Unit-III

E-waste: Electronic waste, or e-waste, refers to all items of electrical and electronic equipments (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use.

Sources of E-waste: E-waste sources can be numerous.

1) Large household appliances like refrigerators/freezers, washing machines, dishwashers, televisions.
2) Small household appliances which include toasters, coffee makers, irons, hairdryers.
3) Information Technology (IT) and Telecommunications equipment namely personal computers, telephones, mobile phones, laptops, printers, scanners,photocopiers etc.
4) Lighting equipments.
5) Equipments such as fluorescent lamps.
6) Electronic or Electrical tools i.e. handheld drills, saws, screwdrivers etc.
7) Toys, leisure and sports equipments.
8) Monitoring and control instruments.
9) Automatic dispensers.

Composition of E-waste:

1) Valuable metals like gold, platinum, silver and palladium.
2) Useful metals like copper, aluminium, iron etc.
3) Hazardous substances like radioactive isotopes and mercury.
4) Toxic substances like PCB's and Dioxins.
5) Plastic like High Impact Polystyrene (HIPS), Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polyphenylene oxide (PPO) etc.
6) Glass material like Cathode Ray Tube glass made up of SiO_2, CaO, Na.

A single electronic goods can have one or more of the above components. For instance, a mobile phone contains more than 40 elements, base metalssuch as Copper (Cu) and Tin (Sn), special metals such as Lithium (Li), Cobalt (Co), Indium (In) and Antimony (Sb) and precious metals such as Silver (Ag),Gold (Au), and Palladium (Pd).

Characteristics of E–waste: E-waste is characterized by its hazardous and non-hazardous components.

1) E-waste contains hazardous substances such as lead, polychlorinated biphenyls (PCBs), polybrominated biphenyls (PBBs), mercury, polybrominated diphenyl ethers (PBDEs), brominated flame retardants (BFRs), and toxic metal like mercury, lead, cadmium, chromium.
2) It also contains non-hazardous substances like plywood, wood, iron, steel, copper, aluminum, gold, silver, platinum, palladium, and other metals along with plastics.

Need of E-waste management:

There is a serious need of e-waste management because of following reasons.

1) Electrical and electronic equipment utilization and e-waste generation is increasing rapidly.
2) E-waste can percolate into the soil polluting the air and waterways, harming human health and the environment.

3) The recycling process can help to decrease the demand for raw materials.
4) The more we use recycled products, less the demand for greenhouse gas emissions.
5) When you recycle e-waste, every material is used ideally, helping to save raw material, environment, and money.
6) It lowers the business cost and helps to increase employees' morale.
7) E-waste, like smartphones and tablets, can have crucial information which is to be avoided of sharing with any other person. Hence it's beneficial to recycle the e-waste instead of dumping it in landfills.
8) Recycling e-waste helps to put the material back to use.

Toxic materials used in manufacturing electronic and electrical products:

The following materials are the mostly frequently found toxic substances in e-waste.

	Substance	Occurrence in e-waste
1	**Halogenated compounds**	
	PCB (polychlorinated biphenyls)	Condensers, Transformers
	TBBA (tetrabromo bisphenol-A)	Fire retardants for plastics (thermoplastic components, cable insulation) TBBA is presently the most widely used flame retardant in printed wiring boards and casings.
	PBB (polybrominated biphenyls)	
	PBDE (polybrominated diphenyl ethers)	
	Chlorofluorocarbon (CFC)	Cooling unit, Insulation foam
	PVC (polyvinyl chloride)	Cable insulation
2	**Heavy metals and other metals**	
	Arsenic	Small quantities in the form of gallium arsenide within light emitting diodes
	Barium	Getters in CRT
	Beryllium	Power supply boxes which contain silicon-controlled rectifiers and X-ray lenses.
	Cadmium	Rechargeable NiCd-batteries, fluorescent layer (CRT screens), printer inks and toners, photocopying-machines (printer drums)
	Chromium VI	Data tapes, floppy-disks
	Lead	CRT screens, batteries, printed wiring boards
	Lithium	Li-batteries
	Mercury	Fluorescent lamps that provide backlighting in LCDs, in some alkaline batteries and mercury wetted switches
	Nickel	Rechargeable Ni-Cd batteries or Ni-MH batteries, electron gun in CRT
	Rare earth elements (Yttrium, Europium)	Fluorescent layer (CRT Screen)
	Selenium	Older photocopying-machines (photo drums)
	Zinc sulphide	Older Interior of CRT screens, mixed with rare earth metals

