THERMAL TREATMENT

- Thermal processing significantly helps in volume reduction and energy recovery, making it a key component of ISWM. Typically applied after recycling and organic waste processing.

Thermal Processes

1. **Combustion** – thermal destruction in the present of oxygen
    - ***Incineration:*** Combustion to destroy waste significantly to reduce its volume.
    - ***Co-generation:*** Simultaneously generates electricity and useful heat from the combustion of MSW
    - ***Energy from waste:*** heat generated is captured and converted to energy.
    - ***Co-incineration:*** Combustion of solid or liquid waste in industrial processes not primarily designed for waste disposal.
2. **Pyrolysis** – thermal processing in the absence of oxygen
3. **Gasification** – partial combustion to generate a combustible gas

STOICHIOMETRIC COMBUSTION: BASIC REACTIONS

- Combustion of Carbon (C): $$\underset{12}{C} + \underset{32}{O_2} \rightarrow \underset{44}{CO_2}$$

- Combustion of Hydrogen (H_2): $$\underset{4}{2H_2} + \underset{32}{O_2} \rightarrow \underset{36}{2H_2O}$$

- Combustion of Sulfur (S): $$\underset{32}{S} + \underset{32}{O_2} \rightarrow \underset{64}{SO_2}$$

STOICHIOMETRIC COMBUSTION

- The quantity of oxygen required for the complete combustion of fuel will be,

$$= (32/12\ C + 32/4\ H + 32/32\ S - O)\ \text{kg}$$

$$= (32/12\ C + 8\ H + S - O)\ \text{kg}$$

Where C, H, O and S are expressed per kg

NUMERICAL

Q. Calculate the total amount of air required for the combustion of propane, which is the main constituent of LPG, having 0.04% oxygen.

SOLUTION

The chemical reaction involving propane (C_3H_8) is

$$C_3H_8 + 5\ O_2 = 3\ CO_2 + 4\ H_2O$$

$$44\ \text{kg} + 160\ \text{kg} \quad 132\ \text{kg} + 72\ \text{kg}$$

44 kg of propane requires 160 kg of oxygen to form 72 kg of water and 132 kg of CO_2.

1 kg of propane requires 160/44 kg = 3.64 kg of oxygen for combustion.

The oxygen already available in fuel is 0.04 kg.

So, additional oxygen required = 3.64 – 0.04 = 3.6 kg.

The air contains 23% of oxygen by weight.

So, the quantity of air required = 3.64/0.23 = 15.65 kg of air

Air requirement in volume = 15.65 /1.29 = 12.13 m^3

NUMERICAL

Q. A coal sample has the following elemental composition by weight:

Carbon (C) = 82%

Hydrogen (H) = 7%

Nitrogen (N) = 3.5%

Sulfur (S) = 1%

Oxygen (O) = 2%

The remainder is ash.

Calculate the minimum volume of air required for the complete combustion of 7 kg of this fuel sample. Express the air requirement in m^3.

Coal composition	Per kg
C = 82%	0.82
H = 7%	0.07
N = 3.5%	0.035
S = 1%	0.01
O = 2%	0.02
Ash = 4.5%	0.045

The minimum quantity of oxygen required per kg of coal

$= 32/12\ C + 8\ H + S - O$

$= (32/12 \times 0.82) + (8 \times 0.07) + 0.01 - 0.02$

$= 2.19 + 0.56 + 0.01 - 0.02$

$= 2.74$ kg

For 1 kg of coal, oxygen required = 2.74 kg

$\therefore$ For 7 kg of coal, oxygen required = $2.74 \times 7 = 19.18$ kg

SOLUTION

Assuming air to be a mixture of 77% nitrogen and 23% oxygen by weight, the minimum quantity of air required for 7 kg coal = 19.18 x 100/23 = 83.39 kg

To calculate volume of air required,

$$= 83.39 / 1.29 = 64.64 \text{ m}^3$$

SOLUTION

EXCESS AIR

- The main goal of combustion is to completely destroy organic waste and convert it into non-toxic gases.
- Due to the non-uniform nature of MSW, the process requires excess air for complete combustion.
- Excess air is usually 120 – 200% of the design requirement.
- However, supplying too much oxygen can lower the combustion temperature, reducing efficiency.

NUMERICAL

Determine the amount of air required per hour for the combustion of an MSW with the following molecular formula:

$\mathbf{C_{760}H_{1980}O_{875}N_{13}S}$

The operating conditions are:

- Waste feed rate: 500 tonnes/day (on a dry basis)
- Excess air requirement: 175% per tonne of waste
- Incinerator operation: Continuous (24 hours/day, 7 days/week)

- **Molar Mass of the Waste**

Using atomic weights,

Molar mass = (760×12)+(1980×1)+(875×16)+(13×14)+(1×32)

= 25314 g/mol

- **Elemental Weight Percentages**

$$C = \frac{760 \times 12}{25314} = 0.360$$

$$H = \frac{1980 \times 1}{25314} = 0.078$$

$$O = \frac{875 \times 16}{25314} = 0.553$$

$$N = \frac{13 \times 14}{25314} = 0.007$$

$$S = \frac{1 \times 32}{25314} = 0.001$$

SOLUTION

- **Waste processing rate**

$$= \left(500 \frac{\text{tonne}}{\text{day}} \times \frac{1\,\text{day}}{24\,\text{hour}} \times \frac{1000\,\text{kg}}{\text{tonne}} \right) = 20{,}833\,\text{kg/hr}$$

- **Oxygen required for complete combustion**

$$= \left(\frac{32}{12} \cdot 0.360 \right) + (8 \cdot 0.078) + 0.001 - 0.553$$

$$= 1.032\,\text{kg of } O_2 \text{ per kg of waste}$$

- **Air contains 23% oxygen by weight**

Air required per kg of waste:

$$= \frac{1.032}{0.23} = 4.487\,\text{kg}$$

SOLUTION

- **Volume of air per kg of waste**

$$= 4.487/1.29 = 3.478\ m^3$$

- **Excess air = 175%**

Total air required per kg of waste

$$= 3.478 \times 1.75 = 6.0865\ m^3/kg$$

- **Multiply with waste rate**

Total air required per h

$$= 6.0865 \times 20833$$

$$= 126800\ m^3/h$$

SOLUTION

THE 3 T OF EFFICIENT COMBUSTION

1. Temperature

- Must be high enough to ignite all waste components.
- Below 790°C: leads to release of odorous compounds.
- Above 980°C: helps minimize dioxins, furans, and VOCs.

2. Time

- Sufficient residence time is needed to ensure complete combustion.

3. Turbulence

- Promotes thorough mixing of waste with oxygen.
- Ensures efficient burning in both solid and gaseous phases for maximum destruction of pollutants.

COMBUSTION PROCESS

Phase 1 – Drying Phase

- Moisture is evaporated from the waste at temperatures up to 150°C. No combustion occurs yet—just water removal.

Phase 2 – Volatilization

- Combustible vapors and gases are released as volatile organics reach their flash points (150°C–700°C). These vapors begin to ignite and sustain the combustion process.

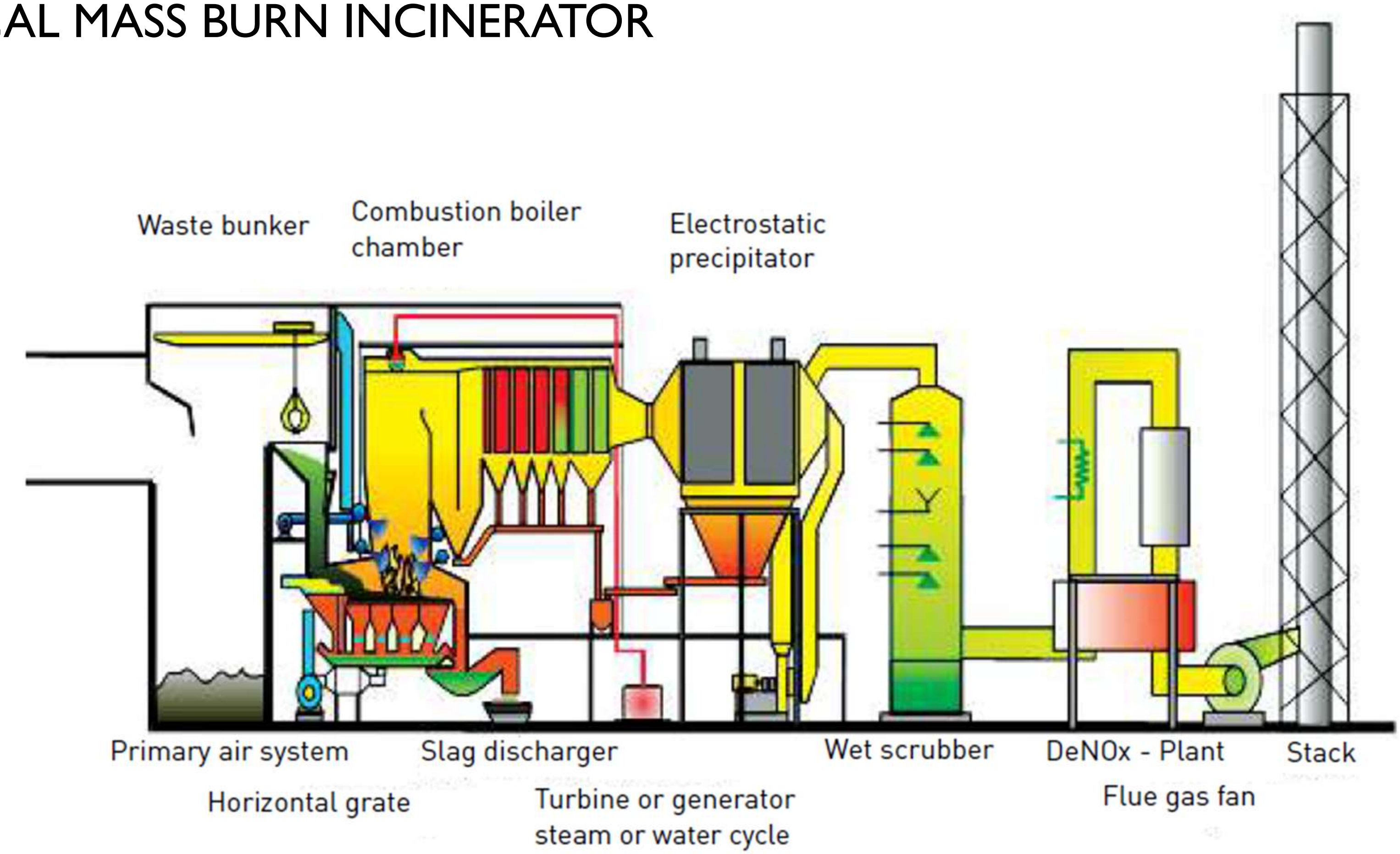
Phase 3 – Combustion of Solids

- The remaining fixed carbon (e.g., cellulose, lignin) undergoes oxidation at 700°C–1100°C. This is the main energy-generating phase of the process.

