UNIT V

ENERGY SOURCES AND E-WASTE MANAGEMENT

Fuel cells: Introduction, construction, working and applications of methanol–oxygen and polymer electrolyte fuel cell.

Solar energy: Introduction, importance of solar PV cell, construction and working solar PV cell, advantages and disadvantages.

E-Waste management: Introduction, sources, types, effects of e-waste on environment and human health. Methods of disposal. Recycling – Advantages. Extraction of gold from e-waste

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ENERGY SOURCES

FUEL CELLS

Introduction

The study of the link between electrical energy and chemical changes is the subject of **electrochemistry**, a chemistry sub discipline. Electrochemical reactions are chemical processes that include the input or creation of electric currents. A fuel cell is an electrochemical cell that uses an electrochemical process to create electrical energy from fuel. To keep the processes that generate electricity going, these cells need a constant supply of fuel and an oxidizing agent (usually oxygen). As a result, until the supply of fuel and oxygen is shut off, these cells can continue to generate power.

Fuel cells, while being conceived in 1838, did not enter commercial usage until a century later, when NASA utilized them to power space capsules and satellites. Many establishments, including businesses, commercial buildings, and residential structures, now employ these devices as a major or secondary source of electricity

In a fuel cell electrical energy is obtained from oxygen and a fuel that can be oxidized The essential process in a fuel cell is

Fuel + Oxygen $\rightarrow$ Oxidation product +Electricity

Methanol – oxygen fuel cell are powered by pure methanol. In the early 1960s, the mechanism of this reaction was the subject of many studies in different countries. Still, the specific power attained was quite small. Only in the mid 1990s, after the great successes achieved in the development of hydrogen-oxygen fuel cells with the proton-conducting ion exchange membrane, was a breakthrough reached in the development of fuel cells with direct (without preliminary conversion) oxidation of methanol. Fuel cells of this type were now called “direct-methanol fuel cells” (DMFC). The design of modern DMFCs is very similar to the design of proton exchange-membrane fuel cells. The membranes (Nafion) and catalysts (Platinum) are used.

Definition of Fuel Cell

Fuel cells are cells that directly transform the chemical energy of a fuel cell into electrical energy.

Fuels such as hydrogen (H_2), carbon dioxide (CO_2), methane (CH_4), propane (C_3H_8), methanol (CH_3OH), and others are used to create electrical energy. The fuel cell is constantly supplied with fuel, while the products are continuously removed. There are a great number of fuel cells on the market. The most popular type is a hydrogen-oxygen fuel cell.

Fuel cells are electrochemical cells consisting of two electrodes and an electrolyte which convert the chemical energy of chemical reaction between fuel and the oxidant directly into electrical energy.

Types of Fuel Cells

Fuel cells come in a variety of forms.

1. Polymer Electrolyte Membrane (PEM) Fuel Cell
2. Phosphoric Acid Fuel Cell

3. Solid Acid Fuel Cell
4. Alkaline Fuel Cell
5. Molten Carbonate Fuel Cell
6. Hydrogen-Oxygen fuel cell
7. Microbial fuel cells (MFCs)
8. Solid Oxide Fuel Cells (SOFCs)
9. Zinc-Air Fuel Cell (ZAFC)
10. Direct Methanol Fuel Cell (DMFC)

Advantages of Fuel Cell

Fuel cells are a possible source of electrical energy, and they offer an advantage over galvanic cells and other traditional techniques of generating electricity by burning fuel. The following are some of the major benefits of fuel cells:

1. It has high conversion efficiency i.e. 50 to 60%.
2. It is simple and safe.
3. Fuel cell can be installed near the load point.
4. It has no moving parts.
5. It is pollution free method to generate electricity.
6. It is compact and light in weight.
7. It takes little time to get into operation.
8. Low noise and low thermal pollution.
9. Low maintenance cost.

Limitations of Fuel Cells

1. Gaseous fuel is tough to handle. The fuel gas (hydrogen, oxygen, etc.) must be held as a liquid in a specifically built cylinder at a very low temperature and high pressure. This rise is due to the increased cost of the cell, which comes with a number of practical issues.

2. High initial cost. [The catalysts required for electrode reactions, such as platinum (Pt), palladium (Pd), silver (Ag), and others, are highly costly and add to the cell's cost.]
3. The electrolytes employed in fuel cells are extremely caustic, posing a number of practical issues.
4. High cost of pure hydrogen.

Applications of Fuel cells

Various applications of fuel cell given below:

1. Domestic use.
2. Power stations.
3. Automotive vehicles.
4. Special applications.

Differentiate between fuel cell and battery:

Sl. No	Battery	Fuel Cell
1	They store energy in the form of chemical energy	They cannot store chemical energy.
2	Reactants are integral part of construction of cell	Reactants for chemical reaction are supplied continuously from outside the cell
3	Chemical reaction products remain inside the cell itself	Chemical reaction products are removed from the cell
4	Rechargeable	Not rechargeable
5	Not rechargeable	High efficiency
6	It consists of limited amount of fuel and oxidant and these reactants diminish with time	Needs a continuous supply of fuel and oxygen from an external source
7	Supply energy for a limited period of time	Supply energy for a long period of time
8	Less expensive	They are expensive
9	Example : lithium ion batteries, Ni-MH batteries	Example : hydrogen-oxygen fuel cell, Methanol-oxygen fuel cell

Construction and working of Methanol-Oxygen fuel cell:

Construction

These cells can use either alkaline or acidic medium.

1. Anode – It is a porous nickel electrode impregnated with platinium (Pt) catalyst

2. Cathode - It is a porous nickel electrode impregnated with platinium (Pt) or silver catalyst

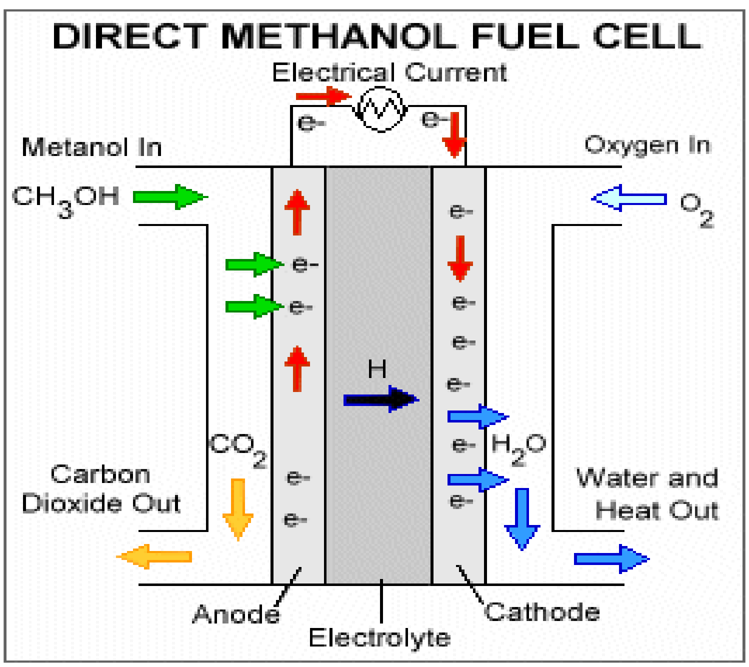
3. Electrolyte – Aqueous sulphuric acid (H_2SO_4)

4. Active components: (a) Fuel – Methanol mixed with sulphuric acid supplied at anode.

(b) Oxidant – Pure oxygen is supplied at cathode.