3	**Others:**	
	Toner Dust	Toner cartridges for laser printers / copiers
4	**Radio-active substances:**	
	Americium	Medical equipment, fire detectors, active sensing element in smoke detectors

Health hazards (ill effects) due to exposure to e-waste:

(i) **Arsenic:** Chronic exposure to arsenic can lead to various diseases of the skin and decrease nerve conduction velocity. Chronic exposure to arsenic can also cause lung cancer and can often be fatal.

(ii) **Barium**: Being highly unstable in the pure form, it forms poisonous oxides when in contact with air. Short-term exposure to barium could lead to brain swelling, muscle weakness, damage to the heart, liver and spleen. It increases blood pressure and changes in the heart.

(iii) **Beryllium:** It can cause lung cancer. The primary health concern is inhalation of beryllium dust, fume or mist. Workers who are constantly exposed to beryllium, can develop beryllicosis, a disease which primarily affects the lungs. Exposure to beryllium also causes a form of skin disease that is characterized by poor wound healing and wart-like bumps. People can still develop beryllium diseases even many years following the last exposure.

(iv) **Brominated flame retardants (BFRs):** Combustion of halogenated case material and printed wiring boards at lower temperatures releases toxic emissions including dioxins which can lead to severe hormonal disorders.

(v) **Cadmium**: Cadmium components may have serious impacts on the kidneys. Cadmium is adsorbed through respiration but is also taken up with food. Due to the long half-life in the body, cadmium can easily be accumulated in amounts that cause symptoms of poisoning. Cadmium shows a danger of cumulative effects in the environment due to its acute and chronic toxicity. Acute exposure to cadmium fumes causes flu-like symptoms of weakness, fever, headache, chills, sweating and muscular pain. The primary health risks of long-term exposure are lung cancer and kidney damage. Cadmium also is believed to cause pulmonary emphysema and bone disease (osteomalacia and osteoporosis).

(vi) **CFCs (Chlorofluorocarbons)**: When released into the atmosphere, they accumulate in the stratosphere and have a deleterious effect on the ozone layer. This results in increased incidence of skin cancer in humans and in genetic damage in many organisms.

(vii) **Chromium**: Chromium (VI) is easily absorbed in the human body and can produce various toxic effects within cells. Most Cr (VI) compounds are irritating to eyes, skin and mucous membranes. Chronic exposure to Cr (VI) compounds can cause permanent eye injury, unless properly treated. It may also cause DNA damage.

(viii) **Dioxins:** Dioxins are known to be highly toxic to animals and humans because they bio-accumulate in the body and can lead to malformations of the foetus, decreased reproduction and growth rates and cause impairment of the immune system among other things.

(ix) **Lead**: Short term exposure to high levels of lead can cause vomiting, diarrhea, convulsions, coma or even death. Other symptoms are appetite loss, abdominal pain, constipation, fatigue, sleeplessness, irritability and headache. Continued excessive exposure, as in an industrial setting, can affect the kidneys. It can damage nervous connections and cause blood and brain disorders

(x) **Mercury:** It is a toxic heavy metal that bio-accumulates causing brain and liver damage if ingested or inhaled.

(xi) **Polychlorinated biphenyls (PCBs)**: PCBs have been shown to cause cancer in animals. PCBs have also been shown to cause a number of serious non-cancer health effects in animals, including effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. PCBs are persistent contaminants in the environment. Due to the high lipid solubility and slow metabolism rate of these chemicals, PCBs accumulate in the fat-rich tissues of almost all organisms (bio-accumulation).