Phase 4 – Final Char Burn-down

- Residual char is fully combusted, leaving behind bottom ash. After cooling on the grate, the ash is collected in a dry hopper for disposal.

TYPICAL MASS BURN INCINERATOR



Source: Municipal solid waste Management manual, Part II: The manual, *CPHEEO* (2016)

PYROLYSIS

- Pyrolysis is the thermal decomposition of organic materials in the absence of oxygen.
- Operates at 500°C to 800°C
- Also called destructive distillation, carbonization, or thermal cracking.
- It is an endothermic reaction – requires external heat (unlike incineration).

Primary products:

  - **Gas:** Combustible gases like H_2, CH_4, CO, CO_2, and hydrocarbons.
  - **Liquid:** Tar, pitch, light oils, and low-boiling organics like methanol, acetone, acetic acid
  - **Char:** Carbon-rich solid residue with inert materials (e.g., ash, metals).

- Part of the gas or char is often reused to heat the reactor.
- After self-sustaining heat is applied, excess energy can be harnessed for commercial use.

GASIFICATION

- A thermochemical process that converts organic or fossil-based materials (e.g., plastics, biomass, MSW) into syngas (synthetic gas).
- Performed under high temperatures (≥ 650°C) with a controlled supply of air, oxygen, or steam.
- Unlike incineration, gasification involves partial combustion, not full oxidation.
- Primary Products:
    - Syngas: Mainly CO, H_2, CH_4
    - Liquid: Tar and oil
    - Solid residue (ash): Non-combustible material with low carbon content.
- The process is mostly exothermic, but some heat input may be needed initially.
- Lower emissions than direct incineration (with proper controls)

Parameter	Combustion	Pyrolysis	Gasification
Oxygen Supply	Stoichiometric or Excess air	No oxygen, In absence of air	Controlled oxygen, Sub-stoichiometric supply of air
Operating Temperature	800–1100°C	500–800°C	650–1200°C
Reaction Type	Exothermic (self-sustaining)	Endothermic (requires external heat)	Mostly exothermic (may need start-up heat)
End Products	Flue gases (CO_2, H_2O, SO_2, NO_x), ash	Syngas, bio-oil (tar), and char	Syngas (CO, H_2, CH_4), tar, ash
Energy Recovery	Possible, heat and/or electricity	Possible, but less direct (requires refining of products)	Electricity, fuels, chemical feedstocks
Energy Efficiency	Moderate (~15–25%)	Low to Moderate	Moderate to High (~30–50%)
Byproducts	Bottom ash, fly ash (needs disposal/treatment)	Char and tar (can be used as fuel or for recovery)	Ash (inert), some tar or slag
Emission Control Needs	High (dioxins, furans, acidic gases)	Moderate (depending on system)	Moderate (cleaning of syngas required)
Feedstock Requirements	Must be dry and well-segregated	Moisture-sensitive, pre-treatment may be needed	Needs uniform feed; low moisture preferred
Commercial Maturity	Widely used, proven technology	Developing; limited large-scale use	Emerging, more common in industrial/energy applications
Environmental Impact	High unless well controlled	Low if well managed	Lower than combustion, cleaner energy output

- **Solid Waste Management**
  1. Waste generation
  2. On-site handling, storage, and processing
  3. Collection
  4. Transfer and transport
  5. Processing and recovery, and
  6. **Disposal**

LANDFILL

- Landfills are the physical facilities used for the disposal of solid wastes on the surface of the earth.
- Landfill can present problems with respect to:
  - Spread of disease
  - Odors
  - Fires
  - Contamination of groundwater
  - Gas emissions

MODERN LANDFILLS ARE ENGINEERED STRUCTURES

- Modern landfills are scientifically designed, constructed, operated, and monitored in accordance with strict environmental regulations to minimize risks.
- Landfills are specifically engineered to prevent contamination of soil, air, and groundwater from waste materials.
- Help control hazards such as rodent and pest infestation, fire outbreaks, bird menace, slope failures, and erosion.
- Waste categories suitable for landfills are the following:
  - i. Non-biodegradable and inert waste by nature or through pretreatment;
  - ii. Pre-processing and post-processing rejects from waste processing sites; and
  - iii. Non-hazardous waste not being processed or recycled.

LANDFILL-RELEVANT PHYSICAL PROPERTIES

a. Field Capacity:

- Max moisture waste retains without leachate
- **Importance:** Helps estimate leachate volume

b. Permeability:

- Definition: Ability of liquids/gases to pass through
- **Importance:** Affects leachate flow and gas collection

c. Compressibility:

- Definition: Degree of volume reduction under load
- **Importance:** Impacts landfill settlement and lifespan

Bulk Density of Mixed Materials:

$$\frac{M_A + M_B}{\left[\frac{M_A}{\rho_A} + \frac{M_B}{\rho_B}\right]} = \rho_{(A+B)}$$

M_A = mass of material A

M_B = mass of material B

ρ_A = bulk density of material A

ρ_B = bulk density of material B

Volume Reduction/ Compaction Ratio (CR):

$$\%\text{reduction} = \frac{V_{uncomp} - V_{comp}}{V_{uncomp}} \times 100$$

$$\%\text{Volume reduction} = \left(1 - \frac{\rho_{uncomp}}{\rho_{comp}}\right) \times 100$$

$$CR = \frac{\rho_{comp}}{\rho_{uncomp}}$$

$$\%\text{Volume Reduction} = \left(1 - \frac{1}{CR}\right) \times 100$$

NUMERICAL

For a particular community, assume that refuse has the following components and bulk densities:

Component	Percentage (by weight)	Uncompacted bulk density (lb/ft^3)
Miscellaneous paper	50	3.81
Garden waste	25	4.45
Glass	25	18.45

Assume that the compaction in the landfill is 1200 lb/yd^3 (44.4 lb/ft^3). Estimate the percent volume reduction achieved during compaction of the waste. Estimate the overall uncompacted bulk density if the miscellaneous paper is removed.

SOLUTION

The overall bulk density prior to compaction is.

$$= \frac{50 + 25 + 25}{\frac{50}{3.81} + \frac{25}{4.45} + \frac{25}{18.45}} = 4.98\ lb / ft^3$$

If the mixed paper is removed, the uncompacted density is

$$= \frac{25 + 25}{\frac{25}{4.45} + \frac{25}{18.45}} = 7.18\ lb / ft^3$$

The volume reduction achieved during compaction is

$$\left(1 - \frac{4.98}{44.4}\right) \times 100 = 88.8\%$$

So, the required landfill volume is approximately 11% of the volume required without compaction.

HOW IS A LANDFILL OPERATED?

