
Water
H2O
Unused
Gases
Out
Anode
Electrolyte
Cathode

Solar Energy

Introduction:

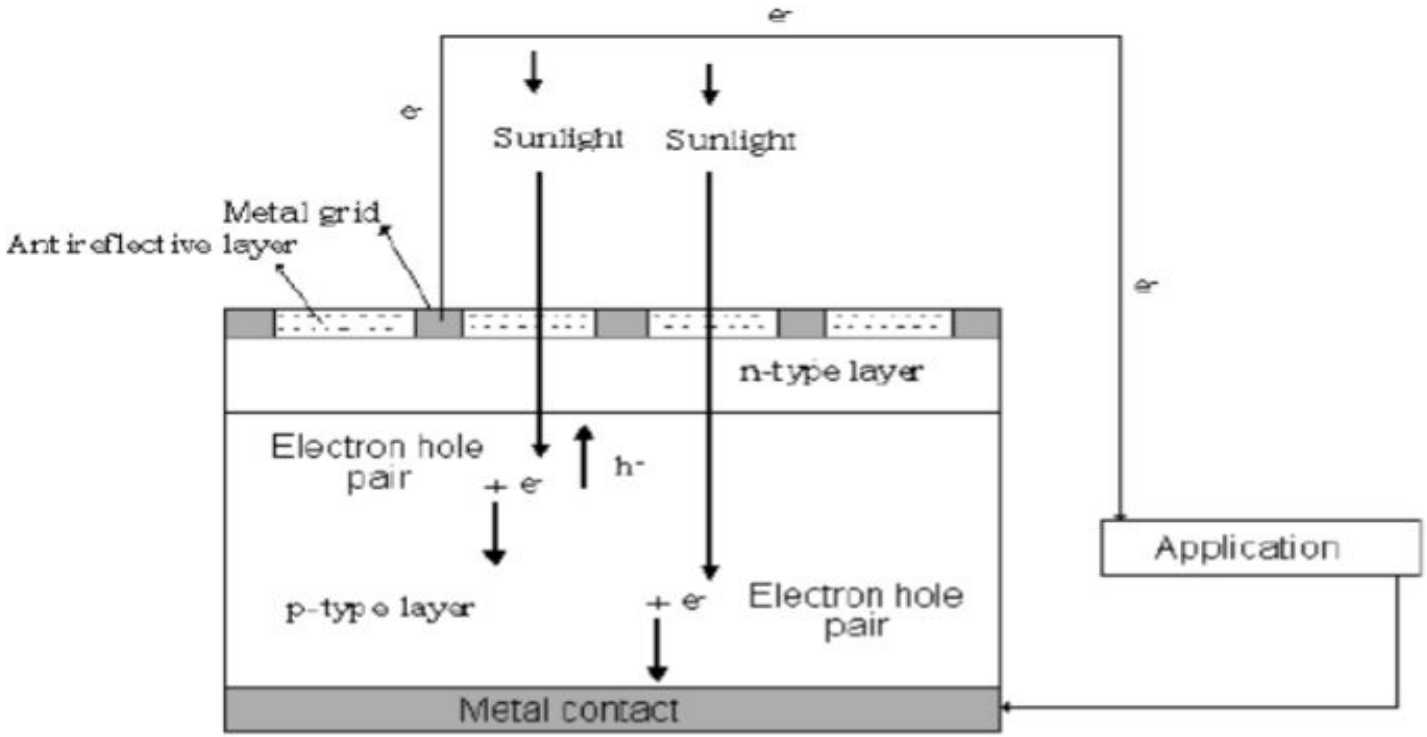
- At presently dominant energy sources are petroleum, natural gas, hydro power and nuclear energy.
- As the reserves of fossil fuels are very limited and are being depleted very fast, search for alternative sources of energy has gained lot of importance.
- The world is looking towards the natural resources such as solar energy, wind energy, etc., out of these solar energy is the potentialcandidate.
- The energy supplied by this is enormous, continuous and free of cost. Solar energy provides heat and light. Therefore in last few decades lot of effort has been made towards the use of solar energy. It is also possible to convert heat energy of the sun into electricity.
- It is the renewable form of energy available abundantly in earth as well as in space.

Photovoltaic cells or Solar cells:

- These are semiconductor devices that convert sunlight into direct current electricity.

Photovoltaic cell

- It is a typical silicon photovoltaic cell is composed of an ultra thin layer of phosphorous doped (n-type) silicon on top of boron doped (p-type) silicon. Hence a p-n junction is formed between the two. A metallic grid forms one of the electrical contacts of the diode & allows light to fall on the semiconductor between the grid lines. An antireflective layer between the grid lines increases the intensity of light transmitted to the semiconductor. The cells other electrical contact is formed by a metallic layer on the back of the solar cell.
- When light radiation falls on the p-n junction diode, electron-hole pairs are generated by the absorption of the radiation. The electrons are drifted to & collected at the n-type end & the holes are drifted to & collected at the p-type end. When these two ends are electrically connected through a conductor, there is a flow of current between the two ends through the external circuit. Thus photoelectric current is produced & available for use.


e-
e-
Sunlight
Sunlight
Metal grid
Antireflective layer
e-
n-type layer
Electron hole pair
+ e-
h+
Application
p-type layer
+ e-
Electron hole pair
Metal contact

Preparation of solar cell grade silicon by Union carbide process:

The process involves following steps:

- The hydrogenation of tetrachlorosilane through a bed of metallurgical silicon is carried out in a fluidized bed reactor.

$$3SiCl_4 + 2H_2 + Si \text{ ---------> } 4SiHCl_3$$

- The trichlorosilane is separated by distillation while the unreacted tetrachlorosilane is recycled back to the hydrogenation reactor.
- The purified trichlorosilane is passed through a fixed column filled with quaternary ammonium ion exchange resin acting as catalyst. Trichlorosilane gets converted into dichlorosilane.

$$2SiHCl_3 \text{ ---------> } H_2SiCl_2 + SiCl_4$$

- The products are separated by distillation, tetrachlorosilane is recycled to the hydrogenation reactor & dichlorosilane is passed through a second fixed bed column filled with quaternary ammonium ion exchange resin. Dichlorosilane is converted into silane.

$$3H_2SiCl_2 \text{ ----------> } SiH_4 + 2HSiCl_3$$

- The above products are separated by distillation & trichlorosilane is recycled to the first fixed bed column. Silane gets pyrolysed to form polysilicon i.e. semiconductor grade silicon.

$$SiH_4 \text{ ----------> } Si + 2H_2$$

Advantages of PV Cell:

- Fuel source is vast and essentially infinite.
- No emissions, no combustion or radioactive residues for disposal.
- Low operating cost (no fuel).
- No moving parts and so no wear and tear.
- High reliability in modules.
- No recharging.
- They do not corrode.
- Can be integrated into new or existing building structures

Disadvantages of PV Cell:

- Sun light is a diffuse, i.c. it is relatively low density energy.
- High installation cost.
- Poor reliability of auxiliary elements including storage.
- Energy can be produced only during the day time