(xii) **Polyvinyl chloride (PVC):** PVC is hazardous because it contains up to 56% chlorine which when burned, produces large quantities of hydrogen chloride gas, which when inhaled, leads to respiratory problems.

(xiii) **Selenium:** Exposure to high concentrations of selenium compounds cause selenosis. The major signs of selenosis are hair loss, nail brittleness, and neurological abnormalities (such as numbness and other odd sensations in the extremities).

Recycling and recovery of e-waste:
In e-waste, among various components metals contribute to the significant economic value and efforts are focused on extracting the metals during recycling operation.

Different Approaches of Recycling:

A) Separation:
The *recycling* of e-waste is initiated with physical or mechanical pre-process.
1) The first step involves physical removal of toxic materials and unwanted components Manual dismantling and separation of components such as PCBs, monitors, batteries etc into various fractions like metals, ceramics, plastics, wood and paper using hammer, screwdrivers and conveyer beds for disassembling.
2) In the second step, materials are mechanically shredded through crushers or grinders to collect fragments of metal bearing components. Metals such as Al and Cu can be separated from non-metallic components from eddy current method.
3) Next the waste is passed through electrical separators to separate metallic and non-metallic components.

4) Magnetic separator is used to separate ferrous metals.
5) Gravity separation is used to separate Al metal.
6) Finally, various chemical treatments are employed to recover the precious metals.

B) Thermal treatments:

Thermal treatment involves the application of heat to treat and decompose waste materials through different approaches. Generally, thermal treatment generates substances which are more likely to be toxic in comparison to their ordinary forms. Noxious fumes are emitted during the processes including dioxins, furans, and harmful gases such as mercury and cadmium. Erotic fumes are released with the heating of plastic or PVC circuit boards. The fumes may contain well-known carcinogens such as polychlorinated dibenzo-para-dioxins (PCDDs), polycyclic aromatics (PCAs), and polychlorinated dibenzofurans (PCDFs) along with other toxic gases such as carbon monoxide, sulfur dioxide, and nitrogen oxides . Lower levels of trace metal residues also can be contained in these fumes. The various types of thermal approaches are

1) **Combustion** is oxidation at high temperatures. Open burning is the primary method of thermal waste treatment but is considered as an environmentally invasive process. No pollution controlling devices are engaged in open burning, allowing pollutants to escape into the environment. This method is practiced in most of the countries since it provides a cheaper solution for solid waste treatment.

2) **Incineration** is considered as one of the most common methods where e-waste undergoes combustion at high temperatures. This process is demonstrated to be advantageous as the means of heat and energy recovery. Additionally, a significant reduction in waste volume can be achieved through the process. Nevertheless, incineration plants are considered as a source for a series of extremely toxic pollutants with neurotoxins and carcinogens.

3) **Sintering** and **melting** are extremely efficient for the treatment of volatilizable toxic substances. Sintering is the process of fusing substrates together into one solid material by adjusting both pressure and heat, while the melting process combines substrates by heating them until they liquefy and combine as one material.

4) **Gasification** and **pyrolysis** are more or less similar methods, where the waste materials are allowed to decompose under low oxygen levels and very high temperatures. Pyrolysis is undertaken in the absence of oxygen to convert the wastes into fumes, oils, and charcoal while gasification allows a considerably low amount of oxygen in the process. The emissions are low in comparison to the other thermal treatment methods.

C) Pyrometallurgical process:

Pyrometallurgical approach of recycling involves thermal treatment of e-wastes to bring about physical and chemical transformations so as to enable recovery of valuable metals. The treatment commonly involves smelting in furnaces at high temperatures, incineration, combustion, and pyrolysis. It is possible to achieve pure Cu recovery through smelting which involves high temperature (~ 1100 °C) treatment.

Pyrometallurgical methods make metal recovery easier from PCBs by feeding the recovered PCBs into an incinerator or blast furnace to remove the non-metallic fractions. In the next stage, the enriched metal is collected in a molten bath or slag and can be further processed using hydrometallurgical or electro-refining methods. This method is often used to recover Cu, Au, Ag, Fe, Al, and Pd.
However, the process is highly energy-intensive, requiring high temperatures (300–1100 °C), and can also generate toxic gases involving corrosive acids like H_2SO_4, HCl, and HNO_3. The release of PBDEs from PCBs and e-waste during pyrometallurgy and the formation of dioxins during combustion are also potential hazards.