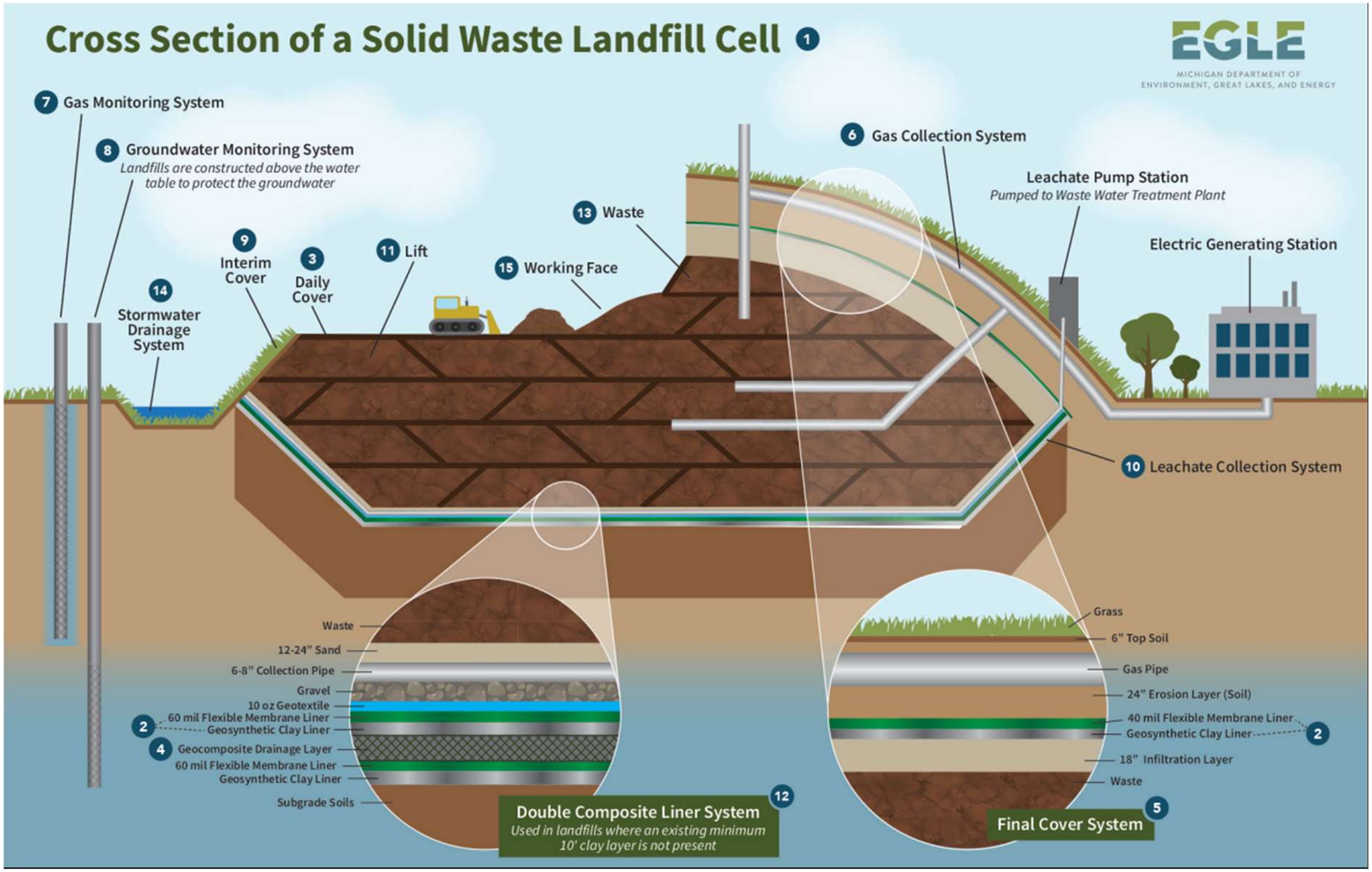
Once a suitable location is identified and approved, the structured landfill process begins:

- Waste is transported to the landfill facility, where it is sorted and directed to an open area known as a "cell."
- A cell refers to a defined volume of waste deposited during a single operating period.
- Each cell is separated from adjacent ones by engineered barriers to maintain isolation.
- The base of each cell is lined with impermeable materials like reinforced plastic, unweathered gray shale, or clay, preventing leakage into the soil or groundwater.

HOW IS A LANDFILL OPERATED?

Once the waste is deposited:

- Bulldozers and compactors compress the waste, minimizing air space and increasing storage efficiency within the cell.
- At the end of each working day, the exposed waste is covered with a daily cover—typically several inches of dirt or similar material. This:
  - Protects the waste from sun and rain
  - Prevents access by animals or scavengers
  - Prevents wind and water from dispersing loose trash



Source: www.michigan.gov/egle/

HOW IS A LANDFILL OPERATED?

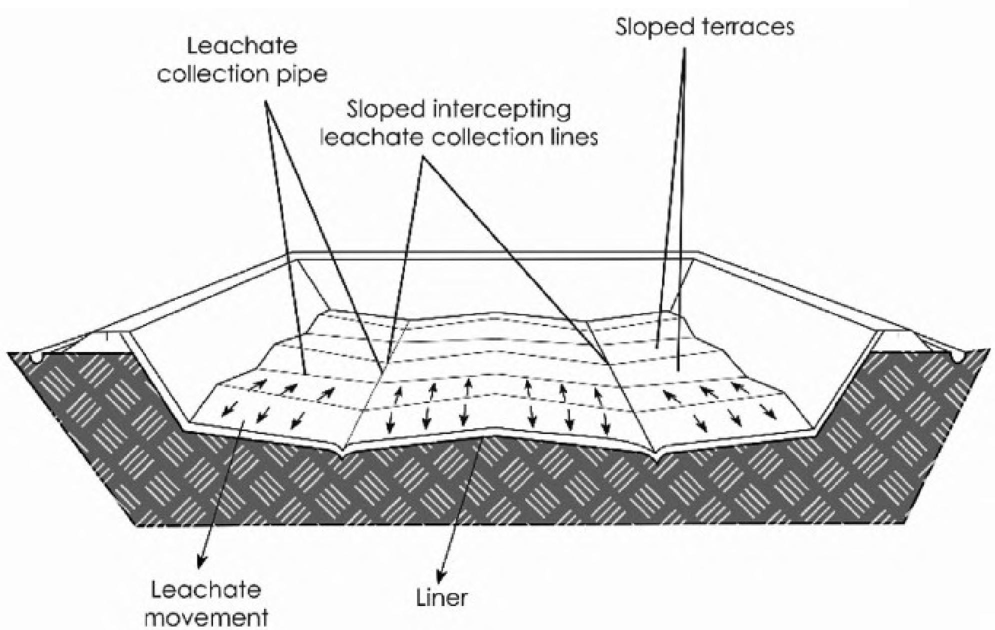
During compaction, leachate is generated:

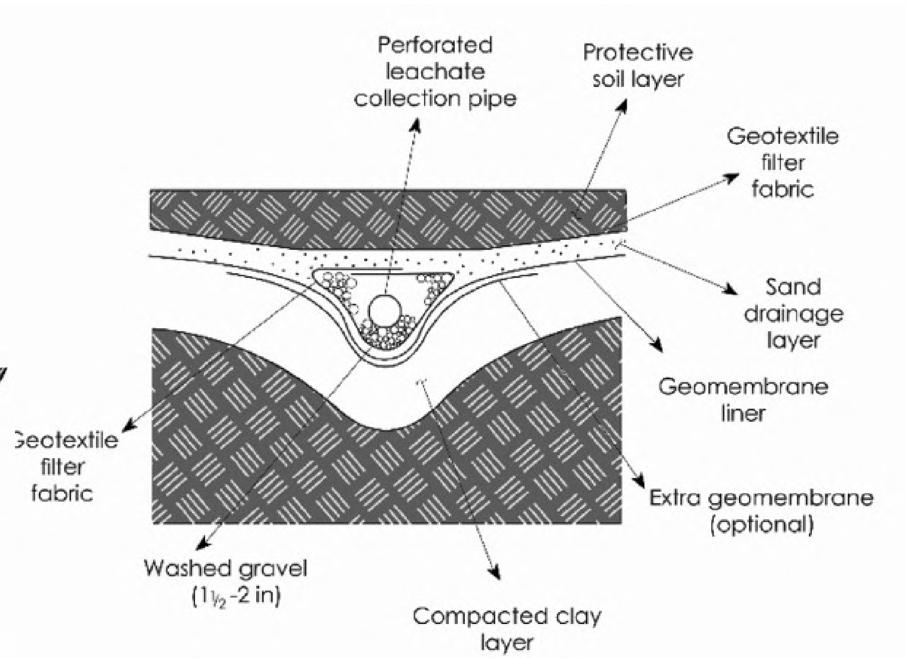
- Leachate is a liquid (or wastewater) that forms when water (rainfall, groundwater) travels through solid waste
- This leachate—originating from crushed organic and food waste—drains down through the waste.
- At the base of the cell, a sump collects the leachate, using a drainage system made up of perforated pipes, gravel, and sand.
- The leachate is pumped out, treated, and tested before being safely discharged into the environment.

This process continues until the cell reaches full capacity. After that:

- A new cell may be constructed above the filled one, or
- The cell is capped with a final cover, including layers of soil and vegetation, to prevent erosion and exposure to waste.

LEACHATE COLLECTION SYSTEM



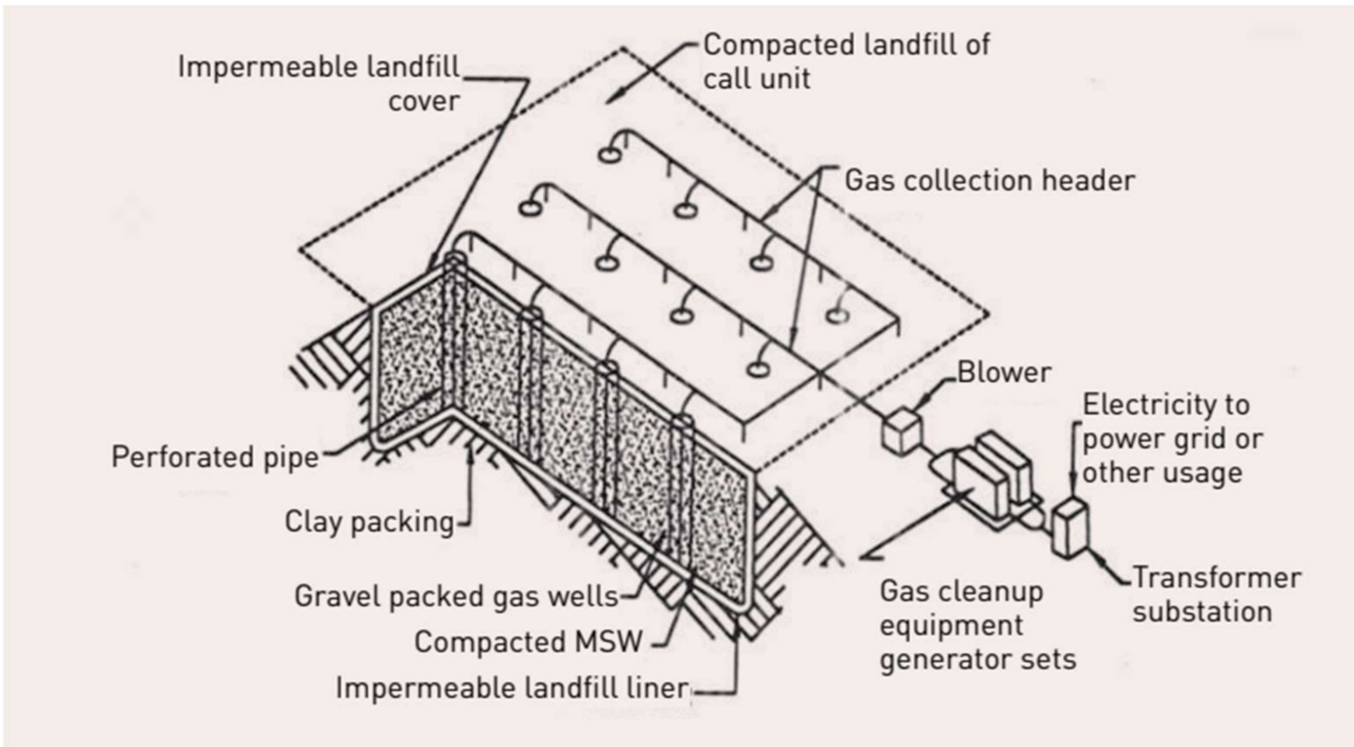


Source: Pazoki, M., Ghasemzadeh, R. (2020). *Landfilling*. In: *Municipal Landfill Leachate Management*. Environmental Science and Engineering. Springer

HOW IS A LANDFILL OPERATED?

