E – WASTE MANAGEMENT

Vision

To provide rich ambience for Academic and Professional Excellence, Research, Employability skills, Entrepreneurship and Social responsibility.

Mission

To empower the students with Technical knowledge, Awareness of up-to-date technical trends, Inclination for research in the areas of human needs, Capacity building for Employment / Entrepreneurship, Application of technology for societal needs.

Course outcomes

Upon successful completion of the course, the student will be able to

- **CO1** : Understand the environmental impacts of e-waste. (L2)
- **CO2** : Apply concepts of e-waste management hierarchy.(L3)
- **CO3 :** Distinguish the role of various national and internal act and laws applicable for e-waste management and handling.(L4)
- **CO4 :** Analyze the e – waste management measures proposed under national and global legislations. (L4)

UNIT-1

Introduction:

- E- waste Composition and generation
- Global context in E- waste
- E-waste pollutants
- E waste hazardous properties
- Effects of pollutant (E- waste) on human health and surrounding environment
- Domestic e-waste disposal
- Basic principles of E-waste management
- Component of E waste management
- Technologies for recovery of resources from electronic waste
- Resource recovery potential of e-waste
- Steps in recycling and recovery of materials-mechanical processing
- Technologies for recovery of materials
- Occupational and environmental health perspectives of recycling e-waste in India.

UNIT-2

- **E-waste hazardous on Global trade**:
- Essential factors in global waste trade economy
- Waste trading as a quint essential part of electronic recycling
- Free trade agreements as a means of waste trading. Import of hazardous e-waste in India; India‘s stand on liberalizing import rules
- E-waste economy in the organized and unorganized sector
- Estimation and recycling of e-waste in metro cities of India

UNIT-3

- E-waste control measures:
- Need for stringent health safeguards and environmental protection laws in India
- Extended Producers Responsibility (EPR)
- Import of e-waste permissions
- Producer-Public-Government cooperation
- Administrative Controls & Engineering controls
- monitoring of compliance of Rules
- Effective regulatory mechanism strengthened by manpower and technical expertise
- Reduction of waste at source.

UNIT-4

- E-waste (Management and Handling) Rules, 2011
- E-Waste (Management) Rules, 2016 - Salient Features and its likely implication.
- Government assistance for TSDFs.

UNIT-5

- The international legislation: The Basel Convention
- The Bamako Convention.
- The Rotterdam Convention.
- Waste Electrical and Electronic Equipment (WEEE) Directive in the European Union
- Restrictions of Hazardous Substances (RoHS) Directive.

E – WASTE MANAGEMENT

Learning Resources

Text Books:

1. Johri R., E-waste: implications, regulations, and management in India and current global best practices, TERI Press, New Delhi

2. Hester R.E., and Harrison R.M, Electronic Waste Management. Science, 2009

Reference Books

1. Fowler B, Electronic Waste – 1st Edition (Toxicology and Public Health Issues), 2017Elsevier

E-Resources

1. https://news.mit.edu/2013/ewaste-mit

UNIT-I

Introduction:

- e-waste or electronic waste broadly describes discarded, surplus, obsolete, broken, electrical or electronic devices which are at the end of their useful life and need to be disposed or dismantled to recover some valuable components.
- The problem of e-waste has become an immediate and long term concern as its unregulated and improper accumulation and recycling can lead to major environmental problems endangering not only human and animal health but also environment health due to toxic and other dangerous materials available in them.
- The countries of the European Union (EU) and other developed countries are adopting scientific methods of recycling and disposal of such waste. The EU defines this e-waste stream as 'Waste Electrical and Electronic Equipment' (WEEE).

Definition

- Electronic waste or e-waste describes discarded electrical or electronic devices. It is also commonly known as waste electrical and electronic equipment(WEEE) or end-of-life electronics.
- "E-Waste is a term used to cover items of all types of electrical and electronic equipment (EEE) and its parts that have been discarded by the owner as waste without the intention of re-use."

Definition

- Electronic waste, popularly known as ‘e-waste’ can be defined as electronic equipments or products connects with power plug, batteries which have become obsolete due to:
    1. Advancement in technology
    2. Changes in fashion, style and status
    3. Nearing the end of their useful life.

- The creation of innovative and new technologies and the globalization of the economy have made a whole range of products available and affordable to the people changing their lifestyles significantly
- New electronic products have become an integral part of our daily lives providing us with more comfort, security, easy and faster acquisition and exchange of information

Need of E-Waste Management

- Pollution of ground water.
- Acidification of soil.
- Emission of toxic fumes and gases.
- It is the fastest growing portion of municipal waste.
- Releases harmful gases into the air.

Management Of E-waste

- Due to advancement in techniques the old instruments are becoming outdated.
- This necessitates implemental management measures.
- India as a developing country needs simpler, low cost technology for proper management of E-waste.

Classification of e-waste

Large household appliances	- Refrigerators and Freezers, Other appliances used for refrigeration, conservation and storage of food , Washing machines, Clothes dryers, Dish washing machines, - Cooking ranges/stoves Electric hot plates, Microwaves, Other appliances used for cooking and other processing of food, - Electric heating appliances, Electric radiators, Other fanning, exhaust ventilation and conditioning equipment.
Small household appliances	- Vacuum cleaners, Carpet sweepers, Other appliances used for cleaning, - Appliances used for sewing, knitting, weaving and other processing for textiles, Iron and other appliances used for ironing and other care of clothing, - Toasters, Fryers, Grinders, coffee machines and equipment for opening or sealing containers or packages, - Electric knives, Appliances for hair-cutting, hair drying, tooth brushing, shaving, massage and other body care appliances, - Digital clocks, watches and equipment for measuring indicating or registering time Scales

Toys, leisure and sports equipment	- Electric trains or car racing sets, Hand-held video game consoles, Video games, - - Computers for biking, diving, running, rowing, etc., - Sports equipment with electric or electronic components, - Coin slot machines
Electrical and electronic tools (except large-scale stationary industrial tools)	- Drills, Saws, Sewing machines, Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, making holes, punching, folding, bending or similar processing of wood, metal and other materials, - Tools for riveting, nailing or screwing or removing rivets, nails, screws or similar uses, - Tools for welding, soldering or similar use, - Equipment for spraying, spreading, dispersing or other treatment of liquid or gaseous substances by other means, - Tools for mowing or other gardening activities
Medical devices (except implanted and infected products)	- Radiotherapy equipment, Cardiology, Dialysis, Pulmonary ventilators, Nuclear medicine