D) Hydrometallurgical extraction:
Hydrometallurgical method is considered as an alternative to the pyrometallurgical process owing to its low energy requirements, lesser release of hazardous substances and economic viability. Hydrometallurgy consists of two stages: (i) leaching and (ii) recover.

(i) Leaching stage
This stage involves treatment with chemicals to convert the metals into soluble salts or complexes.

1. Cyanide leaching*:* Leaching gold with a cyanide solution remains the most widely used hydrometallurgical process for the extraction of gold from ores and concentrates.

2. Acid Leaching*:* Nitric acid, sulphuric acid and hydrochloric acid are used to leach the target metals. Ascorbic acids, citric acids and acetic acids are used to leach light metals from spent batteries and mobile devices.

3. Thiourea leaching*:* Thiourea is used as a complexing agent that forms cationic soluble complex with target metal. Thiourea is not stable and decomposes easily in alkaline solutions and hence the reaction is carried in acidic conditions.

4. Thiosulphate leaching*:* Thiosulfate leaching can be considered a non-toxic process, the gold dissolution rates can be faster than conventional cyanidation and, due to the decreased interference of foreign cations, high gold recoveries can be obtained from the thiosulfate leaching of complex. Ammonium thiosulphate solution is used as a leaching agent.

5. Halide leaching*:* Chloride, iodide and bromide are used to leach gold from PCB waste. These are high rate of leaching, cheaper and selective method.

(ii) Metal Recovery stage
In this process, metal is recovered from leached metal solution. A variety of methods such as solvent extraction, ion exchange, adsorption, etc. are followed.

1. Solvent extraction*:* In this process, leachate is treated with organic solvent in separating funnel. It results in two phase system. Metal is extracted from leachate to organic phase system. Different extractants such as amides or amines are used for extraction of metals such as gold, vanadium, iridium, rhodium and tungsten.

2. Electrodeposition*:* In this method, pure metal is obtained from leachate by electrodeposition. Pure metal same as metal to be extracted is taken as cathode and inert metal as anode. They are dipped in leachate. When current is applied pure metal gets electrodeposited at cathode. Metals such as gold, lead, tin, copper can be recovered from leachate. The method is highly efficient, low environment impact and cost effective.

3. Ion exchange*:* It is an improved version of solvent extraction method. In this method solvent extracting reagents are impregnated on polymer beads. The functional group of reagents act as a chelating group and selectively bind metal ions. The method is selective to recover selective metal ion. It is a low cost, no loss of reagent and environmental safety method. The method is effective to recover gold from cyanide and thiosulphate leachate.

4. Adsorption: The metals can be recovered from leachate by adsorption on appropriate adsorbents. Activated charcoal is one of the effective adsorbents. It is an efficient, low-cost process. Pt, Au, Ag, Cu metals can be removed from cyanide solution with 95-100 % efficiency.

E) Direct recycling of e-waste

In this process, the electronic components are harvested directly from e-waste without breaking them further into small components. The harvested materials are further processed with healing methods to regenerate recycled materials. The regenerated materials have performance equivalent to originally manufactured materials. Thus, in this method the complicated chemical and metallurgical steps involved in conversion of e-waste components into chemicals are avoided. The process requires less energy and is eco-friendly.

Direct regeneration of components depends upon state of health of used electronic materials. Defects and impurities accumulated during usage could affect the quality of refurbished active material.

An example of direct recycling is the recycling of lithium-ion batteries. Here, battery is discharged first to avoid short circuiting and self-ignition of battery and dismantled to separate anode, cathode, electrolyte and separated. These components are not dismantled further. Here each component is regenerated using appropriate process to recover its function. These components are reassembled for reuse.