- As the waste decomposes beneath the final cover, it generates landfill gas — primarily CH_4 and CO_2 — due to anaerobic microbial activity.
- This landfill gas must be captured using a gas collection system to:
  - Prevent uncontrolled emissions (methane is a potent greenhouse gas)
  - Flare the gas safely, or
  - Convert it into renewable energy, such as: Electricity (via gas engines or turbines), Renewable natural gas after treatment and purification
- Many modern landfills are designed to integrate energy recovery systems, making landfill gas-to-energy projects an important component of sustainable waste management.

GAS COLLECTION SYTEM



Source: Municipal solid waste Management manual, Part II: The manual, *CPHEEO* (2016)

HOW IS A LANDFILL OPERATED?

- Once a cell is closed and capped, it enters a post-closure care phase, which typically lasts for 30 years, during which:
  - Groundwater and gas monitoring systems are maintained
  - The final cover is inspected for integrity and erosion
  - The area is managed to ensure no negative environmental impacts
- Landfilling primarily relies on containment of waste rather than its treatment, aiming to isolate waste materials from the environment safely and permanently.

LANDFILL COMPONENT

Key Features of an Environmentally Sound Landfill

- Protective liner system – Prevents groundwater contamination
- Surface runoff control – Minimizes rainwater infiltration and erosion
- Leachate collection & treatment – Captures and treats liquid waste
- Gas monitoring & control wells – Detects and manages landfill gases
- Engineered final cover – Prevents water ingress, supports vegetation, and reduces emissions

NUMERICAL

Q. A landfill area of (150 m x 100 m) is available for handling 25 years MSW for a town of 5,00,000 people. Out of the total landfill area, only 80% is actually available for landfill, and the other is used for auxiliary services. Assuming that average per capita MSW discard per year in town is 0.05 tonne, landfill density is 500 kg/m^3, and that 15 % of the actual landfill cell volume is used for soil cover, Estimate (a) the landfill lift in one year. (b) number of years for which the landfill can be used if the landfill can't be increased beyond 25 m.

SOLUTION

Parameter	Value
Total landfill area	150 m × 100 m = 15,000 m^2
Usable landfill area	80% of total = 0.8 × 15,000 = 12,000 m^2
Population	5,00,000
Per capita MSW per year	0.05 tonne/year = 50 kg/year
Landfill density	500 kg/m^3
Soil cover requirement	15% of landfill volume is for soil, so only 85% is MSW
Maximum landfill height (or total lift possible)	25 m

(a) The landfill lift in one year

- Total MSW mass generated per year

$$5,00,000 \text{ people} \times 0.05 \text{ tonne/person/year} = 25,000 \text{ tonnes/year}$$

$$= \boxed{25,000,000 \text{ kg}}$$

- Convert MSW mass to volume

$$\text{Volume} = \frac{\text{Mass}}{\text{Density}} = \frac{25,000,000 \text{ kg}}{500 \text{ kg/m}^3} = \boxed{50,000 \text{ m}^3}$$

- Only 85% of the volume is available for MSW because 15% is soil cover.

So, actual MSW volume = 85% of landfill volume

$$\text{Total landfill volume needed} = \frac{50,000}{0.85} = 58,823.5 \text{ m}^3\text{/year}$$

- Now, you have 12,000 m^2 of usable landfill area.

  Lift (height) = Volume / Area

$$\text{Lift/year} = \frac{58,823.5}{12,000} = \boxed{4.902\,\text{m/year}}$$

(b) Number of years landfill can be used

- Maximum height of landfill = 25 m
  Landfill grows at a rate of 4.902 m/year, so:

$$\text{Number of years} = \frac{25}{4.902} = \boxed{5.1\,\text{years}}$$

NUMERICAL

Q. An Indian city is generating solid waste @ 1.2 k g/day per capita for four months and @ 0.5 kg per day per capita for eight months in a year. The population of the city is 2.489 million as per the census of 2011. It is planned to earmark land for land filling of the garbage for 5 years. Assuming the landfill garbage density of 452 kg/m^3 and a 10.5 m lift, determine the area for

(a) 25% soil in cell volume,

(b) 30% soil in cell volume.

(a) Waste for 4 months:

$$= 2,489,000 \text{ people} \times 1.2 \text{ kg/day} \times 120 \text{ days} = 358,416,000 \text{ kg}$$

(b) Waste for 8 months:

$$= 2,489,000 \times 0.5 \times 240 = 298,680,000 \text{ kg}$$

Total waste per year:

$$= 358,416,000 + 298,680,000 = 657,096,000 \text{ kg/year}$$

Waste generated in 5 years:

$$= 657,096,000 \times 5 = 3,285,480,000 \text{ kg}$$

$$\text{Volume of MSW only} = \frac{\text{Mass}}{\text{Density}} = \frac{3,285,480,000}{452} \approx 7,269,867.26 \text{ m}^3$$

SOLUTION

SOLUTION

(a): **25% soil** in total cell volume → MSW = 75%

$$\text{Total landfill volume} = \frac{7,269,867.26}{0.75} \approx 9,693,156.35\,\text{m}^3$$

(b): **30% soil** in total cell volume → MSW = 70%

$$\text{Total landfill volume} = \frac{7,269,867.26}{0.70} \approx 10,385,524.66\,\text{m}^3$$

$$\text{Area} = \frac{\text{Volume}}{\text{Lift height}}$$

(a): **25% soil** $= \dfrac{9,693,156.35}{10.5} \approx \boxed{923,157\,\text{m}^2}$

(b): **30% soil** $= \dfrac{10,385,524.66}{10.5} \approx \boxed{989,098\,\text{m}^2}$

WASTE STABILIZATION PROCESS

- Landfill stabilization refers to the biological, chemical, and physical processes that transform waste into a more stable and inert form over time.
- The stabilization process occurs in distinct phases, and each phase significantly affects the composition and behavior of both leachate and landfill gas.

1. Initial Adjustment Phase

- Occurs immediately after waste placement.
- Aerobic degradation begins due to the presence of oxygen in waste pores.
- Small amounts of CO_2 and water are produced.
- Leachate is mainly composed of dissolved organic matter and easily biodegradable compounds.

WASTE STABILIZATION PROCESS

2. Transition Phase

- Oxygen is depleted; the environment becomes anaerobic.
- Facultative and anaerobic microorganisms become dominant.
- Acid production begins, lowering pH in the leachate.
- Heavy metals and other compounds may become more mobile.

3. Acid Formation Phase

- It marks intensified microbial activity, building upon the anaerobic conditions established in Phase 2.
- Complex organics are broken down into VFAs.
- Leachate has low pH, high COD, BOD, and high organic loading.
- It is a three-step biological process: Hydrolysis, Acidogenesis, Acetogenesis