5. Adjacent to cathode towards electrolyte side, a semi permeable membrane is inserted to allow the diffusion of H+ ions, but disallow the diffusion of methanol and its direct oxidation at cathode.

Cell representation: $CH_3OH/Pt/H_2SO_4$ (3.7M)/Pt/O_2



Working:

The cell reaction is

At anode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6\,e^-$ (Oxidation)

At cathode: $3/2\ O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$ (Reduction)

Over all reaction: $CH_3OH + 3/2\ O_2 \rightarrow CO_2 + 2H_2O$

At anode, the methanol is oxidized into carbon dioxide and six protons (as hydronium ions) plus six electrons. The six protons formed react at the cathode with oxygen to form water. The overall reaction looks like a combustion reaction and is thus sometimes referred to as cold combustion. Actually the cell is a mean to control this reaction and use it to produce current directly. The standard cell voltage for a MFC at 25ºC is 1.21V. However, this potential is never obtained in reality. The open circuit potential is usually about 0.6 to 0.8V.

Advantages of methanol-oxygen fuel cell

1. Stable at all atmospheric conditioned.
2. CO_2 a product of the reaction can be easily removed
3. Easy handling
4. Methanol has low carbon content.
5. The OH group is readily oxidized
6. Low cost liquid fuel.
7. Methanol is highly soluble in water.

Application of methanol-oxygen fuel cell

1. The cells find application in military and large-scale power production.
2. It is also used in fuel cell vehicles and space shuttles.
3. It is ideal for powering smaller vehicles as forklift etc.

Disadvantages of methanol oxygen fuel cells

1. Slow reaction
2. Requires membrane to avoid cross over from anode to cathode
3. Low power density

Construction and working of Polymer electrolyte membrane fuel cell [PEMFC]:

Construction:

It is also called as proton exchange membrane fuel cells.

1. Anode –Porous carbon electrode impregnated with platinium (Pt) or palladium catalyst.

2. Cathode - Porous carbon electrode with platinium (Pt) or silver catalyst.

3. Electrolyte – Polymer electrolyte membrane – Perflurosulphonic acid, or Teflon based ion-exchange membranes containing sulphonic acid groups ($-SO_3H$) are frequently used.

The polymer electrolyte membrane serves two important purposes: (a) provides ionic migration and (b) separates anodic and cathodic compartments so that the species do not get mixed.

4. Active components: (a) Fuel – Hydrogen gas is supplied at anode.

(b) Oxidant – Pure oxygen is supplied at cathode.

Cell representation: H_2/Pt/Polymer electrolyte membrane/Pt/O_2

Working:

Anode: $H_2 \rightarrow 2H^+ + 2e^-$

Cathode: $O_2 + 4H^+ + 2e^- \rightarrow 2H_2O$

Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$

The hydrogen supplied through hydrogen storage tank at the anode where electrons are separated from protons and it flows through external circuit towards cathode. The protons move towards cathode through electrolyte.

At the cathode, protons and electrons combine with oxygen to produce pure water as by product. Oxygen can be supplied at the cathode side in it's purified for.

The platinum catalyst produces carbon monoxide therefore additional reactor required to reduce carbon monoxide in the fuel gas.

This reactor adds additional cost.

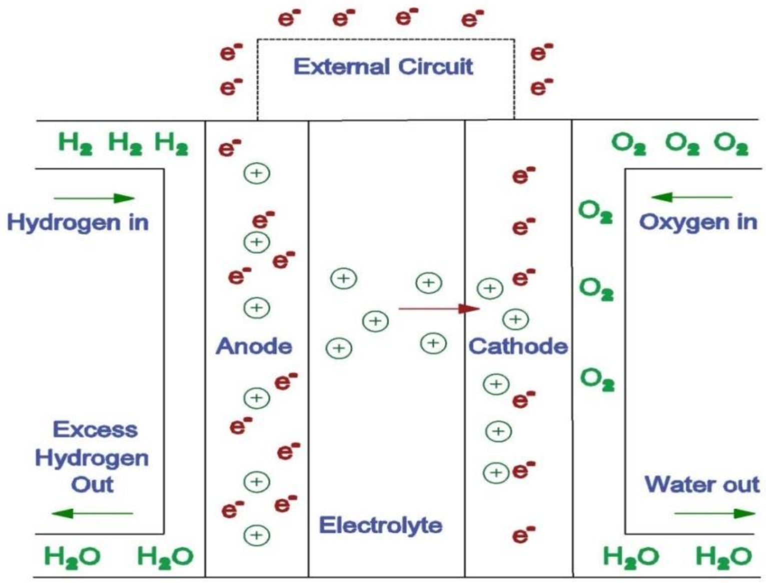


FIG : Polymer Electrolyte Membrane (PEM) Fuel Cell

It delivers high power density and offers low weight and volume as compared to other fuel cells.

This type of fuel cell requires only hydrogen, oxygen from air and water to operate. It operates at low temperature at 80 degree C , low pressure operation allows them to quick warm up time.

It will result in better durability and less wear on the system.

PEM Fuel Cell: Advantages

- Low weight and volume
- High power density
- Low temperature operation
- Solid electrolyte reduces corrosion and electrolyte management systems
- Quick start up and load following
- Low / zero emission when operating on hydrogen

PEM Fuel Cell: Disadvantages

- Expensive catalysts
- Sensitive to fuel impurities
- Addition cost required for reactor to reduce carbon monoxide

PEM Fuel Cell: Applications

- Portable power
- Backup power
- Primarily used for transportation applications
- Some stationary applications
- Vehicles like cars, buses, and heavy-duty trucks

SOLAR ENERGY

Introduction

“Because we are running out of gas and oil, we must prepare quickly for a third change, to strict conservation and to the use of…permanent renewable sources, like solar power”. These are the words of former US president Jimmy Carter. Solar energy has stood the test of time with its use dating as far as the history of humans.

Every hour, the sun strikes the earth with over 430 quintillion joules of energy. The power is enough to sustain all the activities that require electricity for a whole year. But what have we done to tap the enormous energy from the sun?

The sun is a source of an electric and thermal form of usable energy known as solar power. There are different ways to tap it. One of them is the use of photovoltaic solar panels. It is the most common method of capturing this energy. It converts rays from the sun to electricity. Additionally, solar power is crucial in indoor regulation of temperature.

Hot water heating systems on your residential and commercial properties can be installed. When designing your house, you should consider how you can utilize solar energy.

Solar energy is the energy obtained by capturing heat and light from the Sun. Energy from the Sun is referred to as solar energy. Technology has provided a number of ways to utilize this abundant resource. It is considered a green technology because it does not emit greenhouse gases. Solar energy is abundantly available and has been utilized since long both as electricity and as a source of heat.