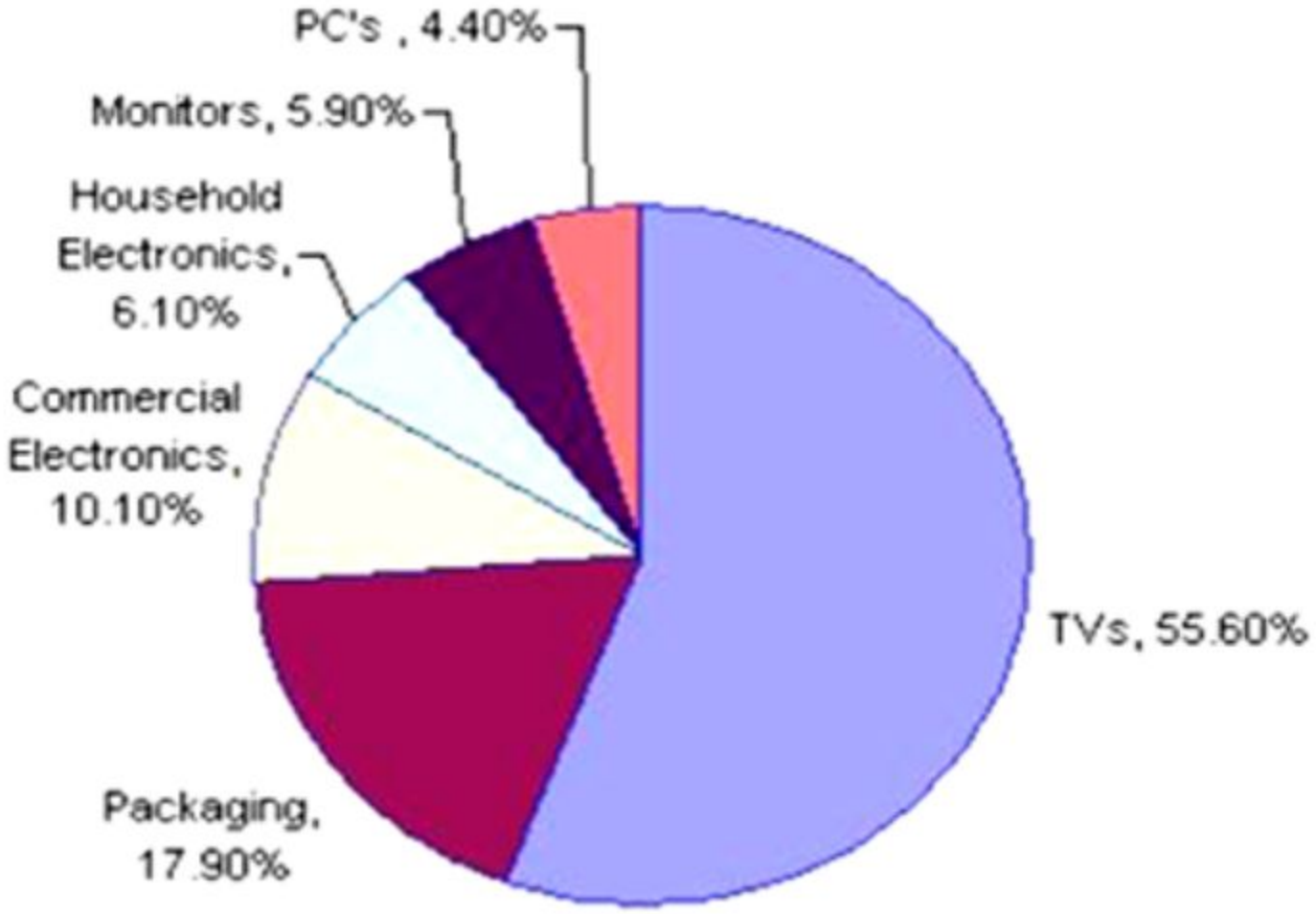
Monitoring and control instruments	- Smoke detector - Heating regulators - Thermostats - Measuring, weighing or adjusting appliances for household or as laboratory equipment - Other monitoring and control instruments used in industrial installations (e.g. in control panels)
Automatic dispensers	- Automatic dispensers for beverages - Automatic dispensers for hot or cold bottles or cans - Automatic dispensers for solid products - Automatic dispensers for money - All appliances which deliver automatically all kind of products
IT and telecommunication equipments	- Centralised data processing: Mainframes, Minicomputers, - Personal computing: Personal Computers (CPU with input and output devices), Laptop (CPU with input and output devices), Notebook, Notepad etc., - Printers - Copying equipment, Electrical and electronic typewriters - Pocket and desk calculators - Other products and equipment for the collection, storage, processing, presentation or communication of information by electronic means - User terminals and systems - Facsimile, Telex, Telephones, Pay telephones, Cordless telephones, Cellular telephones, Answering systems, And other products or equipment of transmitting sound, images or other information by Telecommunications

	Consumer electronics	- Radio sets, Television sets, Video cameras, Video recorders, Digital cameras, Hi-fi recorders, Audio amplifiers, Musical instruments, And other products or equipment for the, purpose of recording or reproducing sound or image, including signals or other technologies for the distribution of sound and image than by telecommunications

Sources of E-Waste

E-Waste Deposition

Composition of E-Waste



Composition of E-Waste:

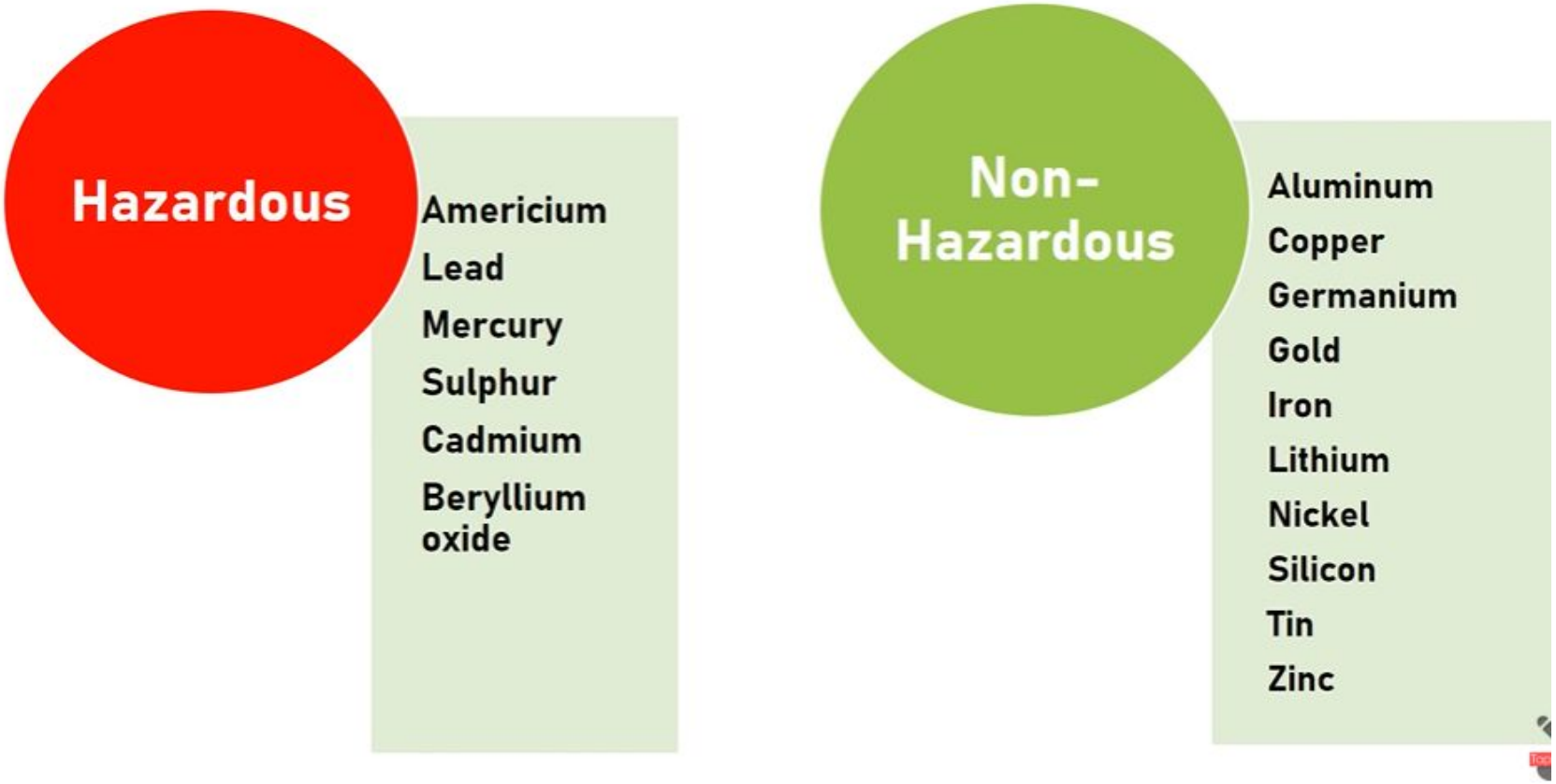
- E-waste consists of all waste from electronic and electrical appliances which have reached their end- of- life period or are no longer fit for their original intended use and are destined for recovery, recycling or disposal.