WASTE STABILIZATION PROCESS

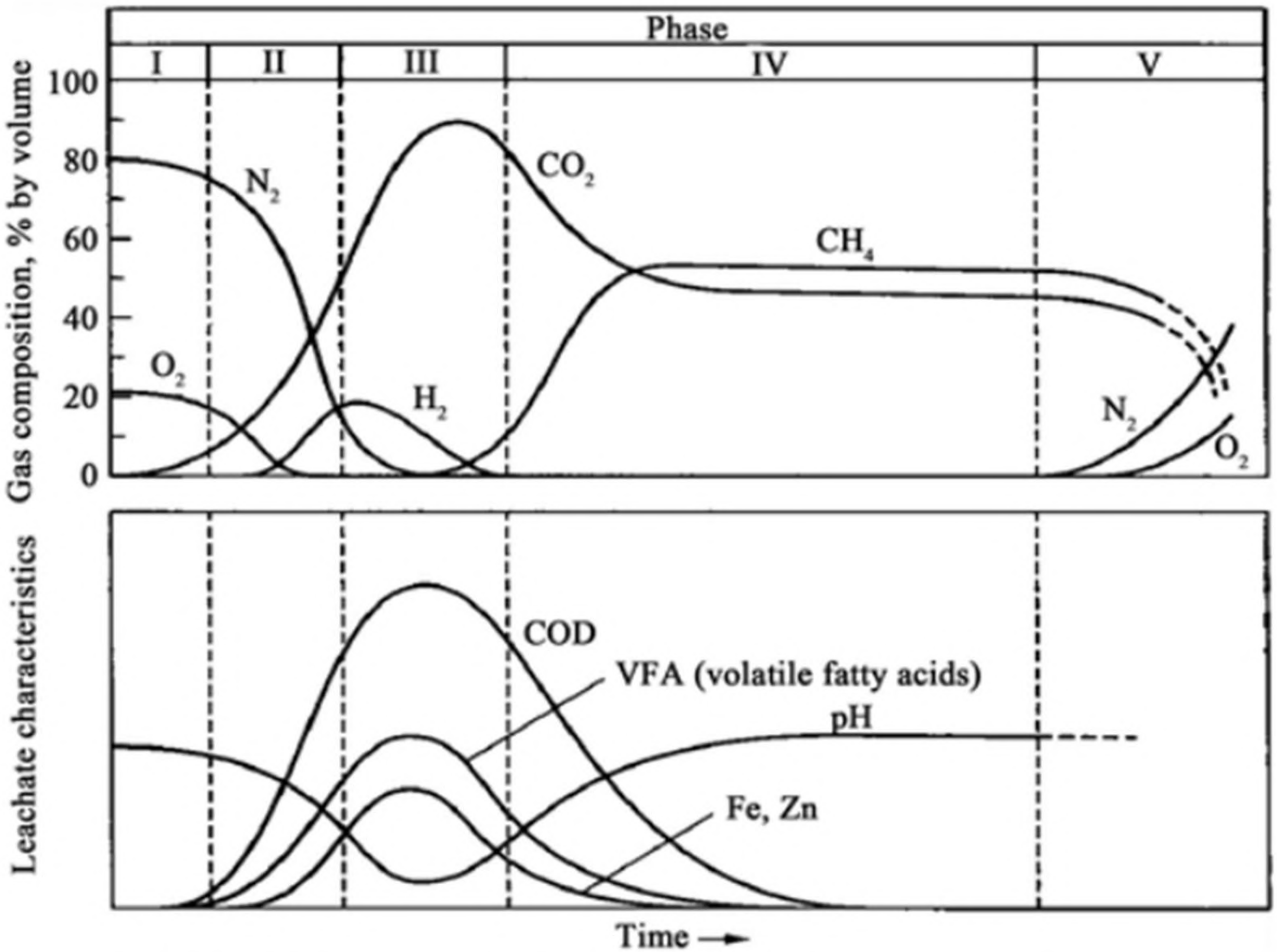
4 . Methanogenesis Phase

- Methane-producing bacteria (methanogens) become active.
- VFAs are converted into CH_4 and CO_2.
- Leachate becomes less acidic, with reduced BOD/COD.
- The landfill gas now mainly consists of CH_4 (50–60%) and CO_2 (40–50%).

5. Maturation (Humification) Phase

- Readily biodegradable materials are exhausted.
- Waste reaches a stabilized or inert state.
- Gas production declines significantly, and leachate generation reduces.
- Leachate is now low in organic strength and resembles weak wastewater.

WASTE STABILIZATION PHASES



Source: Integrated Solid Waste Management: Engineering Principle and Management Issue. McGraw Hill Inc. (1993)

E-WASTE MANAGEMENT

References:

1. E-waste Management In India: Challenges and Agenda by *Atin Biswas and Siddharth Ghanshyam Singh*, Centre for Science and Environment
2. A New Circular Vision for Electronics: Time for a Global Reboot, Platform for Accelerating the Circular Economy

WHAT IS E-WASTE?

- "E-waste," also known as "Electronic waste," includes a range of discarded electronic devices, including computers, entertainment gadgets like televisions, mobile phones, and radios, as well as refrigerators and office electronic equipment.

CATEGORIES OF E-WASTE

LARGE APPLIANCES

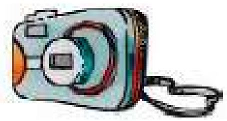
Refrigerators,
washing machines,
dryers,
dishwashers,
cookers,
electric stoves,
radiators,
microwaves,
fans and
air conditioners

SMALL APPLIANCES

Vacuums,
irons,
toasters,
fryers,
electric coffee makers,
electric knives,
hair dryers,
razors and
watches

COMPUTER AND TELECOMMUNICATIONS EQUIPMENT

Computers,
laptops,
printers,
computer screens,
mice,
calculators,
phones and
mobile phones



LOW CONSUMPTION ELECTRONIC DEVICES

Music players,
radios,
televisions,
camcorders,
speakers,
amplifiers
sound and
instruments
musicals
electrical

LIGHTING FIXTURES

Fluorescent tubes,
energy saving
lightbulbs,
LEDs and luminaires

ELECTRIC AND ELECTRONIC TOOLS

Drills,
screwdrivers
electrical,
sewing machines,
lawn mowers
and electric saws

TOYS AND SPORTS AND LEISURE EQUIPMENT

Electric cars,
trains and trucks,
portable consoles,
video game,
heart rate monitors
and sports timers

MEDICAL DEVICES

Electronic
thermometers,
sphygmomanometers,
etc

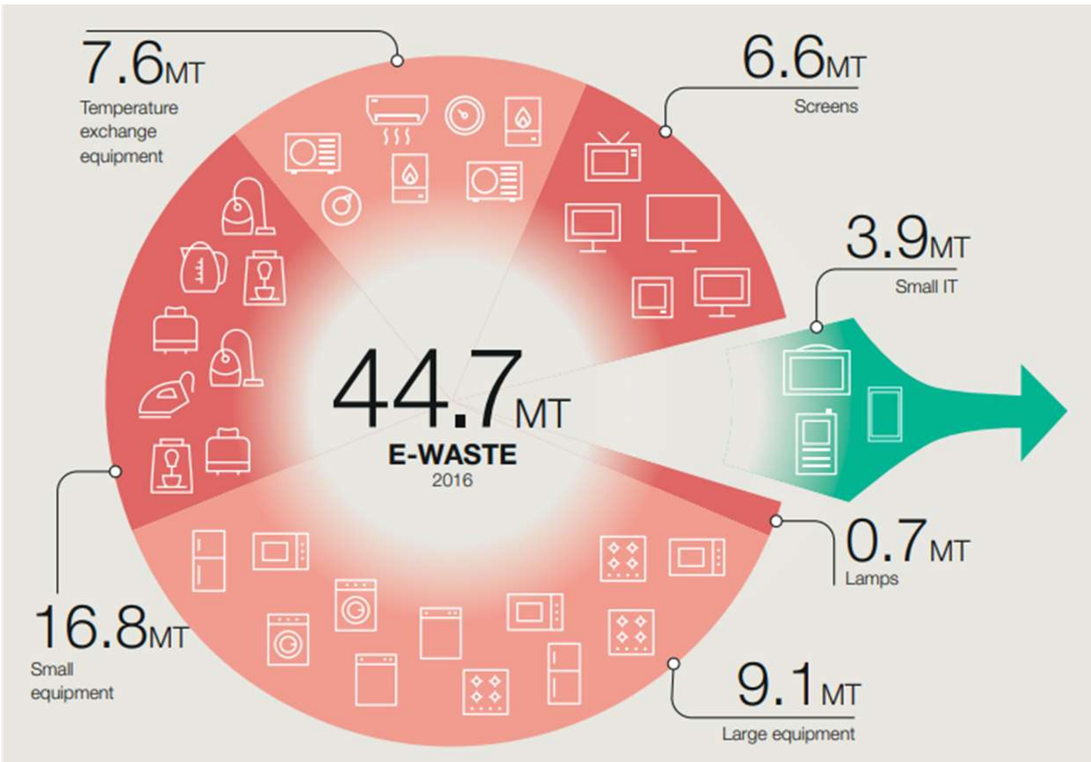
MONITORING AND CONTROL INSTRUMENTS

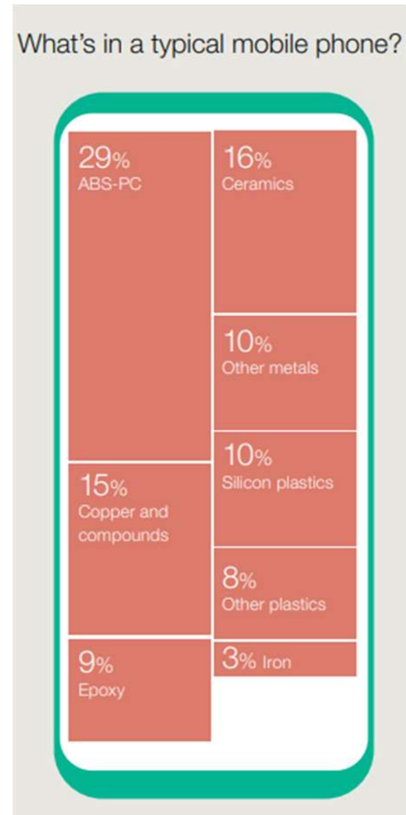
Smoke
detectors,
heating regulators
and thermostats