Extraction of gold from e-waste:

Gold has good electrical conductivity and chemical stability and hence it is used for making integrated circuits of electronic devices, coating for contacts and connectors.

Among the e-waste, PCBs are rich in metals. It contains around 35% Cu, 0.16% silver, and 0.13% gold by weight.

Gold Recovery (Hydrometallurgical method)

There are three stages in metal recovery by hydrometallurgical method

(i) Pretreatment; (ii) Chemical treatment stage; (iii) Metal recovery stage.

(i) Pretreatment stage

In the pretreatment stage, e-waste is manually dismantled to separate various fractions like metals, ceramics, plastics, wood and paper. Techniques such as gravity separation electrostatic separation, magnetic separation and eddy current separation are used to separate metals from fractions.

(ii) Chemical treatment stage

In the chemical treatment step, targeted metal is leached into solution by treating with appropriate leaching agents such as thiosulfate, alkali cyanide and many acids such as hydrochloric acid, sulphuric acid and nitric acid can be used to leach gold into solutions.

Cyanide leaching is the most common method used to extract gold metal. Sodium salt of 3-nitrobenzene sulfonic acid with potassium cyanide in the presence of oxygen is used as leaching agent. A water soluble dicyanoaurate gold complex is obtained in the process.

$$4Au + 8CN^- + O_2 + 2H_2O \rightarrow 4Au(CN)_2^- + 4OH^-$$

(iii) Metal recovery stage

In the last step, metal is recovered from leach solutions. Varieties of methods like electro-deposition, solvent extraction, ion exchange adsorption, precipitation and cementation are used to recover metals from leached solutions. Selective recovery is possible for most processes.

Gold can also be extracted from leaching solution by electro-deposition of gold from dicyanoaurate gold complex. Pure gold metal taken as cathode and inert anode are dipped in leached solution. When current is applied, gold is electrodeposited on cathode.

Role of stake holders in environment management of e-waste:
(Producers, consumers, recyclers and statutory bodies):

The e-waste management program is designed by statutory government regulatory bodies. The members of the body, frame the policies and execute it for protection of the environment. To achieve the plan of management of e-waste, a green tax is collected from consumer through manufacturer. Penalties are implied on manufacturer and consumers when green tax is not paid. Manufacturing units must support the agenda of e-waste management by doing dismantling processing of e-waste, management of scarp materials and reselling of recycled materials. Consumer must pay green tax and must be aware of importance of e-waste management. All stakeholders must effectively work in tandem form for effective e-waste management.

There are four stakeholders in environmental management of e-waste. They are as follows.

1. Statutory Government Regulatory bodies
2. Producers (Manufacturing units)
3. Recyclers (Recycling units and collection units)
4. Consumers

1. Statutory government regulatory bodies

The statutory bodies play a vital role in management of e-waste. Following are the major roles:

a) To collect the green tax from consumer through producer.

b) Apply extra charges on producers (manufacturing units) in form of penalty when no proper recycling is assured from manufacturing units.
c) Provide incentives in form of subsidy to recyclers and collectors when recycling of e-waste is done properly.
d) To conduct programs of awareness in the society about importance of e-waste recycling in reduction of hazardous substances.

1.1 The Central Pollution Control Board (CPCB) is responsible for the following activities:

a) Setting up the guidelines: It provides technical guidelines for different stakeholders (segregation, collection, disposal, co-processing) and different types of e- waste. It also provides guidelines about how to comply with these guidelines by providing an action plan.
b) Holding stakeholder consultations: The participants represent the entire spectrum of e-waste management including the ULBs, PCBs, representatives from industry associations like FICCI/CII, brand owners, NGOs, recyclers. Most of these consultations result in addressing the issues faced by the stakeholders. The guidelines published for the compliance related documentation is one such result of such consultations.
c) Coordination with State PCBs: It coordinates with the state pollution control boards to ensure regular monitoring of the stakeholders performing EPR.
d) Data compilation: The CPCB receives quarterly reports from all the PIBOs performing EPR. It also performs queries and researches to verify and compile this data to prepare national-level reports.