- It includes computer and its accessories monitors, printers, keyboards, central processing units; typewriters, mobile phones and chargers, remotes, compact discs, headphones, batteries, LCD/Plasma TVs, air conditioners, refrigerators and other household appliances.

- The composition of e-waste is diverse and falls under ‘hazardous’ and ‘non-hazardous’ categories.

- Broadly, it consists of ferrous and non-ferrous metals, plastics, glass, wood and plywood, printed circuit boards, concrete, ceramics, rubber and other items.

TOXIC SUBSTANCES PRESENT IN E-WASTE



- Iron and steel constitute about 50% of the waste
- Plastics - 21%
- Non-ferrous metals - 13% and other constituents.
- Non-ferrous metals consist of metals like copper, aluminum and precious metals like silver, gold, platinum, palladium and so on.
- The presence of elements like lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants beyond threshold quantities make e-waste hazardous in nature.
- It contains over 1000 different substances, many of which are toxic, and creates serious pollution upon disposal.
- Obsolete computers pose the most significant environmental and health hazard among the e-wastes

E-waste generation:

- All over the world, the quantity of electrical and electronic waste generated each year, especially computers and televisions, has assumed alarming proportions.
- In 2006, the International Association of Electronics Recyclers (IAER) projected that 3 billion electronic and electrical appliances would become WEEE or e-waste by 2010. That would tantamount to an **average e-waste generation rate of 400 million units a year till 2010.**
- Globally, about 20-50 MT (million tonnes) of e-wastes are disposed off each year, which accounts for 5% of all municipal solid waste.

INDIA SCENARIO OF E-WASTE

In India about 200,000 MT of e-waste is generated annually.

There are only two sectors which carry out e-waste recycling process formally in India. These facilities are M/s. Trishiraya recycling facility, Chennai and M/s. E-Parisara, Bengaluru

- According to the Comptroller and Auditor- General's (CAG) report, over 7.2 MT of industrial hazardous waste, 4 lakh tonnes of electronic waste, 1.5 MT of plastic waste, 1.7 MT of medical waste, 48 MT of municipal waste are generated in the country annually.
- In 2005, the Central Pollution Control Board (CPCB) estimated India's e-waste at 1.47 lakh tonnes or 0.573 MT per day.
- A study released by the Electronics Industry Association of India (ELCINA) at the electronics industry expo – "Componex Nepcon 2009" had estimated the total e-waste generation in India at a whopping 4.34 lakh tonnes by end 2009.
- The CPCB has estimated that it will exceed the 8 lakh tonnes or 0.8 MT mark by 2012.
- The main sources of electronic waste in India are the government, public and private (industrial) sectors, which account for almost 70 per cent of total waste generation.
- The contribution of individual households is relatively small at about 15 per cent; the rest being contributed by manufacturers. Though individual households are not large contributors to waste generated by computers, they consume large quantities of consumer durables and are, therefore, potential creators of waste.
- An Indian market Research Bureau (IMRB) survey of 'E-waste generation at Source' in 2009 found that out of the total e-waste volume in India, televisions and desktops including servers comprised 68 per cent and 27 per cent respectively.
- Imports and mobile phones comprised of 2 per cent and 1 per cent respectively.

Electronic waste in the global context:

- As the fastest growing component of municipal waste across the world, it is estimated that more than 50 MT of e-waste is generated globally every year.
- A report of the United Nations predicted that by 2020, e-waste from **old computers** would jump by 400 per cent on 2007 levels in China and by 500 per cent in India.
- Additionally, e-waste from **discarded mobile phones** would be about seven times higher than 2007 levels and, in India, 18 times higher by 2020.
- China already produces about 2.3 million tonnes of e-waste domestically, second only to the **U.S. with about three million tonnes**.
- The EU and the U.S. would account for maximum e-waste generation during this current decade.
- As per the Inventory Assessment Manual of the UNEP, 2007, it is estimated that the total e-waste generated in the EU is about 14-15 kg per capita or 5MT to 7MT per annum.
- In countries like India and China, annual generation per capita is less than 1kg.

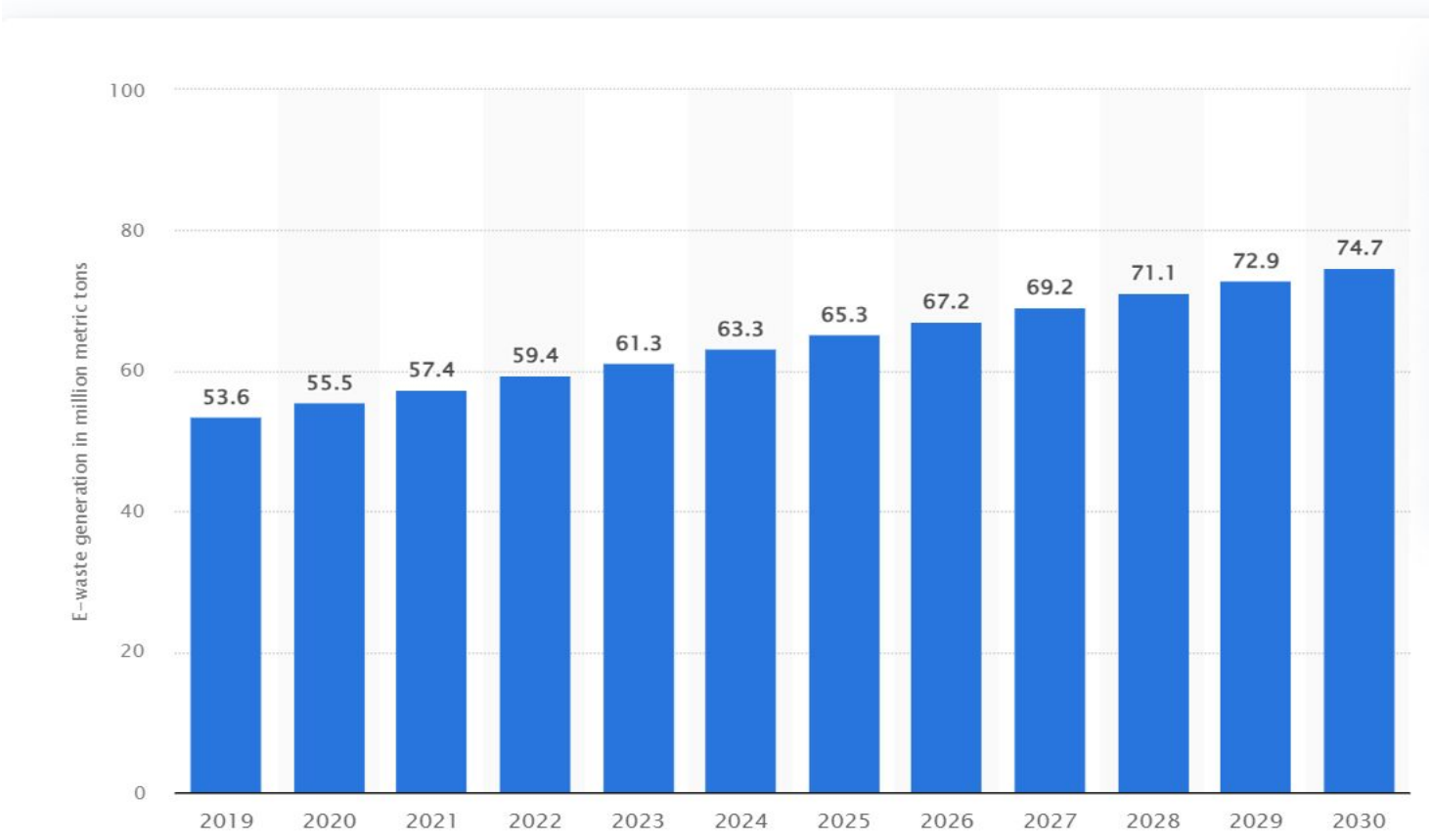
These Countries Generate the Most Electronic Waste