VENDING MACHINES

Drinking
machines,
snacks,
coffee,
etc

E-WASTE GENERATION





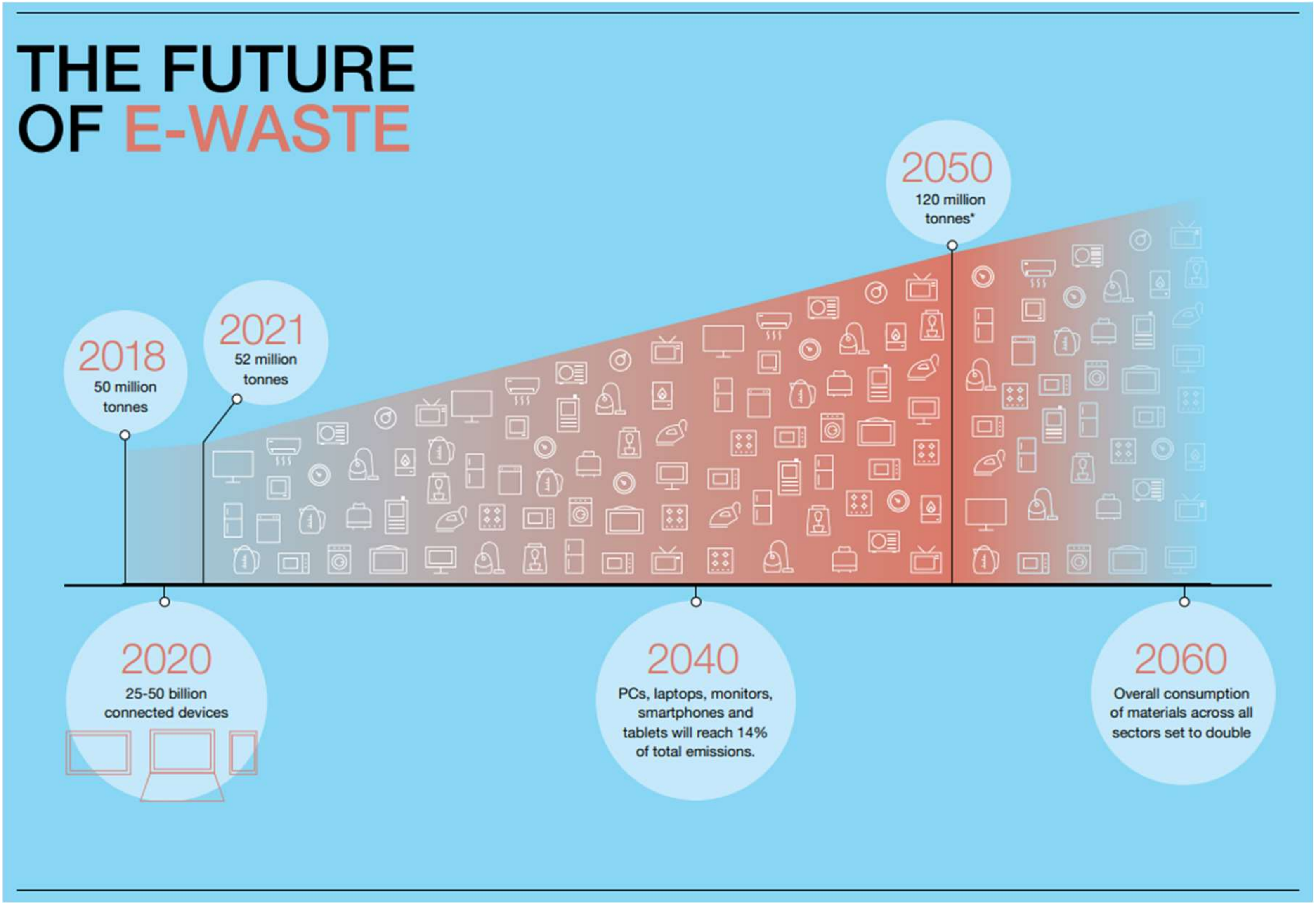
Toxic compound / metal	Sources of e-waste
Lead	Circuit boards, cathode ray tubes (CRTs), glass panels in monitors
Nickel	Circuit boards, batteries
Cadmium	Cathode ray tubes (CRTs), batteries
Mercury	Switches, flat screen monitors, fluorescent lights, thermostats, sensors, medical equipment, mobile phones
Brominated plastics	Printed circuit boards, plastic casing
Chlorinated plastics	PVC, cable insulation
Phosphors (compounds with transition and rare earth metals)	CRTs, flat screen monitors
PCBs	Old capacitors
CFCs	Old refrigerators, cooling units

STATISTICS

Statistics of top five e-waste generating countries in 2019

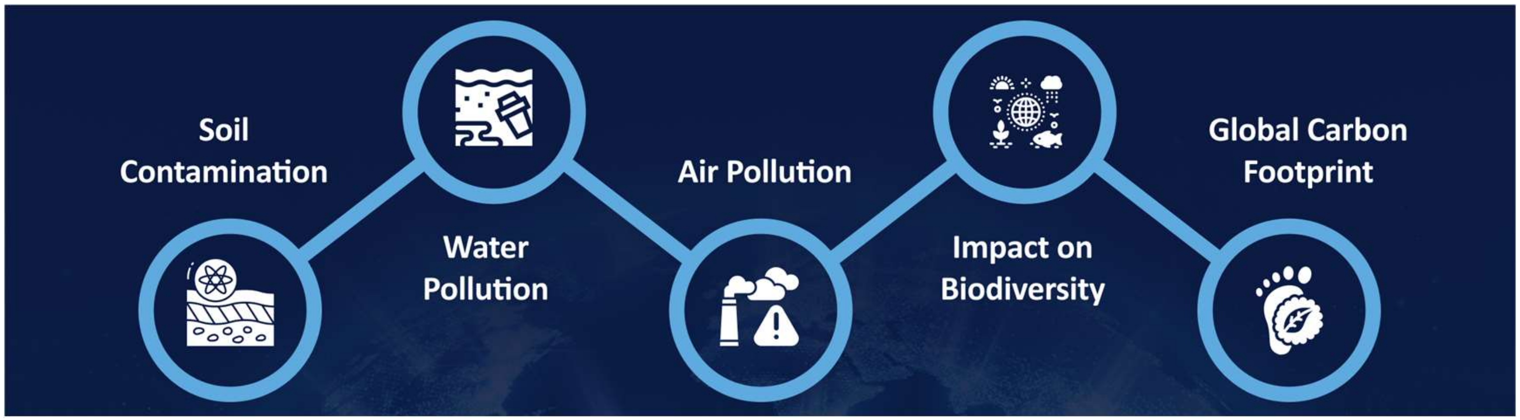
Rank	Country and rank in e-waste generation	EEE placed on the market (kg/capita)	E-waste generation (kg/capita)	E-waste collection rate (per cent)
1	China	13.3	7.2	16
2	USA	25.3	21	15
3	India	5.8	2.4	1
4	Japan	21.3	20.4	22
5	Germany	18.2	19.4	52

Source: CSE 2020

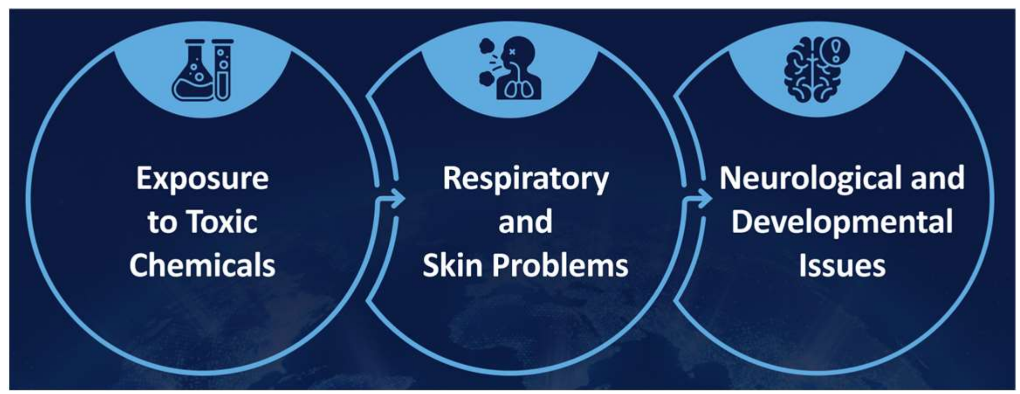


THE FUTURE OF E-WASTE
2018
50 million tonnes
2021
52 million tonnes
2050
120 million tonnes*
2020
25-50 billion connected devices
2040
PCs, laptops, monitors, smartphones and tablets will reach 14% of total emissions.
2060
Overall consumption of materials across all sectors set to double

IMPACT OF E-WASTE ON THE ENVIRONMENT

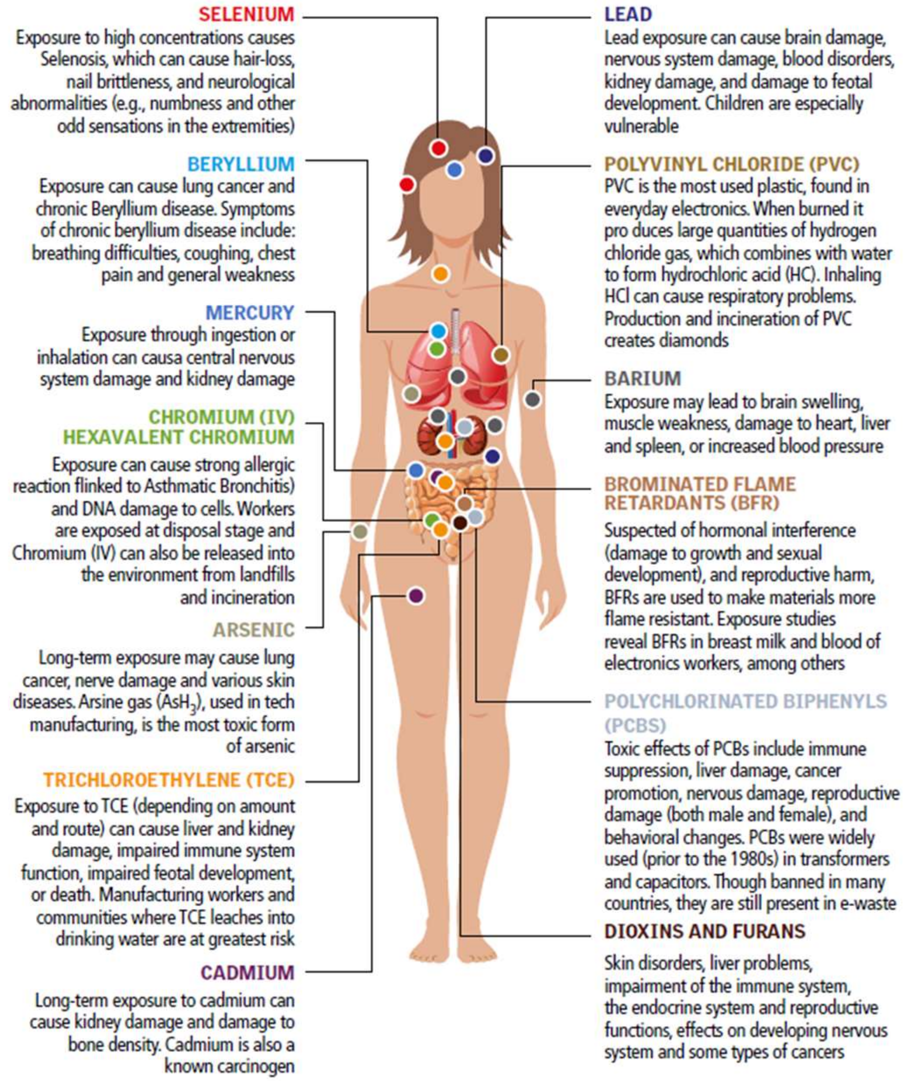


IMPACT ON HUMAN HEALTH



IMPACT ON HUMAN HEALTH

- E-waste contains toxic wastes, cadmium, lead and several different toxic substances which are not biodegradable.
- With the presence of deadly chemicals and toxic substances in electronic gadgets, the disposal of e-waste is becoming an environmental and health nightmare.