Solar technology can be broadly classified as −

- **Active Solar** − Active solar techniques include the use of photovoltaic systems, concentrated solar power and solar water heating to harness the energy. Active solar is directly consumed in activities such as drying clothes and warming of air.
- **Passive Solar** − Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light-dispersing properties, and designing spaces that naturally circulate air.

The method of obtaining electricity from sunlight is referred to as the Photovoltaic method. This is achieved using a semiconductor material.

The other form of obtaining solar energy is through thermal technologies, which give two forms of energy tapping methods.

- The first is solar concentration, which focuses solar energy to drive thermal turbines.
- The second method is heating and cooling systems used in solar water heating and air conditioning respectively.

The process of converting solar energy into electricity so as to utilize its energy in day-to-day activities is given below −

- Absorption of energy carrying particles in Sun's rays called photons.
- Photovoltaic conversion, inside the solar cells.
- Combination of current from several cells. This step is necessary since a single cell has a voltage of less than 0.5 V.
- Conversion of the resultant DC to AC.

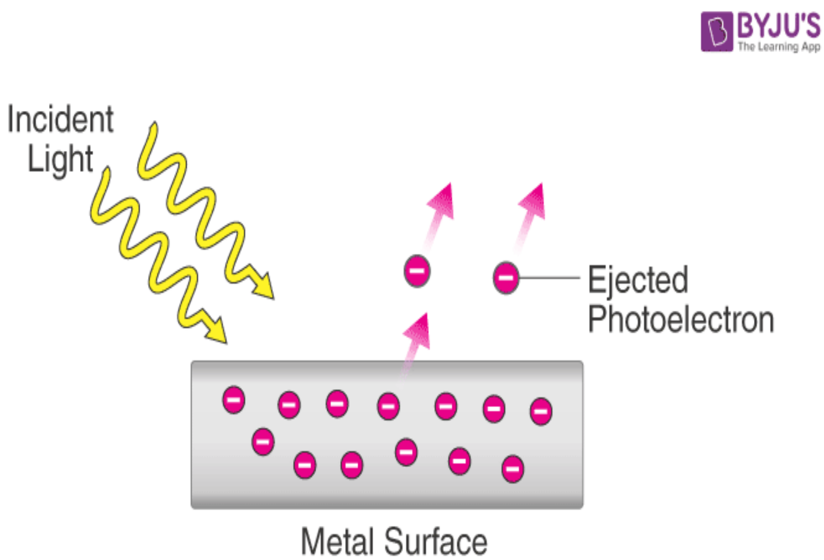
IMPORTANCE OF PHOTOVOLTAIC CELLS (PV CELLS)

1. Solar energy is unlimited, inexhaustible and devoid of energy associated with present electricity production techniques such as burning of fossil fuels and nuclear fission reactions.
2. Photovoltaic cells have both off-grid and on-grid applications. It can be used for off-grid professional devices and supply systems such as telecommunication equipment, solar home systems, etc. It is also used in the production of large scale electricity.
3. By using photovoltaic cells, electricity can be generated in rural areas individual families which are living far away from electric grid connection and as well as in remote areas such as mountains.
4. Photovoltaic cells ensure sustainable pollution free energy production. During the operation of the PV cells, there is no harmful emission or transformation of matter nor any production of noise by products.
5. Photovoltaic electricity can contribute considerably to the abatement of the man made global warming due to CO_2.
6. Photovoltaic can be used as roof integrated systems, providing power and also serving as optical shading elements for the preventing overheating in the summer.
7. Photovoltaic cells provide power for space crafts and satellites.
8. The semiconductor industry and storage battery industries will be boosted by the development in the field of PV cells.
9. Photovoltaic cells have many applications such as in homes it can be used for lighting, spinning of fans, grinding grains, transistor radios, small TV sets, tape recorders etc. It can be used in schools to educational TV, internet, in social, religious and cultural gatherings for lighting, loud speakers, VCR, in health centers for surgery, for refrigerators, sterilizers, in telephones, broadcasting stations, etc. It is also used in agricultural sector for irrigation, in animal husbandry for watering and milking etc.

Principle of Photovoltaic cell

- It is based on the principle of the photovoltaic effect.
- The photovoltaic effect is a process in which a light-sensitive semiconductor converts the visible light (sun light) into voltage. This action occurs in all semiconductors that are constructed to absorb energy.

- The photoelectric effect is a phenomenon in which electrons are ejected from the surface of a metal when light is incident on it. These ejected electrons are called **photoelectrons**. It is important to note that the emission of photoelectrons and the kinetic energy of the ejected photoelectrons is dependent on the frequency of the light that is incident on the metal's surface. The process through which photoelectrons are ejected from the surface of the metal due to the action of light is commonly referred to as **photoemission**.
- The photoelectric effect occurs because the electrons at the surface of the metal tend to absorb energy from the incident light and use it to overcome the attractive forces that bind them to the metallic nuclei. An illustration detailing the emission of photoelectrons as a result of the photoelectric effect is provided below.



Construction and working of Photovoltaic Cell (PV cell):

Photovoltaic cells/Solar cells:

These cells are semiconductor devices which convert solar energy into electrical energy. It is based on the principle of photoelectric effect.

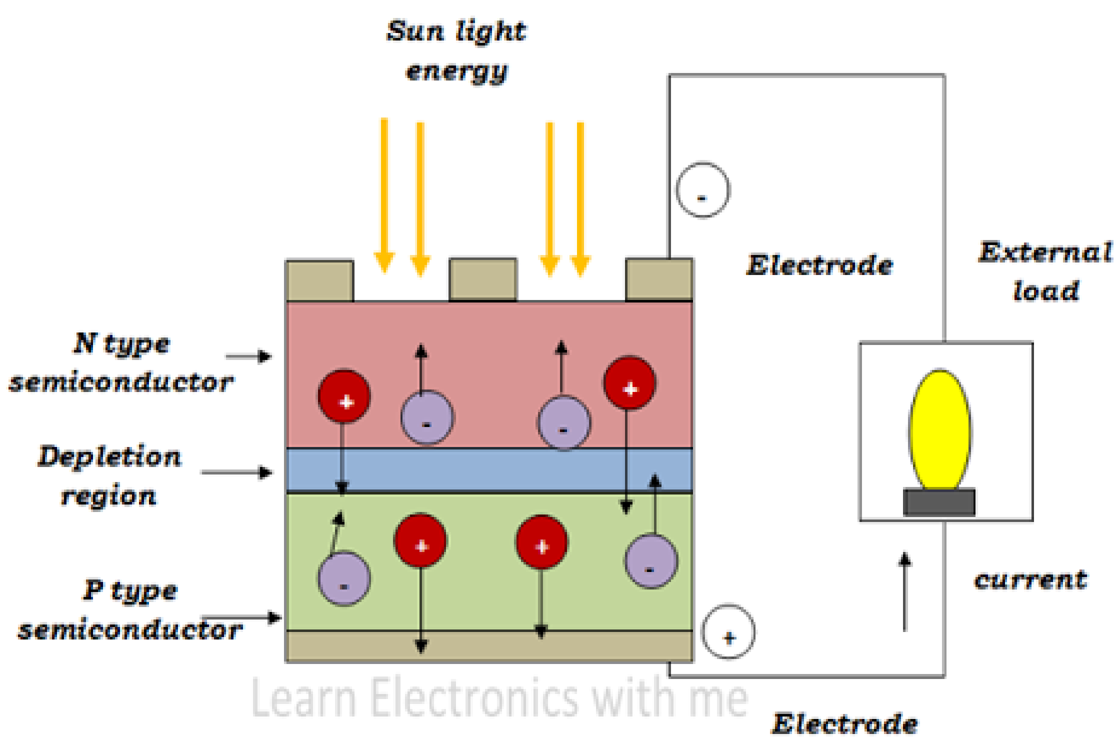
OR

An electrical device which converts light energy into electrical energy through the photovoltaic effect is known as **photovoltaic cell** or **PV cell** or **solar cell**. A photovoltaic cell is basically a specially designed p-n junction diode.