Top 10 countries by the amount of e-waste generated in 2016*

	Total E-Waste generated (million metric tons)	kg per capita
China	7.2	5.2
United States	6.3	19.4
Japan	2.1	16.9
India	2.0	1.5
Germany	1.9	22.8
Brazil	1.5	7.4
Russia	1.4	9.7
France	1.4	21.3
Indonesia	1.3	4.9
Italy	1.2	18.9

* includes discarded products with a battery or plug including mobile phones, laptops, televisions, refrigerators, electrical toys and other electronic equipment

Projected electronic waste generation worldwide from 2019 to 2030 (in million metric tons)



- In Europe, e-waste contributes up to 6 million tonnes of solid waste per annum.
- The e-waste generation in the EU is expected to grow at a rate of 3 per cent to 5 per cent per year.
- In the past, e-waste had increased by 16 per cent to 28 per cent every five years which is three times faster than average annual municipal solid waste generation.
- In the U.S., e-waste accounts for 1 to 3 per cent of the total municipal waste generation.
- As per the United States Environmental Protection Agency (USEPA), it generated 2.6 MT of e-waste in 2005, which accounted for 1.4 per cent of total wastes.

Electronic waste is generated by three major sectors in the U.S.:

- Individuals and small businesses;
- Large businesses, institutions and governments; and
- Original equipment manufacturers (OEMs)

E-waste pollutants:

- Pollutants or toxins in e-waste are typically concentrated in circuit boards, batteries, plastics, and LCDs (liquid crystal displays). Pollutants and their occurrence in waste electrical and electronic equipment are:

Pollutants	Occurrence
Arsenic	Semiconductors, diodes, microwaves, LEDs (Light-emitting diodes), solar cells
Barium	Electron tubes, filler for plastic and rubber, lubricant additives
Brominated flame-proofing agent	Casing, circuit boards (plastic), cables and PVC cables
Cadmium	Batteries, pigments, solder, alloys, circuit boards, computer batteries, monitor cathode ray tubes (CRTs)
Chrome	Dyes/pigments, switches, solar

Pollutants	Occurrence
Cobalt	Insulators
Copper	Conducted in cables, copper ribbons, coils, circuitry, pigments
Lead	Lead rechargeable batteries, solar, transistors, lithium batteries, PVC (polyvinyl chloride) stabilizers, lasers, LEDs, thermoelectric elements, circuit boards
Liquid crystal	Displays
Lithium	Mobile telephones, photographic equipment, video equipment (batteries)
Mercury	Components in copper machines and steam irons; batteries in clocks and pocket calculators, switches, LCDs
Nickel	Alloys, batteries, relays, semiconductors, pigments
PCBs (polychlorinated biphenyls)	Transformers, capacitors, softening agents for paint, glue, plastic
Selenium	Photoelectric cells, pigments, photocopiers, fax machines
Silver	Capacitors, switches (contacts), batteries, resistors
Zinc	Steel, brass, alloys, disposable and rechargeable batteries, luminous substances

E waste hazardous properties

Hazarrdous Waste

- Hazardous waste is a waste with properties that results in harmful effect in environment and biological organism.

Properties of Hazardous Waste

- ignitability, or something flammable
- corrosivity, or something that can rust or decompose
- reactivity, or something explosive
- toxicity, or something poisonous

(i) Ignitability

A waste is an ignitable hazardous waste, if it has a flash point of **less than 60C**; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidiser.

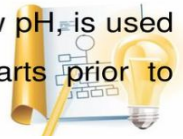
Naphtha, lacquer thinner, epoxy resins, adhesives and oil based paints are all examples of ignitable hazardous wastes.

ii) Corrosivity

A liquid waste which has a pH of **less than or equal to 2 or greater than or equal to 12.5** is considered to be a corrosive hazardous waste.

Sodium hydroxide, a caustic solution with a high pH, is often used by many industries to clean or degrease metal parts.

Hydrochloric acid, a solution with a low pH, is used by many industries to clean metal parts prior to painting.



(iii) Reactivity

A material is considered a reactive hazardous waste, if it is **unstable, reacts violently with water, generates toxic gases** when exposed to water or corrosive materials, or if it is capable of detonation or explosion when exposed to heat or a flame.

Examples of reactive wastes would be waste **gunpowder, sodium metal** or wastes containing cyanides or sulphides.

(iv) Toxicity

To determine if a waste is a toxic hazardous waste, a representative sample of the material must be subjected to a **test conducted** in a certified laboratory.

The toxic characteristic identifies wastes that are likely to leach **dangerous concentrations of toxic chemicals** into ground water.

Effects of pollutant (E- waste) on human health and surrounding environment

Listed in the table below are the harmful elements in the compositions of electrical and electronic appliances that can be hazardous to health and environment:[49]

Metal	Danger
Lead	A neurotoxin that affects the kidneys and the reproductive system. High quantities can be fatal. It affects mental development in children. Mechanical breaking of CRTs (cathode ray tubes) and removing solder from microchips release lead as powder and fumes.
Plastics	Found in circuit boards, cabinets and cables, they contain carcinogens. BFRs or brominated flame retardants give out carcinogenic brominated dioxins and furans. Dioxins can harm reproductive and immune systems. Burning PVC, a component of plastics, also produces dioxins. BFR can leach into landfills. Even the dust on computer cabinets contains BFR.
Chromium	Used to protect metal housings and plates in a computer from corrosion. Inhaling hexavalent chromium or chromium 6 can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer.

Mercury	Affects the central nervous system, kidneys and immune system. It impairs foetus growth and harms infants through mother's milk. It is released while breaking and burning of circuit boards and switches. Mercury in water bodies can form methylated mercury through microbial activity. Methylated mercury is toxic and can enter the human food chain through aquatic.
Beryllium	Found in switch boards and printed circuit boards. It is carcinogenic and causes lung diseases.
Cadmium	A carcinogen. Long-term exposure causes *Itai-itai* disease, which causes severe pain in the joints and spine. It affects the kidneys and softens bones. Cadmium is released into the environment as powder while crushing and milling of plastics, CRTs and circuit boards. Cadmium may be released with dust, entering surface water and groundwater.
Acid	Sulphuric and hydrochloric acids are used to separate metals from circuit boards. Fumes contain chlorine and sulphur dioxide, which cause respiratory problems. They are corrosive to the eye and skin.

- Mercury is mobile and poisonous in any form - inorganic, organic or elemental. Its organic compound methyl mercury has been scientifically proved to be a neuro-toxicant that damages the brain.
- Mercury is known to cause severe and permanent damage to the central nervous system, lungs and kidneys.
- It can trigger depression and suicidal tendencies and cause paralysis, Alzheimer's disease, speech and vision impairment, allergies.

Common E-waste Disposal Methods

There are a few different ways to dispose of e-waste that have historically been employed; each come with their own set of environmental issues.

Landfilling

This refers to the practice of essentially digging a massive hole in the ground, filling it with waste and then covering it back up with soil. While the pits are lined with clay or plastic with a leachate basin to prevent toxic waste from leeching into the surrounding environment, some substances such as cadmium, lead, and mercury inevitably finds their way into the soil and groundwater, causing contamination.