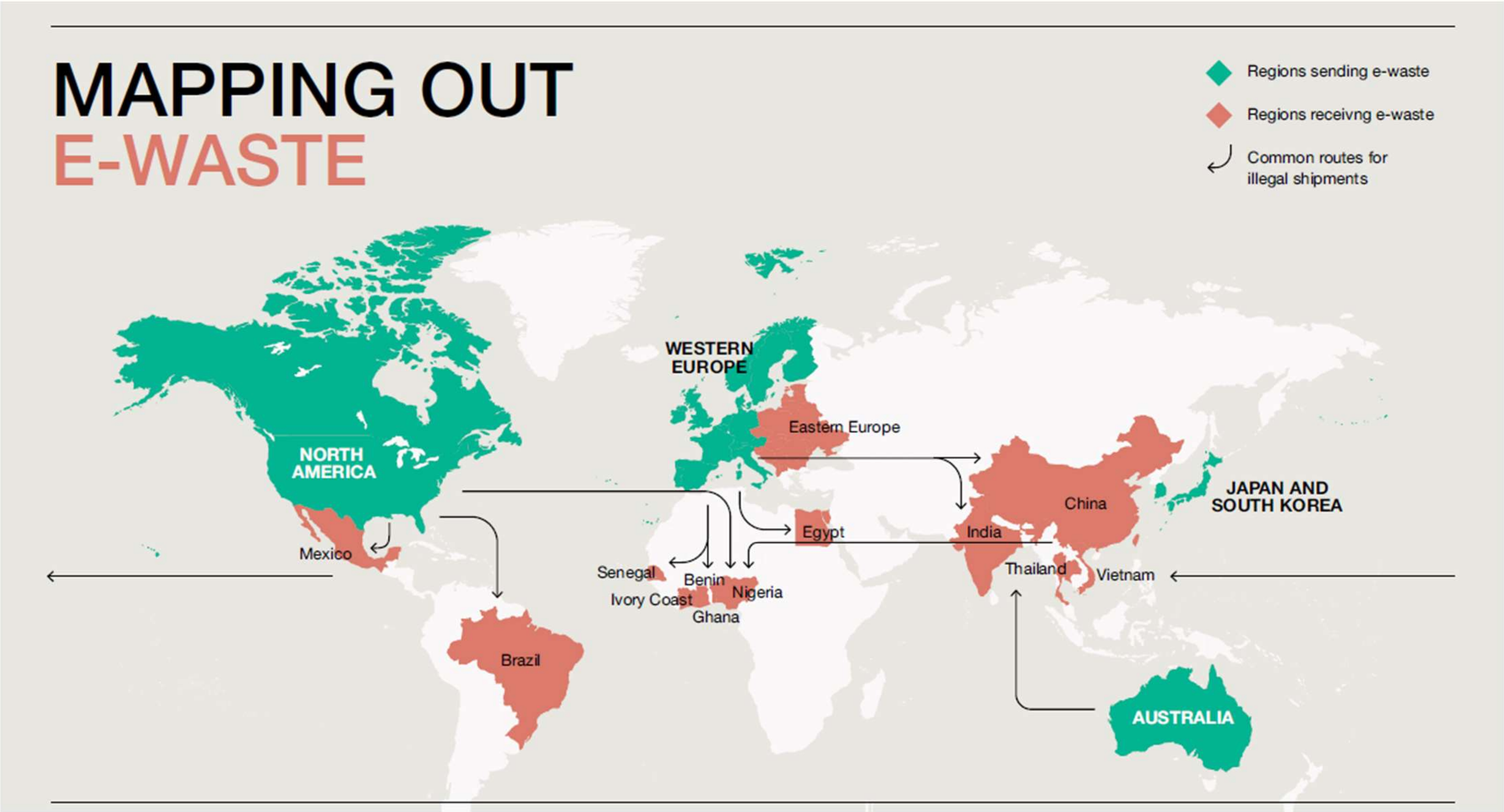


WHY DUMPED IN DEVELOPING COUNTRIES?

- Globally, only 15 – 20 per cent of e-waste is recycled, while the rest is dumped into developing countries.

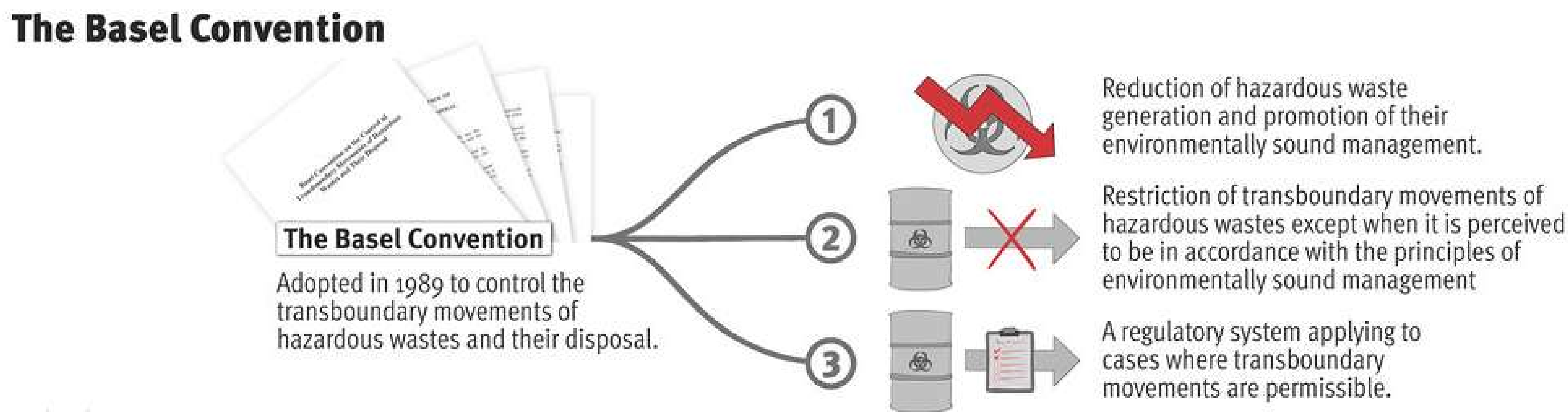
Why?

- **Cheap Labor:** Developing countries like India, Ghana, and Nigeria have abundant informal workers who dismantle e-waste at low cost.
- **Weak Environmental Laws:** Looser regulations make it easier and cheaper for developed nations to export waste under the label of "second-hand goods."
- **Profit from Valuable Materials:** Informal recyclers extract precious metals (gold, copper, palladium) from e-waste using unsafe methods.
- **Cost Avoidance:** Developed countries avoid the high cost of safe recycling by shipping waste abroad.


MAPPING OUT
E-WASTE
Regions sending e-waste
Regions receivng e-waste
Common routes for illegal shipments
WESTERN EUROPE
Eastern Europe
NORTH AMERICA
Mexico
Brazil
Senegal
Benin
Ivory Coast
Nigeria
Ghana
Egypt
India
China
Thailand
Vietnam
JAPAN AND SOUTH KOREA
AUSTRALIA

BASEL CONVENTION

- The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted on 22 March 1989 by the Conference of Plenipotentiaries in Basel, Switzerland. The Convention entered into force on 5 May 1992.
- The objective is to protect human health and the environment against the adverse effects of hazardous and other wastes.



UNEP (2021). Drowning in plastics – Marine Litter and Plastic Waste Vital Graphics.

Basel Ban Amendment (2019)

- Prohibits export of hazardous waste from the Organisation for Economic Co-operation and Development (OECD) countries (developed) to non-OECD countries (developing) for any reason, including recycling.