Construction:

The semiconductor materials like arsenide, indium, cadmium, silicon, selenium and gallium are used for making the PV cells. Mostly silicon and selenium are used for making the cell.

1. PV cells are made up of a thin semiconductor wafer (silicon alloys) i.e. light sensitive p-n junction photo diode as shown in the figure.



2. A photovoltaic cell is created when a positively charged (P-type) layer of silicon is placed against a negatively charged (N-type) layer of silicon to create a diode and this diode is connected in a circuit via metal conductors on the top and bottom of the silicon sandwich.
3. An actual PV cell includes these elements with an anti-reflective coating to accept more sunlight into the silicon sandwich.
4. The photovoltaic cell, a sandwich of two semiconductor materials. The cell reacts to solar energy and produces an electrical charge.
5. Metal conductor strips that run along the top layer of silicon. These strips capture the electrons freed when solar energy hits the cell and concentrate them into a current. Another metal panel, attached to the bottom layer of silicon, feeds electrons back into the cell
6. An anti-reflective coating placed on top of or directly adhered to the silicon sandwich. This sheet reduces the amount of sunlight reflected off the glass allowing more sunlight to hit the cell and increasing the panel's efficiency.
7. A p-n junction can form by joining p-type and n-type semiconductor and the region of separation is called junction.
8. p-type region which is connected to the positive terminal of battery contains holes ie, deficiency of electrons.
9. n-type region which is connected to the negative terminal of battery contains excess of electrons.
10. The holes are repelled by the positive charge of the battery while the electrons are repelled by the negative charge of the battery. Hence electrons and holes are pushed towards the junction who decreases the depletion region.

Working:

1. The photons of solar radiations enter n-type semiconductor breaks barrier potential and moves to p-type semiconductor where photons knocks the electrons in p-type to form electron pair.
2. The electrons travel from n-type to p-type semiconductor, thereby completing the whole electric circuit. Hence obtain electricity which is shown by glowing of the bulb attached.

3. When light hits the depletion region, electrons and holes are generated due to photons striking the valence electrons and imparting energy to them.
4. The optically generated electron-hole pairs are quickly separated and swept outside the depletion region by the electric field.
5. These electrons and holes flow to constitute the photocurrent across the load. Thus, it supplies power
6. As the negative charge (light generated electrons) is trapped in one side and positive charge (light generated holes) is trapped in opposite side of a cell, there will be a potential difference between these two sides of the cell. This potential difference is typically 0.5 V. This is how a **photovoltaic cells** or **solar cells** produce potential difference.

Advantages of Photovoltaic Cells

1. The photovoltaic cell does not require any external battery for its own operation, i.e. it is self-generating.
2. Since solar energy is unlimited, once the photovoltaic system is installed, it can produce energy years together (almost 20 years). I.e. High reliability in solar modules.
3. The maintenance cost is minimum.
4. The solar power is highly pollution free.
5. They do not need to be recharged.
6. They operate at ambient temperature.
7. Their parts do not corrode or suffer wear and tear.

Disadvantages of Photovoltaic Cells

1. It is relatively low density energy.
2. They are expensive to install.
3. The photovoltaic devices only produce DC voltage.
4. Poor reliability of auxiliary elements including storage.
5. Energy can be produced only during the day time.

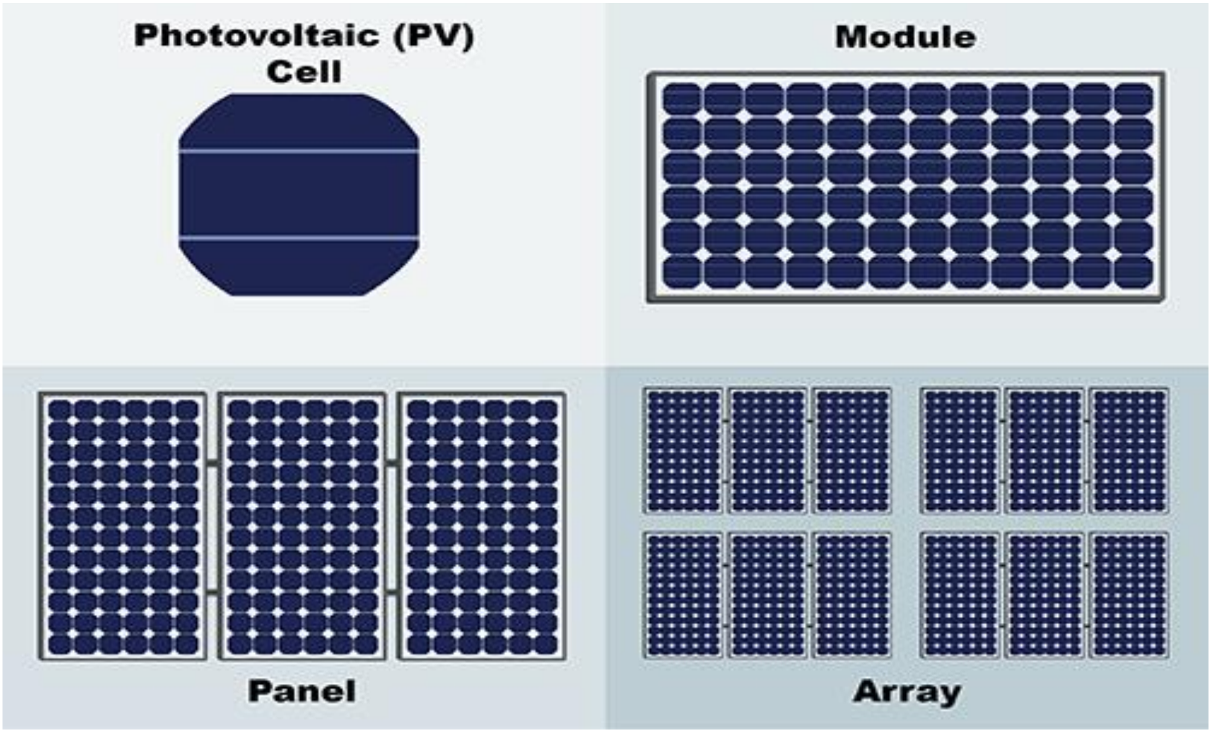
6. Their parts do not corrode or suffer wear and tear.
7. Solar cells have a slow operation.
8. They are temperature sensitive.
9. The output voltage and current is very low (about 0.6 V).
10. Conversion efficiency is low.
11. It is not available at night and is reduced when there is cloud cover, decreasing the reliability of peak output performance.
12. It is only practical in certain areas with a favorable climate and latitude.