1.2 The State pollution control board (SPCB) is responsible for the following activities:

a) Implementation of CPCB guidelines: The SPCB makes sure the guidelines provided are followed by the stakeholders performing EPR. This body conducts frequent inspections to ensure this implementation is done properly.
b) Action Plan: The SPCB undertakes the task of scrutinizing the action plans submitted by the PIBOs to ensure its adherence to the guidelines provided by the CPCB.
c) Industry authorizations: The processors, brand owners, recyclers and co-processors need permission from the government to operate. This consent to operate is issued by the SPCBand needs to be revised at expiry.
d) Monthly communication: The SPCB communicates all the information involving notifications, guidelines & amendments from the CPCB to the PIBOs.
e) Extended Producer Responsibility (EPR) Agency: Their basic responsibility is to carry out the EPR activity on behalf oftheir client's i.e. the PIBOs and it involves the following things.

- Collection of e-waste: Identifying sources of e-waste like ULBs, bulk generators etc. Checking the quality of the material i.e. whether it contains segregated e-waste only instead of mixed municipal solid waste. Signing official agreements with the source for collection of e-waste.
- Scientific disposal: Identifying recyclers/processors who have valid consent to operate from the respective State Pollution Control Boards. The agency needs to sign agreementswith these processors for scientific disposal of e waste on behalf of its clients.

- Documentation: The agency needs to maintain documentation on behalf of the PIBOs for the fulfilment of EPR which includes documentation of material bills, transport and logistics bills and acknowledgements.
- Compliance reports: The agency is also supposed to submit all the necessary documentation/proofs that are required by the PIBO for the preparation of Action Plan, quarterly report. These proofs can be the agreements that the agency has with the sources of waste, processors etc.

2. Producers (manufacturing units)

a) The accountability to collect green tax.
b) Financing the EPR activity.
c) Registration: First step in EPR is registering with the respective pollution control boards with accurate information about their e-waste.
d) Collection system: The company needs to set up a mechanism for take-back/collection of e- waste and its scientific disposal.
e) Communication with government bodies: Regular communication with the CPCB/SPCBs in the form of monthly EPR Activity, Quarterly reports, participating in the stakeholder consultations at CPCB.
f) ULB and other Collection centres: ULBs generally work alongside the informal waste picker networks or organisations unifying these waste pickers.
g) Establishment of Infrastructure: It's the primary responsibility of the ULBs to set up the infrastructure for segregation, collection, storage and disposal of e- waste.
h) Scientific disposal: Creating facilities for the promotion of recycling/processing units locally creates avenues for decentralized and low-cost recycling of waste.
i) Charging an additional amount on consumer during sell of e-products and returning it with interest at the time of exchange of e-product.
j) Forming the group of manufactures who monitor and encourage the recycling of e-waste.
k) Bearing the transportation cost and collection fees to ease collection process.
l) Purchase the recycling material at fixed value and using of recycled e-waste during manufacturing.
m) Giving discount to consumer on the basis of e-waste generated from gadget.

3. Recyclers (recycling units & collection units):

a) The accountability of recycling units is dismantling, recycling processing of e-waste materials, management of scarp materials and reselling of recycling materials
b) Establish collection units and group of people who can ensure return back of e-products by consumer in exchange offer or directly approach consumer for door-to-door collection.
c) Collect the e-waste from the collection units, dealer or retailer.
d) Providing incentives when proper collection of e-waste assured by collection units.
e) The following are responsibilities are of recyclers.
i) Authorisation: Having a valid consent to operate from the state pollution control boards and following all the standards of processing/recycling, and the pollution control norms.
ii) Registration: Registering themselves with the PCBs and Local bodies as recyclers which can be done by issuing Udyog Aadhar Memorandum.
iii) Regular communication with the government: Recyclers have to communicate with

PCBs about their involvement in EPR activity, the details about the e-waste processed, the details of the clients on whose behalf the e-waste is processed.

4. Consumer

a) The accountability to pay green taxes.
b) Develop self-awareness on e-waste management and involve in awareness programs.
c) Returning back of e-waste to collection units.
d) The responsibility of the consumer is to follow a sustainable lifestyle centred around the three Rs -Reduce, reuse and recycle.