Acid Bath

Soaking electronic circuits in powerful sulphuric, hydrochloric, or nitric acid solutions separates metals from the electronic pathways. The metals can then be recycled and used in the manufacture of new products. However, the highly hazardous acid waste needs to be very carefully disposed of to prevent it from finding its way into local water sources – essentially trading one waste disposal problem for another.

Incineration

A very crude e-waste disposal method that involves burning the waste in an extremely high temperature incinerator. This has the twin benefit of significantly reducing the waste volume and generating energy that can be repurposed for other applications. Unfortunately, the process of burning the components which make up electronic waste also produces vast quantities of toxic gasses – including cadmium and mercury – which are released into the atmosphere.

Recycling

Many items of e-waste can be dismantled and their component parts repurposed into new products. E-waste recycling techniques can recover precious metals from circuit boards and be melted down to make new devices or used for other products such as jewellery.

Reuse

By far, the most environmentally friendly e-waste disposal technique is for, where possible, devices to be reused. Many charities will gladly accept old electronic devices that can then be refurbished and redistributed to people in more disadvantaged communities.

Basic principles of E waste management

Four Basic Principle of E-waste Management

- ✓Reduce
- ✓Reuse
- ✓Recycle
- ✓Refurbish

REDUCTION

- Product reuse
- Material volume reduction
- Toxicity reduction
- Increased product lifetime
- Decreased consumption

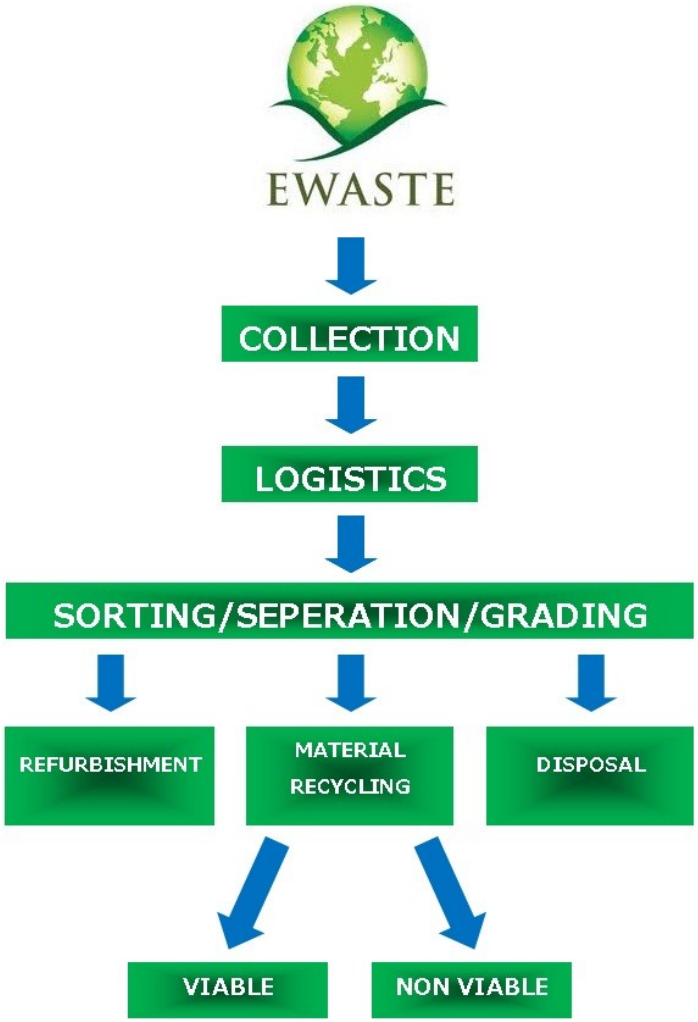
. REUSE

- Containers can be reused at home or for school projects
- Reuse wrapping paper, plastic bags, boxes, and lumber.
- Give outgrown clothing to friends or charity
- Buy beverages in returnable containers
- Donate broken appliances to charity or a local vocational school, which can use them forart classes or for students to practice repairing.
- Offer furniture and household items that are no longer needed to people in need, friends or charity.

RECYCLE

- lessens reliance on landfills and incinerators
- protects human health and the environment by removing harmful substances from the waste stream
- conserves natural resources by reducing the demand for raw materials.

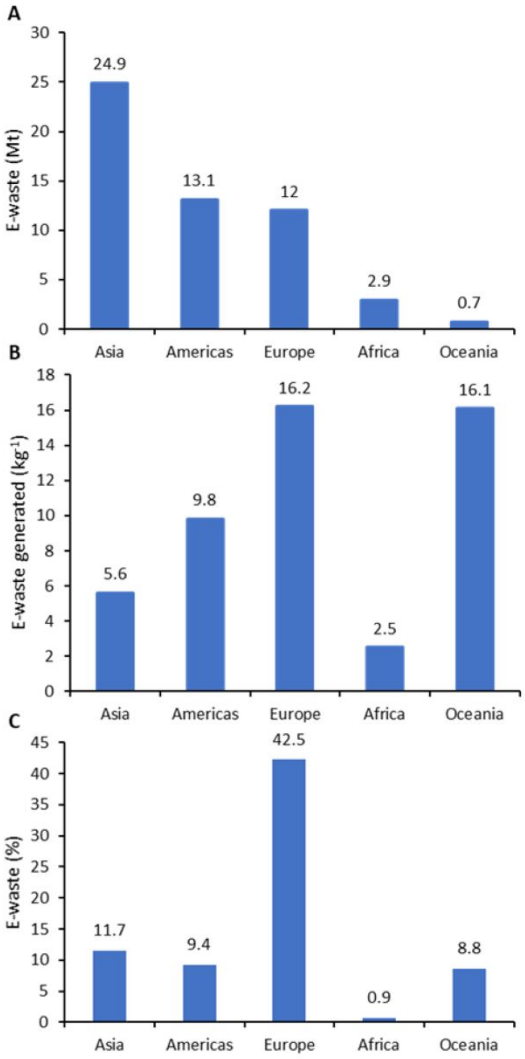
Component of E waste management



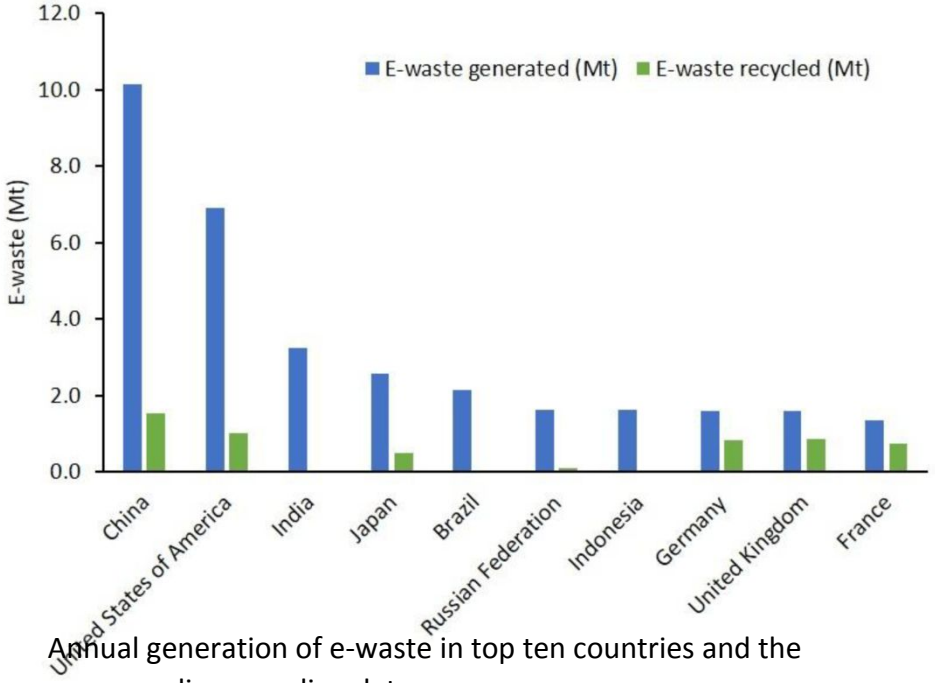
Component of E waste management

Components	Constituents	Affected body parts
Printed circuit boards	Lead & Cadmium	Nervous system and Kidney
Motherboards	Beryllium	Lungs and Skin
CRT (Cathode Rode tube)	Lead oxide, barium and cadmium	Heart, liver and muscles
Flat screen monitors	Mercury	Brain and skin
Computer	Cadmium	Kidney and liver
Cable insulating	PVC(Polyvinyl Chloride)	Immune system
Plastic housing	Bromine	Endocrine system