Application of Photovoltaic cells

1. The photovoltaic cells are used in low-power devices such as light meters.
2. They are used in solar-powered scientific calculators and watches.
3. A large set of photovoltaic cells can be connected together to form solar modules, panels, or arrays.
4. They are used in electronic circuits and satellites.
5. They are used in solar cars and space technology.
6. They are used in batteries.
7. They are used in street lighting and rooftops of houses.

[NOTE: MODULES, PANELS AND ARRAYS

Module: A single solar cell produces only 0.5 volts and hence cannot be used for power generation. Atleast 36 cells are connected to form a module. Thus module is the basic building block of systems for power generation. The cells in a module are connected in series provided with a protective back surface. This is called encapsulation and involves lamination of the cells between a polymer and a thin film of aluminium or stainless steel Encapsulation protects the module from moisture and contaminants and pollutants in the atmosphere and thus prevents failure of the solar module. Though this should produce 18 volts, it produces only 12 -14 volts because the cells get heated in the sun.



Panel: If higher energy is needed, the modules may be connected in series or in parallel. The group of modules that are packaged and connected with wires for installation is called a panel. A set of four or more modules are framed or attached together by struts in what is called a panel. This panel is typically around 1.85 -3.25 square meters in area for ease of handling on a roof.

Array: An array consists of two or more panels and forms the power generating unit. In a arrays, panels may be wired together in a series or parallel to deliver the voltage and current required for particular system.]

E-WASTE MANAGEMENT

Introduction

Managing electronic waste (or e-waste) is one of the most rapidly growing pollution problems worldwide. New technologies are rapidly superseding millions of analogue appliances leading to their disposal in prescribed landfills despite potentially their adverse impacts on the environment. The consistent advent of new designs, ‘‘smart’’ functions and technology during the last 20 years is causing the rapid obsolescence of many electronic items. The lifespan of many electronic goods has been substantially shortened due to advancements in electronics, attractive consumer designs and marketing and compatibility issues. For example, the average lifespan of a new computer has decreased from 4.5 years in 1992 to an estimated 2 years in 2005 and is further decreasing resulting in much greater volumes of computers for either disposal or export to developing countries. While difficult to quantify the volume of e-waste generated globally, Bushehri (2010) presented an overview of the volume of e-waste generated in a range of categories in China, Japan and US based on available information for the period 1997–2010. This report estimates that over 130 million computers, monitors and televisions become obsolete annually and that the annual number is growing n the United States. Around 500 million computers became obsolete between 1997 and 2007 in the United States alone and 610 million computers had been discarded in Japan by the end of December 2010. In China 5 million new computers and 10 million new televisions have been purchased every year since 2003, and around 1.11 million tonnes of e-waste is generated every year, mainly from electrical and electronic manufacturing and production processes, end-of-life of household appliances and information technology products, along with imports from other countries. It is reasonable to assume that a similar generation of e-waste occurs in other countries.

E-waste generation in some developing countries is not such a cause for concern at this stage because of the smaller number and longer half-life of electronic goods in those countries due to financial constraints, on both local community and national scales. The major e-waste problem in developing countries arises from the importation of e-waste and electronic goods from developed countries because it is the older, less ecologically friendly equipment that is discarded from these Western countries 80% of all e-waste in developed countries is being exported. Limited safeguards, legislation, policies and enforcement of the safe disposal of imported e-waste and electronic goods have led to serious human and environmental problems in these countries. For instance, an e-waste disposal impact on human health has become a serious issue that has already been noted in case studies from China.

Concern arises not just from the large volume of e-waste imported into developing countries but also with the large range of toxic chemicals associated with this e-waste. Numerous researchers have demonstrated that toxic metals and polyhalogenated organics including polychlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) can be released from e-waste, posing serious risks of harm to humans and the environment. A review of published reports on e-waste problems in developing countries, and countries in transition, showed that China, Cambodia, India, Indonesia, Pakistan, and Thailand, and African countries such as Nigeria, receive e-waste from developed countries although specific e-waste problems differ considerably between countries. For instance, African countries mainly reuse disposed electronic products whereas Asian countries dismantle those often using unsafe procedures. Social and human health problems have been recognized in some developing countries and it is worth noting that China, India, and some other Asian countries have recently amended their laws to address the management and disposal of e-waste imports. Moreover, some manufacturers of electronic goods have attempted to safely dispose of e-waste with advanced technologies in both developed and developing countries.

Problems associated with e-waste have been challenged by authorities in a number of countries and steps were taken to alleviate them with the introduction of management tools and laws at the national and universal levels. Life Cycle Assessment (LCA), Material Flow Analysis (MFA) and Multi Criteria Analysis (MCA) are tools to manage e-waste problems and Extended Producer Responsibility (EPR) is the regulation for e-waste management at the national scale.

Definition of E-waste

E-waste is electronic products that are unwanted, not working, and nearing or at the end of their "useful life." Computers, televisions, VCRs, stereos, copiers, and fax machines are everyday electronic products.

OR

E-waste is any electrical or electronic equipment that's been discarded. This includes working and broken items that are thrown in the garbage or donated to a charity reseller like Goodwill. Often, if the item goes unsold in the store, it will be thrown away.

E-waste is particularly dangerous due to toxic chemicals that naturally leach from the metals inside when buried.

OR

Electronic waste, or e-waste, refers to all items of electrical and electronic equipment (EEE) and its parts that have been discarded by its owner as waste without the intent of re-use. E-waste is also referred to as WEEE (Waste Electrical and Electronic Equipment), electronic waste or e-scrap in different regions and under different circumstances in the world. It includes a wide range of products – almost any household or business item with circuitry or electrical components with power or battery supply.

OR

Electronic Waste or E-Waste describes rejected electrical or electronic devices. All items of electrical and electronic equipment and its parts that have been discarded by the user as waste without the purpose of re-use or re-cycle is called Electronic Waste.

Types of Electronic Waste with Its Each Definition

It is usually divided into eight types

1. ICT and Telecommunications Equipment

Items classified into ICT include CPUs, screens, monitors, mice, printers, keyboards, networking equipment, laptops, audio amplifiers, CDs, DVDs, and video cameras. And this number is arguably the most in the current era because it is the easiest to obtain.

2. Office Electronics

Office use and the amount of trash in the world seem to be a problem. Office electronics include calculators, photocopying equipment, electronical, typewriters, telephones, fax machines, and facsimiles if they are still in the office.

3. Large Household Appliances

Everyday items such as refrigerators, cookers, air conditioners, radiators, fans, washing machine and many more. And it is classified as **electronic waste** in a large size.

4. Small Household Appliances

These are things like vacuum cleaners, hair dryers, fryers, swing weaving, iron box, coffee makers, water heater kettle and many more.

5. Consumer Equipment

Items used for consumer use will also be included in the **electronic waste** sector. Video and audio equipment, musical instruments.

6. Medical Equipment

Electronic equipment is involved in injury, treatment, prevention, and detection activities.