- <u>Reduce:</u> Consumer should responsibly use the products that are packed in recyclable e-waste only.
- <u>Reuse:</u> Consumer must prefer to reuse the e-waste as it is an inert, long-lasting material and can be used multiple times.
- <u>Recycle:</u> Consumer must ensure that the e-waste is segregated, not soiled and disposed properly to ensure recycling with maximum value.

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GREEN FUELS

Fuel is defined as a naturally occurring or an artificially manufactured combustible carbonaceous material, which serves particularly as a source of heat and light and also in a few cases as a source of raw material.

Green fuels: Green fuel is fuel produced from biomass sources through a variety of biological, thermal and chemical processes or also electrical energy derived from renewable sources (solar, wind, etc.).

Past and future perspective of green fuels:
Green fuels are made from renewable resources and have a number of advantages for the public at large, the economy, and the environment. They are cleaner fuels, which means they emit fewer pollutants when burned. It can be made from a variety of different materials. A country's reliance on fossil fuels can be reduced if more individuals switch to green fuels.
Green fuels are less expensive than fossil fuels for powering homes, businesses, and cars. With a developing green fuel business, more employment will be produced, ensuring the stability of our economy.

Solar (photovoltaic) cells
Photovoltaic cells or Solar cells are the semiconductor devices which convert sunlight into direct current electricity through photoelectric effect. The photovoltaic cells are made out of semiconductors which have the capacity to absorb light. When n-type and p-type semiconductor are bought together, a semiconductor diode is formed. The semiconductor diode separates and collects the carriers (holes and electrons) and conducts the generated electrical current preferentially in a specific direction.
Construction:
A typical silicon photovoltaic cell is composed of a thin poly crystalline silicon wafer consisting of an ultra-thin layer of phosphorus doped (n-type) silicon on top of boron doped (p-type) silicon. Thus a p-n junction is formed. A metallic grid forms one of the electrical current contacts of the diode and allows light to fall on the semiconductor between the grid lines as shown in the figure. An antireflective layer (of silicon nitride) between the grid lines increases the amount of light transmitted to the semiconductor. The cell's other electrical contacts is formed by a metallic layer on the back of the solar cell.

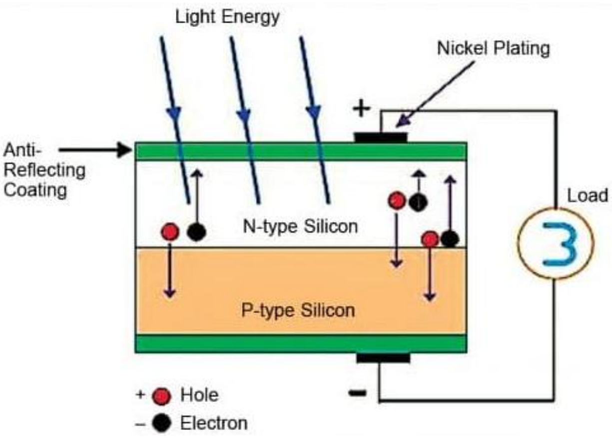

Fig.1. PV Cell

Working: PV cell works on the principle of photoelectric effect $E = h\gamma$, 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 and collected at the n-type end and the holes are drifted to 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. A typical photovoltaic cell develops a voltage of 0.5 to 1 volt and a current density of 20 – 40 mA/cm^2.

Applications:
PV cells can meet the need for electricity for parking meters, temporary traffic signs, emergency phones, radio transmitters, water irrigation pumps, stream-flow gauges, remote guard posts, lighting for roadways, and more.

Advantages:
1) The PV cells are ecofriendly energy conversion devices
2) The PV cells generate electrical energy at ambient temperature.
3) There are no moving parts in PV cells. Hence there is no problem of wear and tear.
4) The raw material silicon used in PV cell is available abundantly.
5) They need no recharging.
6) They do not corrode.