Resource recovery potential of e-waste



Total e-waste generation, (**B**) e-waste generated per capita and (**C**) recycling rate in various regions in 2019



Annual generation of e-waste in top ten countries and the corresponding recycling data

Technologies for recovery of resources from electronic waste

In industries management of e-waste should begin at the point of generation. This can be done by waste minimization techniques and by sustainable product design. Waste minimization in industries involves adopting:

- inventory management,
- production-process modification,
- volume reduction,
- recovery and reuse.

INVENTORY MANAGEMENT

- Proper control over the materials used in the manufacturing process is an important way to reduce waste generation.
- By reducing both the quantity of hazardous materials used in the process and the amount of excess raw materials in stock, the quantity of waste generated can be reduced.
- This can be done in two ways i.e. establishing material-purchase review and control procedures and inventory tracking system.
- Ensure that only the needed quantity of a material is ordered.

PRODUCTION-PROCESS MODIFICATION

- Changes can be made in the production process, which will reduce waste generation.
- Improvements in the operation and maintenance of process equipment can result in significant waste reduction.
- Hazardous materials used in either a product formulation or a production process may be replaced with a less hazardous or non-hazardous material.
- Installing more efficient process equipment or modifying existing equipment to take advantage of better production techniques can significantly reduce waste generation.

VOLUME REDUCTION

- Volume reduction includes those techniques that remove the hazardous portion of a waste from a non-hazardous portion.

- These techniques are usually to reduce the volume, and thus the cost of disposing of a waste material.

- For example, an electronic component manufacturer can use compaction equipment to reduce volume of waste cathode ray-tube.

RECOVERY AND REUSE

- This technique could eliminate waste disposal costs, reduce raw material costs and provide income from a salable waste.

- Waste can be recovered on-site, or at an off-site recovery facility, or through inter industry exchange.

- For example, a printed-circuit board manufacturer can use electrolytic recovery to reclaim metals from copper and tin-lead plating bath.

RESPONSIBILITIES OF THE GOVERNMENT

- Governments should set up regulatory agencies in each state, which are vested with the responsibility of coordinating and consolidating the regulatory functions of the various government authorities regarding hazardous substances.
- Governments must encourage research into the development and standard of hazardous waste management, environmental monitoring and the regulation of hazardous waste-disposal.
- Governments should enforce strict regulations and heavy fines levied on industries, which do not practice waste prevention and recovery in the production facilities.
- Governments should enforce strict regulations against dumping e-waste in the country by outsiders.
- Governments should explore opportunities to partner with manufacturers and retailers to provide recycling services.

RESPONSIBILITY AND ROLE OF INDUSTRIES

- Use label materials to assist in recycling (particularly plastics).
- Standardize components for easy disassembly.
- Re-evaluate 'cheap products' use, make product cycle 'cheap' and so that it
- has no inherent value that would encourage a recycling infrastructure.
- Create computer components and peripherals of biodegradable materials.
- Utilize technology sharing particularly for manufacturing and de manufacturing.
- Encourage / promote / require green procurement for corporate buyers.
- Look at green packaging options.

RESPONSIBILITIES OF THE CITIZEN

- Recycling raw materials from end-of-life electronics is the most effective solution to the growing e-waste problem.
- E-wastes should never be disposed with garbage and other household wastes. This should be segregated at the site and sold or donated to various organizations.
- Reuse, in addition to being an environmentally preferable alternative, also benefits society. By donating used electronics, schools, non-profit organizations, and lower-income families can afford to use equipment that they otherwise could not afford.
- Gather any unwanted chargers, accessories or batteries to recycle – find national recycling center of the company where you can take the equipment for recycling.

SUSTAINABLE PRODUCT DESIGN

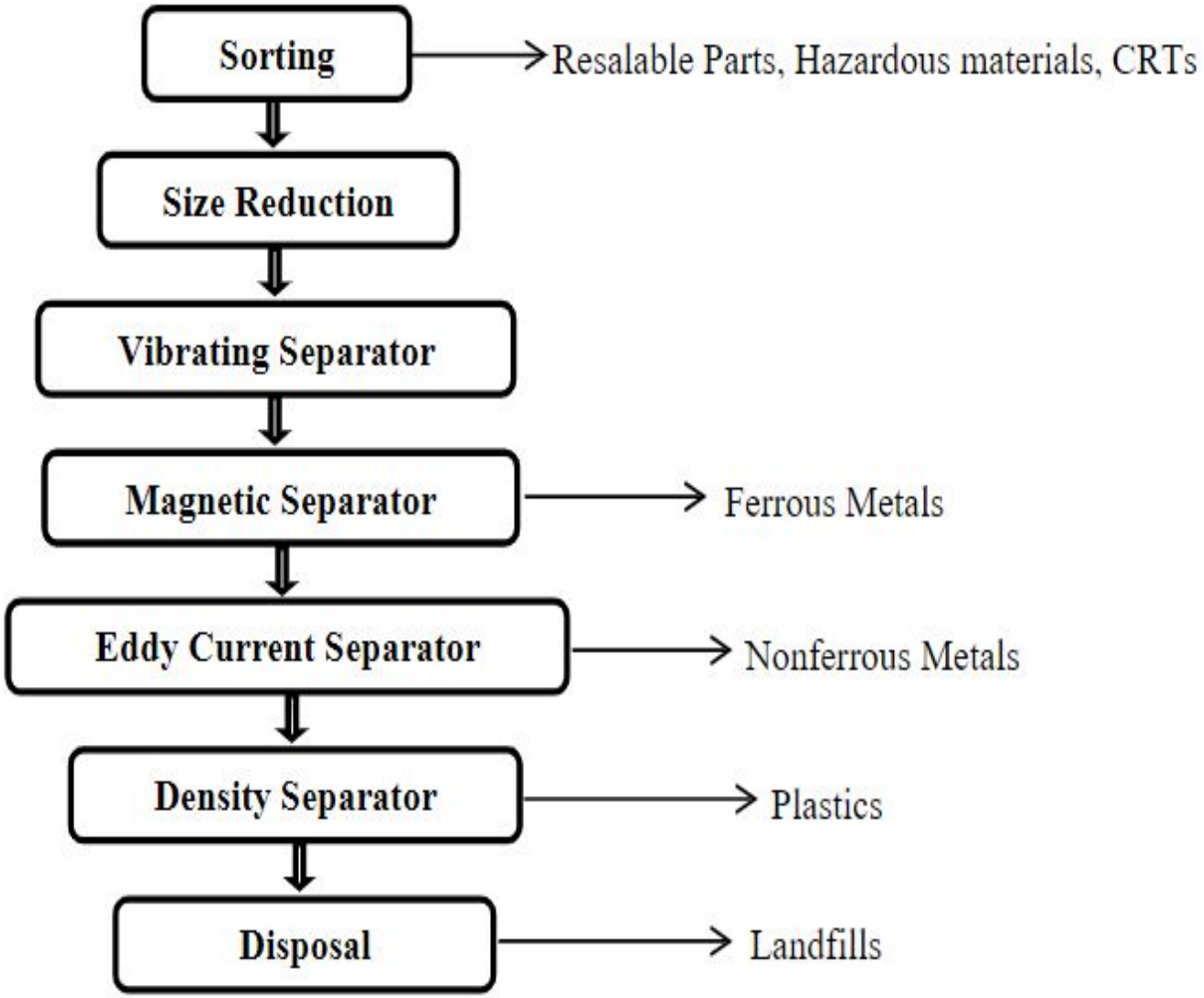
- Minimization of hazardous wastes should be at product design stage itself keeping in mind the following factors
- Rethink the product design
- Use of renewable materials and energy(e.g. use of Bio-based plastics)
- Use of non-renewable materials that are safer (ensure the product is built for re-use, repair and/or upgradeability)