7. Toys Leisure and Sports Equipment

As kids grow older, of course, there are toys or games that they no longer use. And there must be some of those items that belong to electronics. If there is only one electronic component, such as a **battery**, in the toy, then it is classified as e-waste as well.

8. Lighting devices

Incandescent light bulbs, fluorescent tubes, gas-discharge lamps etc.

Sources of Electronic Waste

Any appliance that runs on electricity has the potential to cause damage to the environment if it is not disposed properly. Common things of electrical and electronic waste are:

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

Causes of E- Waste

The main causes of Electronic Waste are:

- Advancement in Technology.
- Changes in style fashion and status.
- End of their helpful life.
- Not taking precautions while handling them.

Composition of E- Waste

Composition of E-Waste includes materials like:

- Valuable metals like gold, platinum, silver and palladium.

- Useful metals like copper, aluminum, iron etc.
- Hazardous substances like radioactive isotopes and mercury.
- Toxic substances like PCB's and Dioxins.
- Plastic like High Impact Polystyrene (HIPS), Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polyphenylene oxide (PPO) etc.
- Glass material like Cathode Ray Tube glass made up of SiO_2, CaO, NaO. For instance, a mobile phone contains more than 40 elements, base metals such 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).

OR

E-waste includes:

- non-ferrous and precious metals,
- alloys,
- glass,
- ceramics,
- organic polymers with toxic content,
- other substances like stabilizers, fillers and pigments.

Effect of E- Waste on environment

The effects of improper disposal of E-waste on the environment pose very real threats and dangers to the global environment at large. Improper disposal of these wastes affect the soil, air and water components of the environment.

- **Effects of E-Waste on Air**: Most common result of E-waste on air is through air pollution. Burning of e waste can release hydrocarbons within the atmosphere that pollutes the air.
- **E-Waste Negatively Impacts Soil**: E-waste can have a negative effect on the soil. As e-waste breaks down, it releases toxic heavy metals. Such heavy metals include lead, arsenic, and cadmium. When these toxins penetrate the soil, they influence the plants and trees. Thus, these toxins can enter the human food supply, which can lead to birth defects as well as a number of other health complications.

- **Effects of E-Waste on Water**: Heavy metals like mercury, lithium, lead present in electronics (found in mobile phone and computer batteries), etc., when not disposed properly, these heavy metals penetrate from soil to groundwater which then runs to the surface as streams or small ponds of water.

Effect of E- Waste on human health

Substance	Applied in e-waste	Health Impact
Antimony (Sb)	a melting agent in CRT glass, plastic computer housings and a solder alloy in cabling	Antimony has been classified as a carcinogen. It can cause stomach pain, vomiting, diarrhoea and stomach ulcers through inhalation of high antimony levels over a long time period
Arsenic (As)	Gallium arsenide is used in light emitting diodes	It has chronic effects that cause skin disease and lung cancer and impaired nerve signalling
Barium (Ba)	Sparkplugs, fluorescent lamps and CRT gutters in vacuum tubes	Causes brain swelling, muscle weakness, damage to the heart, liver and spleen though short-term exposure
Beryllium (Be)	Power supply boxes, motherboards, relays and finger clips	Exposure to beryllium can lead to beryllicosis, lung cancer and skin disease. Beryllium is a carcinogen
Brominated flame retardants (BFRs): (polybrominated biphenyls (PBBs), polybrominated diphenyl ethers (PBDEs) and tetrabromobisphenol (TBBPA))	BFRs are used to reduce flammability in printed circuit boards and plastic housings, keyboards and cable insulation	During combustion printed circuit boards and plastic housings emit toxic vapours known to cause hormonal disorders
Cadmium (Cd)	Rechargeable NiCd batteries, semiconductor chips, infrared detectors, printer inks and toners	Cadmium compounds pose a risk of irreversible impacts on human health, particularly the kidneys
Chlorofluorocarbons (CFCs)	Cooling units and insulation foam	These substances impact on the ozone layer which can lead to greater incidence of skin cancer.
Hexavalent chromium/chromium VI (Cr VI)	Plastic computer housing, cabling, hard discs and as a colourant in pigments	Is extremely toxic in the environment, causing DNA damage and permanent eye impairment
Lead (Pb)	Solder, lead-acid batteries, cathode ray tubes, cabling, printed circuit boards and fluorescent tubes	Can damage the brain, nervous system, kidney and reproductive system and cause blood disorders. Low concentrations of lead can damage the

		brain and nervous system in foetuses and young children. The accumulation of lead in the environment results in both acute and chronic effects on human health
Mercury (Hg)	Batteries, backlight bulbs or lamps, flat panel displays, switches and thermostats	Mercury can damage the brain, kidneys and foetuses
Nickel (Ni)	Batteries, computer housing, cathode ray tube and printed circuit boards	Can cause allergic reaction, bronchitis and reduced lung function and lung cancers
Polychlorinated biphenyls (PCBs)	Condensers, transformers and heat transfer fluids	PCBs cause cancer in animals and can lead to liver damage in humans
Polyvinyl chloride (PVC)	Monitors, keyboards, cabling and plastic computer housing	PVC has the potential for hazardous substances and toxic air contaminants. The incomplete combustion of PVC release huge amounts of hydrogen chloride gas which form hydrochloric acid after combination with moisture. Hydrochloric acid can cause respiratory problems
Selenium (Se)	Older photocopy machines	High concentrations cause selenosis

Disposal Methods of E- Waste

Various methods of treatment and disposal system include:

- **Land Filling**– Disposal of Electronic Waste is mainly through land filling. Mostly, the discarded electronic goods finally end-up in landfill sites along with other municipal waste or are openly burnt releasing toxic and carcinogenic substances into the atmosphere.
- **Incineration**– In this complete combustion process, the waste material is burned in specially designed incinerators at a high temperature (900-1000o C). It reduces waste volume and some environmentally hazardous organic substances are converted into less hazardous compounds.
- **Recycling of E-Waste** – Recycling involves dismantling, processing and end processing. Comparatively, the value of recycling from the element could be much higher in comparison to other treatments.

- **Re-use**– It includes direct second hand use or use after slight modifications to the original functioning equipment like Inkjet cartridge is used after refilling. Old working computers can be donated to schools or organization working in the field of education. Computers beyond repairs can be returned back to the manufacturers. This can considerably reduce the volume of E-Waste generation converted into less hazardous compounds.

Advantages of recycling E- Waste disposal

1. It Prioritizes Environmental Protection

E-waste recycling prioritizes environmental protection. It includes proper handling, processing, and managing of electronic waste. As hazardous and toxic substances such as lead, mercury, and cadmium present in electronics can harm the environment. You may find many valuable resources or materials in an e-waste stream. Through E-waste recycling, we make most of these components instead of discarding them. This way, the hazards that these elements could have potentially caused to our environment are reduced.

2. E waste Recycling Helps to Conserve Available Natural Resources

Electronic waste recycling helps recover valuable materials from electronic products. This saves and conserves natural resources. This way, manufacturers do not need to mine the minerals; instead, they can just recycle and reuse the components of e-waste. So, yes, we can save copper or lead or valuable metals from mother nature. Thus, it promotes the utilization of resources wisely.