Disadvantages:
1) PV cells generate only DC current.
2) PV cells require energy storage device.
3) The installation cost is high.
4) The cost of purification of silicon is high.
5) On cloudy day, proposed amount of current cannot be produced.
6) It is practical only in areas with favorable climate.

Electrolysis of water
It is the splitting of water in to hydrogen and oxygen using energy.

Green hydrogen
It is defined as hydrogen produced by electrolysis of water in to hydrogen and oxygen using renewable energy.

Properties of hydrogen pertaining to fuel:
1) Hydrogen requires "burning" in the presence of molecular oxygen, and this process creates heat which can be used for work. The only by-product of this reaction is water and some nitrogen oxides.
2) Besides combustion in an engine, hydrogen fuel can also be stored for use in fuel cells, which is 2-3 times more efficient than traditional internal combustion engines.
3) Hydrogen fuel is carbon free, clean, non-toxic, lighter than air.
4) The energy in 2.2 pounds (1 kilogram) of hydrogen gas is about the same as the energy in 1 gallon (6.2 pounds, 2.8 kilograms) of gasoline.
5) Since hydrogen is a very light gas, its storage is an obstacle. When combined with air and in sufficient concentration, hydrogen can be flammable. Ventilation and leak

detection are therefore vital wherever hydrogen is stored and used.

Generation of green hydrogen by proton exchange membrane (PEM) electrolysis:

PEM electrolyzer is made up of three parts:

1) **Bipolar plates**: These flow plates are made up of titanium.
2) **Membrane electrode assembly (MEA)**: The combination of the proton exchange membrane (PEM) and the electrocatalysts is collectively known as membrane electrode assembly (MEA).
   a) The PEM is a sulfonated fluorinated polymer. Eg: Nafion
   b) Electrocatalysts: Platinum at the cathode for proton reduction and Iridium oxide at the anode for water oxidation.
3) **Gas diffusion layers (GDL)**: They are the conductive layers present between flow fields of the bipolar plates and the MEA. The cathodic GDL is often made of carbon paper and the anodic GDL is often made of titanium paper. GDL improves the electrical connection between the bipolar plates and the MEA. It also insures the effective mass transport of both the reactant water and the product gases.

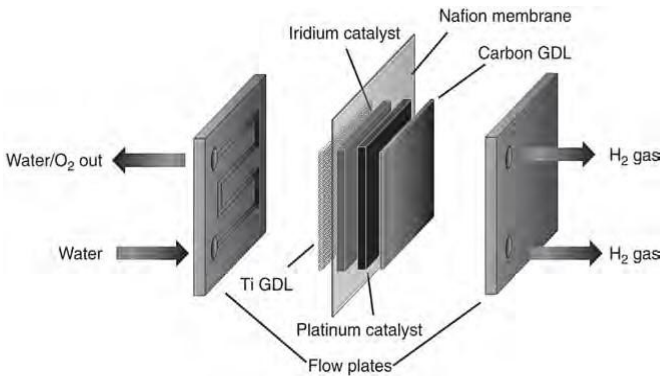

Fig. Cell layout diagram for a PEM Electrolyzer

In PEM water electrolysis, water is electrochemically split into hydrogen and oxygen at their respective electrodes such as hydrogen at the cathode and oxygen at the anode. PEM water electrolysis is accrued by pumping of water to the anode where it is spilt into oxygen (O_2), protons (H^+) and electrons (e^-). These protons are travelled via proton conducting membrane to the cathode side. The electrons exit from the anode through the external power circuit, which provides the driving force (cell voltage) for the reaction. At the cathode side the protons and electrons re-combine to produce the hydrogen.

Anode: $H_2O_{(l)} \longrightarrow \frac{1}{2} O_{2\,(g)} + 2H^+_{(aq)} + 2e^-$

Cathode: $2H^+_{(aq)} + 2e^- \longrightarrow H_{2\,(g)}$

Cell reaction: $H_2O(l) \longrightarrow H_2(g) + \frac{1}{2} O_2(g)$

Advantages:

1) High current density; 2) High voltage efficiency 3) Compact system design 4) High gas purity

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