Steps in recycling and recovery of materials-mechanical processing

Steps in recycling and recovery of materials-mechanical processing

- THE PROCESS E-Waste recycling process should be a balance between disassembly, mechanical separation of complex materials and metallurgical treatment.
- **First Stage** - Manual segregation of components, where different parts of E-waste are separated.
- **Second Stage** - The mechanical separation process is applied. In this process, ferrous, aluminum, plastic and non ferrous material are initially separated.
- **Third Stage** - The plastics are then recycled by plastics recycling process which further processes the plastic.
- **Fourth Stage** - The non-ferrous metals are sent to metallurgical treatment plant where the nonferrous metals are separated into constituent metals.

Schematic Diagram of Mechanical Recycling Process of WEEE



- Mechanical processes, such as screening, shape separation, magnetic separation, Eddy current separation, electrostatic separation, and jigging have been widely utilized in recycling industry.
- **Disassembly** Selective disassembly or dismantling has been an indispensable step in waste recycling because of reuse priority, removal of selective hazardous components and separation of precious/desirable parts such as printed circuit boards, cables, and plastics. It is also crucial for simplification of subsequent steps in pursuit of recovery of materials. Dismantling remains a manual process with application of various tools for increased efficiency and lower time. However, it may be a costly affair to perform manual dismantling of products containing lowgrade precious metals and copper like TV sets, video etc.

- **Screening and Shape Separation**:

Screening is very significant step for size uniformity as well as upgrading metal content. As the particle size-shape properties of metals differ from plastics and ceramics, this process can play a crucial role in making metal rich streams. Rotating screens have been significantly used for metal recovery. Rotating screen shows high resistance to blinding, which helps in the process as the particle shapes and sizes are highly varying in electronic waste. Another widely accepted technique is vibratory screening specifically for non-ferrous recovery sites. Shape separation has played an important role in controlling particle properties. Tilted plate and sieves are the most common approach while inclined conveyor and vibrating plate have also been used to recover metals from waste cable, printed circuit boards, TV and personal computers

- **Magnetic Separation:**

Magnetic separators have been extensively used for separation of ferromagnetic materials. Low-intensity drum separators separates ferromagnetic metals from non-ferrous/nonmagnetic materials in waste stream. With latest advancements in High-intensity magnetic separators, it is now possible to separate copper alloys from the waste matrix.

Electric Conductivity based Separation:

Based on different electric conductivity of materials, it is possible to separate them through Electric conductivity-based separation. Eddy current separation, Corona electrostatic separation, and Triboelectric separation are major techniques based on this concept. Eddy current separators have been highly successful in the recovery non-ferrous metals from shredded coarse size electronic scrap. Electrostatic separator with application of corona charging separates raw materials into conductive and non-conductive fractions. The extreme difference in the electric conductivity of metals and non-metals forms the basis of corona electrostatic separation electronic waste recycling. Recovery of copper, aluminum and precious metals from electronic scrap has been performed using this technique. Triboelectric separation separates plastics based on the difference in electric properties, which has been highly desirable for plastic recovery and refining.

- **Density/Gravity based Separation**:

Heavy materials can be separated from lighter ones based on their density difference. This serves as the principle for density based separation and has been extensively applied for the separation of metals from non-metals. Gravity concentration works on the fact that materials of different specific gravity have different relative movement in response to the force of gravity and other forces like resistance by fluid (air/water). Particle motion in a fluid is affected by multiple factors including particle's density, size as well as shape so size control of feed determines the effectiveness of gravity/density processes. Jigging is one of the widely used methods of gravity concentrations in mineral processing industry for concentrating relatively coarse materials. With a fairly uniform feed size, good separation of a narrow gravity range can be achieved, acting as an efficient way for sorting small pieces of metals. Heterogeneity and high complexity of electronic waste makes it difficult to be separated by jigging process

Technologies for recovery of materials

- Pyro-metallurgy
- Hydrometallurgy
- Bio-metallurgy

PROCESSES FOR RECYCLING

Mechanical-physical separation

Liberation of materials from their interlocked state physically by comminution and separation of valuable materials into concentrates.

- Comminution - shredding and screening
- Separation - shape separation, density separation, magnetic separation, eddy current separation and electrostatic separation

Pyrometallurgical processes

Extraction and purification of metals by processes involving the application of heat.

- Smelting, incineration, combustion, pyrolysis, molten salt, and pyrochemical processes.

Hydrometallurgical processes

Selective leaching of metallic compounds to form a solution from which the metals can be precipitated and recovered.

- Leaching, precipitation, solvent extraction, and resin ion exchange.

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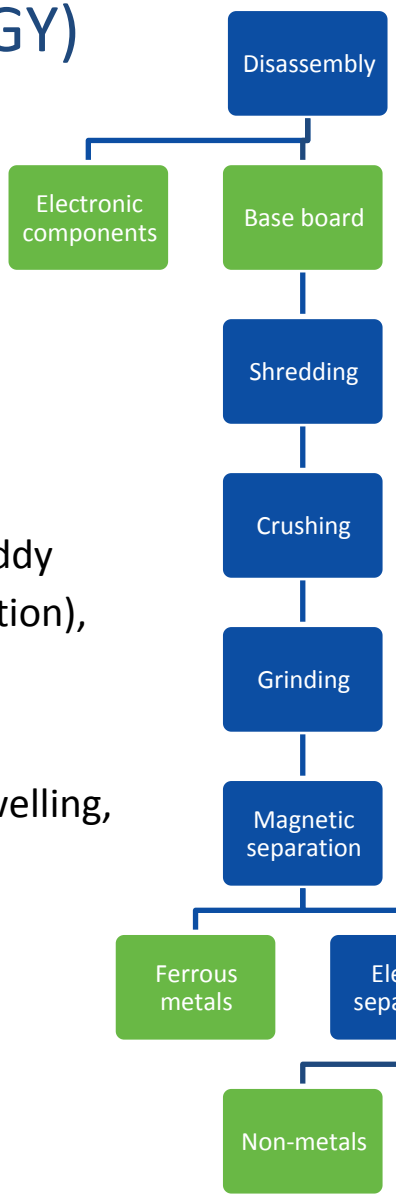
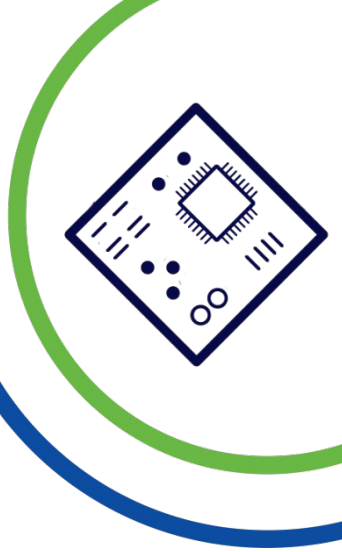
PRE-TREATMENT (HYDROMETALLURGY)

- Disassembly
  - Manual (labor intensive),
  - automated (melting of solder joints).
- Size reduction (optional) :
  - Shredding, crushing and grinding.
- Enrichment (optional) – separation:
  - Size and shape, magnetism, electric conductivity (eddy current, corona electrostatic or triboelectric separation), density.
- Chemical pre-treatment
  - Solder mask dissolving, solder dissolving, organic swelling, supercritical depolymerization, resin dissolving.