3. Creates Jobs

E-waste recycling is creating new jobs for people and local recyclers nearby. The more important thing is that, by doing so, it has created a secondary market. Where recycled materials are the primary commodity. The Environmental Protection Agency released findings that show the magnitude of economic benefits that come from e-waste recycling. In a year, the US's recycling activities provided 757,000 jobs, $6.7 billion in tax revenues, and $36.6 billion in wages. By implication, for every thousand tons you recycle, there are 1.57 jobs created, $ 76,000 in wages paid, and $ 14,101 in tax revenues. So a lot of benefits come from trash, right? But there's more. For a million laptops you recycle, you will have saved the equivalent of electric power capable of running 3657 households for one year. Guess what? For a million cell phones, you can recover gold weighing 75 pounds, silver of 772 pounds, copper of 35,274 pounds, and palladium of 33 pounds! There is also a significant social and economic impact. According to the EPA, recycling and reusing e-waste accounts for 681,000 jobs in a single year. Of course, e-waste is only a part of that, but as the fastest-growing waste stream, it is likely to become increasingly significant as we become more reliant on digital devices.

4. Saves Landfills and Reduces GHG emissions

Usually, e wastes get dumped at incinerators and landfills. By recycling e-waste, we are reducing the amount of e-waste that piles up at these places. This is because two-thirds of waste in landfills is biodegradable and capable of breaking down and returning to its natural elements. As this waste breaks down and decomposes, it produces harmful gasses, or I would say greenhouse gasses, such as methane, carbon monoxide, etc. This heavily contributes to global warming. Since landfill heaps also pollute the water and soil in our local environment. Initiatives like e-waste recycling seek to reduce these environmental concerns.

5. Increases Affordability

Using recycled components obtained from e-waste are cheaper than ones obtained from mining activities. This way, manufacturing costs can be reduced, and the end product can be more affordable. Copper found in e-waste can be reused multiple times. This has made **the copper recycling business** a lucrative industry today.

6. Prevent Water Bodies from Toxic Waste Poisoning

As you have seen above, e-waste heaps in landfills release toxic chemicals into the groundwater, and this finds its way to nearby wells and freshwater bodies. Accumulating these harmful toxicants in water bodies not only harms aquatic ecosystems but also creates havoc for local peoples who depend on that water body for their survival. E-waste recycling prevents the release of these toxic elements into inland water bodies and ensures the water is fresh and safe for utilization. E-waste recycling helps to prevent the degradation of aquatic ecosystems and also helps to increase the lifespan of aquatic organisms.

7. E waste recycling helps reduce air pollution

E-waste recycling not only prevents toxic chemicals from leaching into the soil, but it also prevents the release of poisonous gasses and dust. Since recycling e-waste reduces mining activities, there is considerably less pollution caused. For instance, mining activities involve the blasting of rocks, because of which gasses such as carbon dioxide, sulfur dioxide, and dust are released into the environment. For 1 ton of gold or platinum, about 10000 tons of Carbon dioxide is emitted. Electronic recycling cuts a significant percentage of toxic gas emissions and, as a result, protects the air from pollution.

8. Promote fisheries resources

E-waste is a complex composition of different toxins that, when dumped in landfills, leach into water bodies and kill fish and other aquatic organisms. There is a significant amount of lead, copper, mercury, cadmium, and other deadly material that is discharged into the streams and rivers and killing aquatic life and degrading aquatic ecosystems. Mercury, for example, is a neurotoxin that can kill organisms in a concise duration of time. Recent studies from scientists have shown that dead fishes found in deposits on sea and waterbeds contain high mercury levels determined to come from human activities around water bodies. E-waste recycling helps reduce the discharge of such hazardous toxins and maintains the balance in aquatic ecosystems. As a result, you help preserve the freshwater ecosystem for plants, animals, and even people who depend on them as livelihood sources.

9. Electronic Recycling Promotes Soil Fertility and Maintain Nutrient

E-waste recycling not only prevents toxic chemicals from leaching into the soil and making it poisonous for plant growth. Also, during the burning, shredding and dismantling of e-waste large particles of dust are released. These particles also settle on the ground and make it infertile. A large percentage of the world's population relies on agriculture as a livelihood source and ensuring the fields are fertile and safe to grow plants is essential to promoting overall human well-being. Recycling e-waste helps the integrity of the soil. Thus encouraging agriculture and the growth of natural green resources for plants, animals, and human beings.

10. Encourage Mindful Consumerism and Awareness

Think before you buy! Management of e-waste recycling as a regular practice is a useful reminder for our consumer decisions and behavior. Through this, people become more sensitive toward our environment. Rather than contributing to the waste heap and showing irresponsible throw-away culture, it's time for us to embrace mindful consumerism by thinking before buying. Also, you should go for repairing or recycling before discarding any kind of electronic products.

Extraction of Gold from E- Waste

Acid Treatment Method

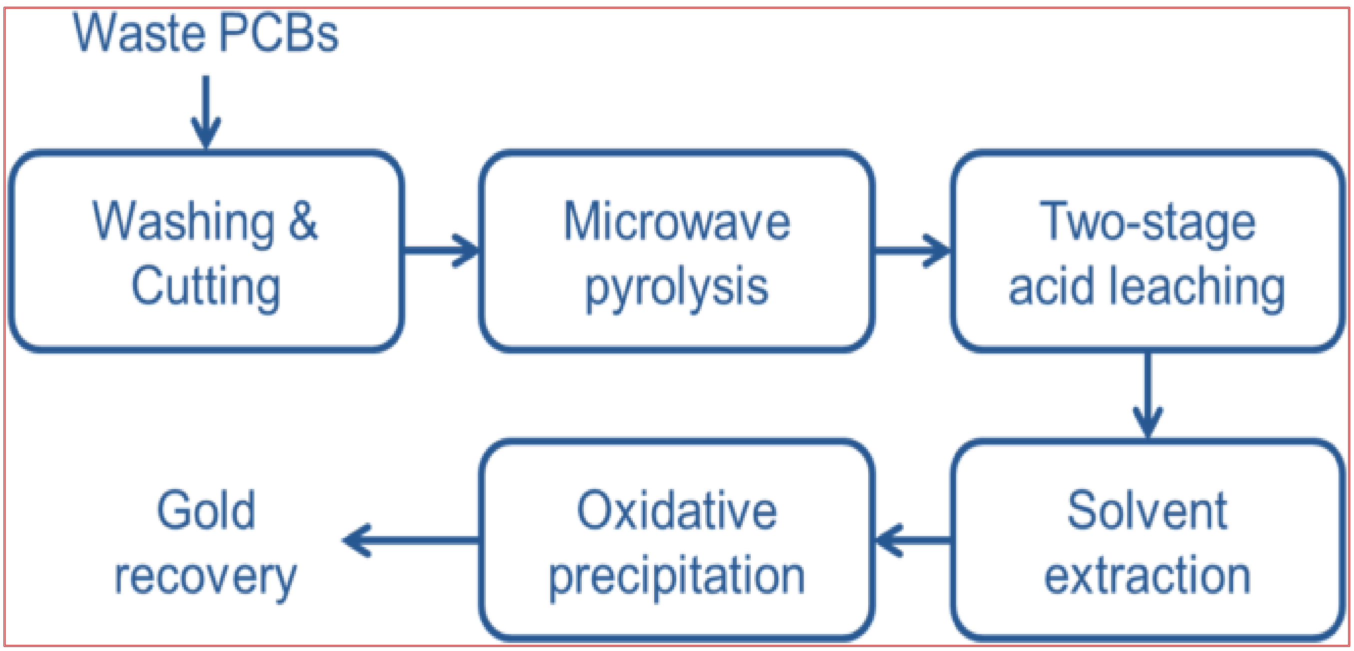
Acid treatment is one of the easiest way to recover gold from e-waste. The mixture of hydrochloric acid (HCl) and nitric acid (HNO_3) have found to be useful chemicals in the extraction of gold from e-waste. Other mild acids have also been successful in their extraction of gold, as these acids can successfully dissolve gold while limiting their potential to cause adverse effects to the environment.

Advantages

- High yield expected.
- Faster extraction of gold is possible.

Disadvantages

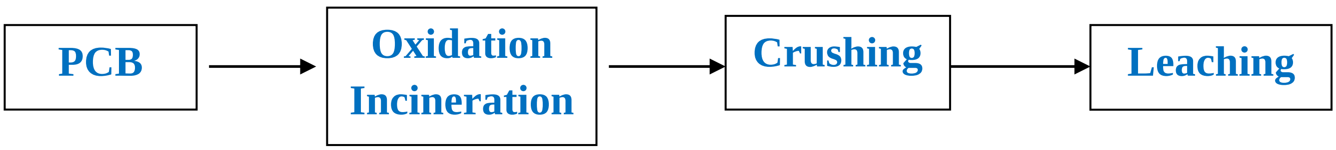
- Chemicals are used.
- Acid residues are not disposed of properly, which harms the environment.



Method for E-waste Gold Recovery

1. There are many possible alternatives to extracting precious metals such as copper, gold, palladium and silver from e-waste.

2. Two different methods or options were tested for leaching Au from obsolete PCB boards. The first method involves the incineration of PCB sample at 800°C for 3 hrs. Then, the size of the sample was reduced by using a cutter mill. The time allowed for the size reduction process was kept constant at 3 min. Next, the sample was subject to acid leaching by using aqua regia, keeping the leaching time at 30 min. and temperature at 20°C.



2. Also, Aqua regia has received a lot of attention in recent years.

3. In the leaching of gold due to its complete dissolution and fast rates.

4. As it is strongly oxidising and corrosive in nature, it is unsuitable for full scale operations. It is a suitable leachant for use in fundamental research.

5. The nitric acid acts as a powerful oxidising agent to form Au3+ ions, while the hydrochloric acid provides a large excess of Cl− ions to form H[AuCl4]. Following are the chemical equations:

[The PCB board circuit includes three Layers copper, Nickel and gold. Nickel and Copper dissolves while adding HCL solution that helps the gold to be free for extraction. Aqua regia dissolves gold, though neither constituent acid will do so alone, because, in combination, each acid performs a different task. Nitric acid is a powerful oxidizer, which will actually dissolve a virtually undetectable amount of gold, forming gold ions (Au3+). The hydrochloric acid provides a ready supply of chloride ions (Cl−), which react with the gold ions to produce tetra chloroaurate (III) anions, also in solution. The reaction with hydrochloric acid is an equilibrium reaction which favors formation of chloroaurate anions (AuCl4−). This results in the removal of gold ions from solution and allows further oxidation of gold to take place. The gold dissolves to become chloroauric acid. In addition, gold may be dissolved by the free chlorine present in aqua regia. Appropriate equations are:]

$$Au(s) + 3HNO_3\ (aq) + 4HCl\ (aq) \rightleftharpoons H[AuCl_4](aq) + 3NO_2(g) + 3H_2O(l)$$

$$Au(s) + HNO_3\ (aq) + 4HCl\ (aq) \rightleftharpoons H[AuCl_4](aq) + NO(g) + 2H_2O(l)$$

6. As an oxidising acid, HNO_3 has been shown to act as a two-stage leachant, selectively dissolving copper, nickel and gold.

7.Initially, a dilute HNO_3 (0.1 M) leach step results in suppression of copper leaching but enhanced nickel leaching due to its higher chemical reactivity; increasing the concentration of HNO_3 (to 1.0 M) results in high recovery of both copper and gold (98%).

8. The oxidation of waste Printed Circuit Boards (PCBs) using supercritical water (i.e. T > 647 K, P > 218 atm) and sodium hydroxide as a first step. It's done by following the removal of harmful organic species originating from the degradation of toxic matter such as brominated flame retardants from waste PCBs has been reported.

9. Later on, this process was modified to enhance the leaching of copper along with precious metals such as gold and many others too.

9. In this latter case, HCl was used as the leaching for the initial recovery of copper, followed by iodine–iodide (oxidant and complexing agent, respectively) for subsequent dissolution of the precious metals.

10. X ray diffraction method is used to check the purity and karat of the gold.

11. The purity of gold and the presence of gold and other elements are also obtained from EDAX microstructure [Energy dispersive x-ray analysis – EDAX].

Important Strategies for E-Waste Management

E-waste is a serious problem at both local and global level. E-waste problems appeared initially in developed countries and now extend widely to other countries around the world. The volume of e-waste is growing fast because consumer technology is rapidly changing and the innovation of technology results in rapid obsolescence, thus generating massive amounts of e-waste. E-waste consists of many different materials, some of which contain a variety of toxic substances that can contaminate the environment and threaten human health, if the end-of-life management is not meticulously managed. The toxic substances present in e-waste, their potential environmental and human health impacts together with management strategies currently being used in certain countries. In order to mitigate e-waste problems, there are investigations in term of the volume, nature and potential environmental and human health impacts of e-waste and extensive research into e-waste management. Several tools including Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA) and Extended Producer Responsibility (EPR) have been developed to manage e-wastes especially in developed countries. Moreover, a national scheme such as EPR is a good policy tool to solve the growing e-waste problem. Interaction of four tools can drive to success for e-waste management. **The key to success in terms of e-waste management is to develop eco-design devices, properly collect e-waste, recover and recycle material by safe methods, dispose of e-waste by suitable techniques, forbid the transfer of used electronic devices to developing countries, and raise awareness of the impact of e-waste.**

SOME IMPORTANT DESCRPTIVE TYPE QUESTIONS

1. Define fuel cell. Explain the difference between fuel cell and battery.
2. Explain the construction and working of methanol-oxygen fuel cell. Mention any two applications and advantages.
3. Describe the construction and working of Polymer electrolyte membrane fuel cell. Mention it's any two applications.
4. Discuss the importance of photovoltaic cells.
5. Define photovoltaic cell. Explain the construction and working of photovoltaic cell,
6. Mention the advantages, disadvantages and applications of PV cells.
7. Define E-waste. Explain the sources and composition of e-waste.
8. What is E-waste? Mention the different types of e-waste with suitable examples.
9. Mention the different methods of e-waste disposal.
10. List out the advantages of recycling e-waste disposal.
11. Explain the effect of e-waste on environment and human health.
12. Explain the extraction of gold from e-waste.

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