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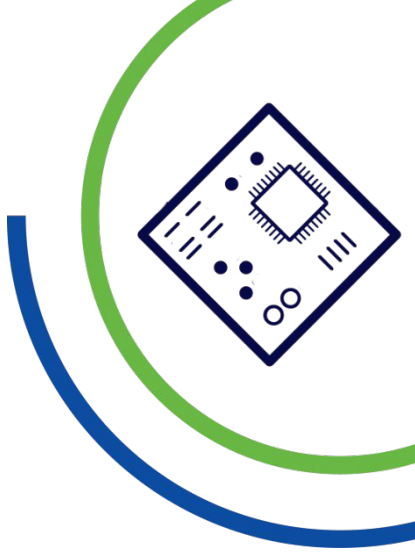
LEACHING OF METALS (HYDROMETALLURGY)



- Transfer of metals from solid materials to a solution
- Traditional leaching methods
  - Leaching of base and precious metals using mineral acids.
    - Mineral acids only - H_2SO_4, HNO_3, HCl and aqua regia ($HCl:HNO_3$ = 3:1, v/v).
    - Using mineral acid and oxidant - metals with high reduction potentials.
    - Multi-stage leaching – selective leaching of metals.
  - Cyanide-based leaching of precious metals
- Mild leaching methods
  - Thiourea leaching of precious metals – acid or alkaline thiourea
  - Thiosulfate leaching of precious metals ($S_2O_3^{2-}$)
  - Thiocyanate leaching of precious metals
  - Halide leaching of precious metals
  - Ammonia-ammonium leaching of base metals
- Novel leaching methods
  - Chelating leaching of base metals
  - Ionic liquid leaching of base metals
  - Supercritical leaching of base and precious metals

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Pre-treatment | Leaching | Purification | Recovery

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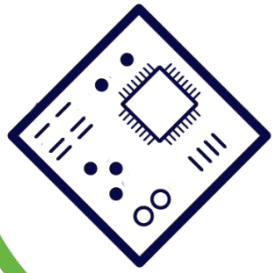
PURIFICATION AND RECOVERY (HYDROMETALLURGY)



- Purification – removal of harmful substances from solutions
- Recovery – precipitation of the dissolved metals and their recovery in solid form.
- Various methods:
  - Chemical precipitation – displacement reaction (more active metal replaces less active metal in solution)
    - Cementation – Fe replaces Cu; base metals replace precious metals.
    - pH adjustment, using other chemicals for precipitations
  - Solvent extraction (metals are passed from the leach solution into extraction solution and the two phases are then separated).
  - Activated carbon adsorption - Au and Ag recovery from cyanide leaching solutions.
  - Ion exchange by resin – comparable to adsorption with activated carbon often with higher adsorption and recovery rates
  - Electrodeposition – utilization of simple electric device with minimal chemicals input – environmental point of view.

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Pre-treatment | Leaching | Purification | Recovery

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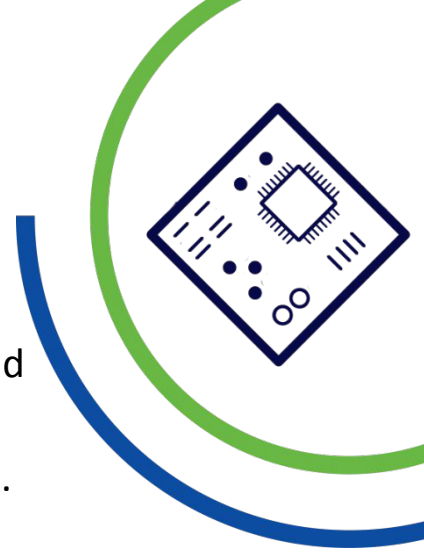
PYROMETALLURGY (PCBs)



- Pre-treatment (dismantling of electronic components, grinding)
- Incineration
  - Aerobic conditions – organic components are thermally decomposed and combusted at high temperature.
  - Glass-fibers and metal oxides (recycled by physical separation methods).
- Pyrolysis
  - Thermochemical decomposition of organic resins in anaerobic conditions.
  - Pyrolysis products (oil and gasses) and residues (glass fibers and metals)
- Plasma
  - Decomposition of organic matter to gasses and melting of glass fibers.
  - Gasses, vitreous body (molten glass fibers), metals.
- Molten salt
  - Molten salt (stable and inert) is used to separate liquid or solid-state metal products at high temperature.

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Pre-treatment | Pyrometallurgical processing | Physical separation

Source: https://www.sciencedirect.com/science/article/pii/S0921344917302409

- Biometallurgy has been utilised in the form of bioleaching for metal extraction and biosorption for metal recovery in mineral processing.
- Bioleaching has been tested for potential metal recovery from electronic scrap material yet it remains at naïve state for lab scale operations

occupational and environmental health perspectives of recycling e-waste in India.

Table 2 The common processes of recycling various computer components and potential occupational and environmental hazard

Computer component	*Common process of recycling*	*Potential occupational hazard*	*Potential environmental hazard*
Cathode ray tubes/monitors	Breaking, removal of copper yoke, recycling of glass	Silicosis, cut injury, inhalation or direct contact with phosphor containing cadmium and other metals such as lead, mercury	Release of lead, mercury, barium, toxic phosphor, and other heavy metals into water and soil
Printed circuit board	De-soldering and removing of computer chips	Inhalation of tin, lead, dioxin, beryllium, cadmium, mercury	Air emission of metals and dioxin
Dismantled printed circuit board	Burning of waste boards to remove chips and final metals	Inhalation of tin, lead, dioxin, beryllium, cadmium, mercury, and respiratory irritation	Tin and lead contamination of soil and water, emission of brominated dioxin, beryllium, cadmium, mercury
Chips and other related components	Chemical processing using nitric acid and hydrochloric acid	Corrosive injury to eye and skin, inhalation of acid fumes and harmful gases such as chlorine and sulphur dioxide	Hydrocarbons, heavy metals, halogenated substances, acids in water and soil, and air emission

Plastics from computers and peripherals	Shredding, low temperature melting	Hydrocarbons, dioxin, and heavy metal—direct contact and inhalation	Emissions of dioxins and heavy metals and hydrocarbons
Wires and cables	Burning to recover metal wire	Inhalation of brominated and chlorinated dioxin, PAHs (polycyclic aromatic hydrocarbons)	Emission of brominated and chlorinated dioxin, PAHs
Miscellaneous computer parts enveloped in rubber	Burning to recover metals	Inhalation of dioxin, PAHs	Emission of dioxin, PAHs
Toner cartridges	Brushes to recover toner	Respiratory irritation, unknown carcinogenic impact of carbon black, cyan, yellow and magenta toners	Soil and water pollution
Secondary steel, copper, and precious metal smelting	Furnace to recover steel and copper	Heat injury, inhalation of dioxins and heavy metals	Emission of dioxins and heavy metals