LEGISLATIVE PROGRESS ON E-WASTE MANAGEMENT IN INDIA

Pre -1989	• No rule, legislation, policy or regulation to address e-waste management
1989–2003	• E-waste was bought under the ambit of Hazardous Wastes (Management and Handling) (HWM) Rules (1989, 2000 and 2003) indirectly • Schedule 1 of the HWM Rules covered hazardous material in e-waste composition
2008	• E-waste addressed as a separate challenge • CPCB issued guidelines to all SPCBs in April 2008 to manage e-waste in an environmentally sound manner • Applicable to all stakeholders, viz., generators, collectors, transporters, dismantlers, recylers, etc.
2011	• E-waste (Management and Handling) Rules were introduced • Enforced from 1 May 2012 • Confirms environmentally friendly handling, transportation, storing and recycling of e-waste • Concept of extended producer responsibility (EPR) introduced
2016	• E-waste (Management) Rules were introduced in 2016 • Enforced from 1 October 2016 • Concept of Producer Responsibility Organization (PRO) introduced • Buy-back, deposit refund and exhange schemes introduced under EPR
2018	• E-waste (Management) Rules 2016 amended in March 2018 • Enforced from 22 March 2018 • Target revisions done for new players in the market

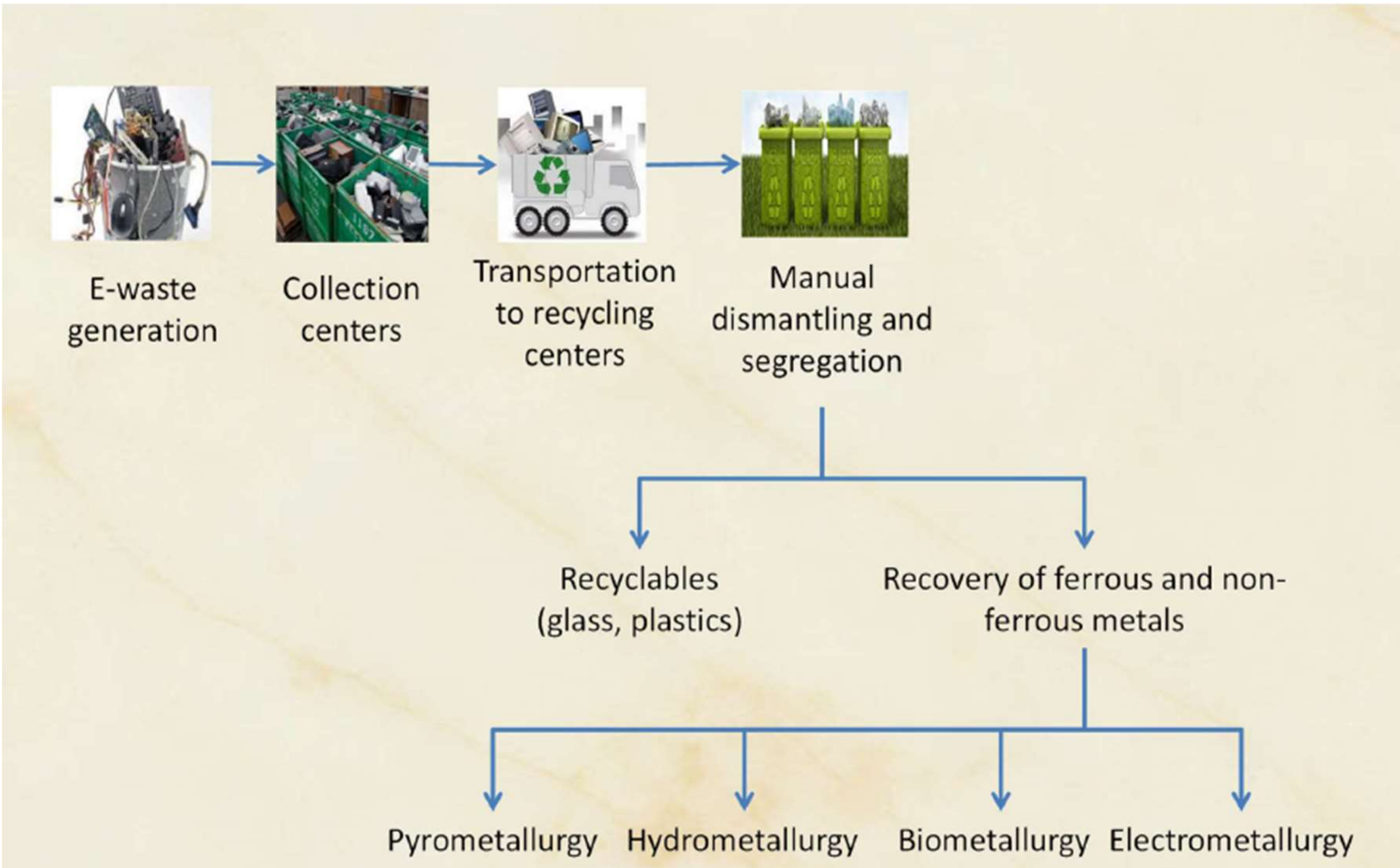
Source: CSE, 2020

E-WASTE MANAGEMENT

- E-waste management focuses on recovering and processing discarded electronic items in a sustainable manner so they can be recycled or refurbished for further use.
- However, recycling electronic devices is often complex since they are made with sophisticated designs and varying proportions of glass, metals, and plastics.

STAGES IN E-WASTE MANAGEMENT

- **Collection and Storage:** Gathering e-waste from households, enterprises, organisations, and individuals, followed by safe storage until further processing.
- **Sorting:** Workers remove specific items that need special processing, such as batteries or lightbulbs. Some parts, like reusable components or valuable metals, are separated at this stage.
- **Dismantling:** The collected devices are disassembled into their components to identify reusable parts and segregate scrap.
- **Recycling:** Segregated materials and parts are processed so they can be used to manufacture new electronic items.
- **Refurbishing:** Functional and good-quality components are repaired and reused to extend the life of other electronic equipment.

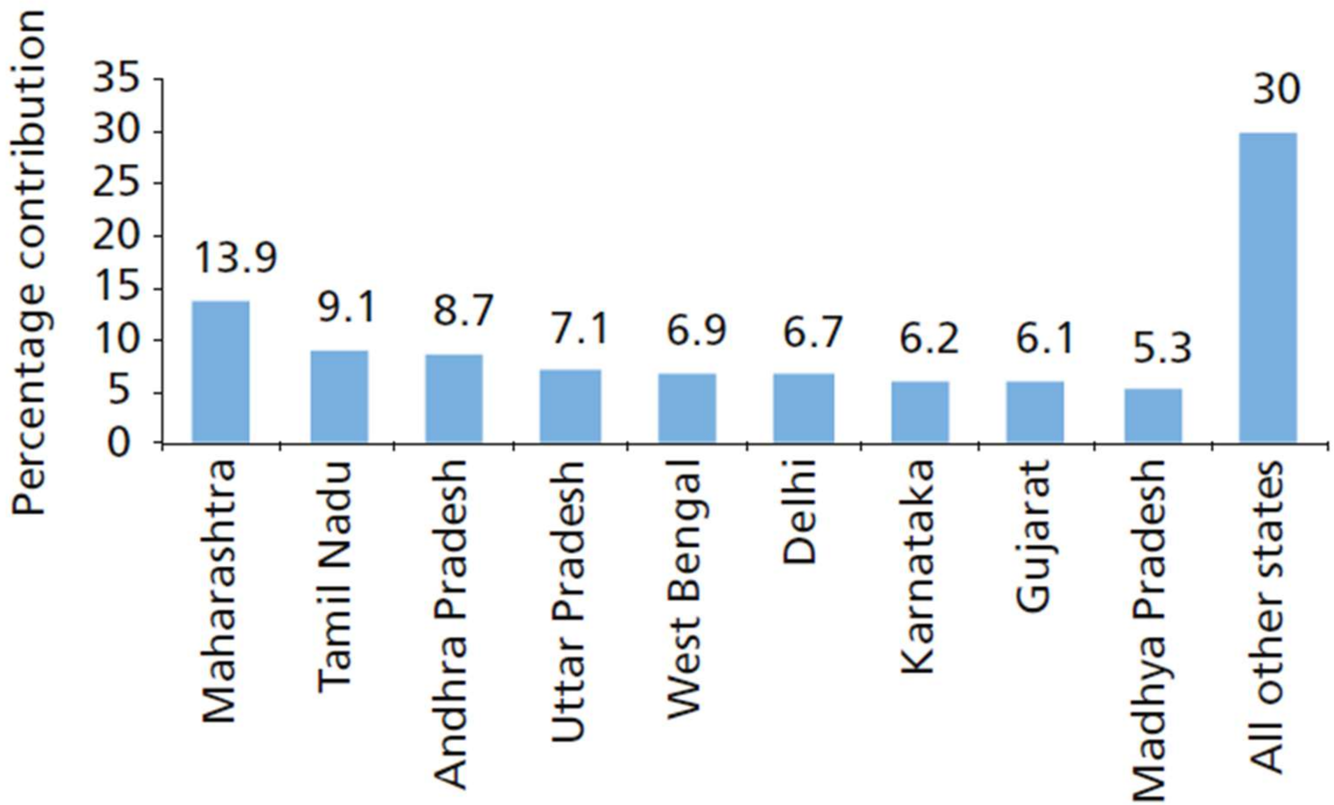

E-waste generation
Collection centers
Transportation to recycling centers
Manual dismantling and segregation
Recyclables (glass, plastics)
Recovery of ferrous and non-ferrous metals
Pyrometallurgy
Hydrometallurgy
Biometallurgy
Electrometallurgy

GENERATION

Year-wise e-waste generation in India

Year	E-waste generation (million metric tonnes)
2015	1.97
2016	2.22
2017	2.53
2018	2.86
2019	3.23

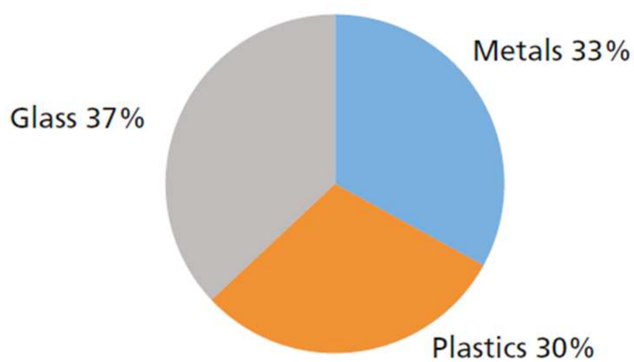
Percentage contribution by states to annual e-waste generation



Source: Electrical and Electronics manufacturing in India, ASSOCHAM & NEC Technologies, 2018

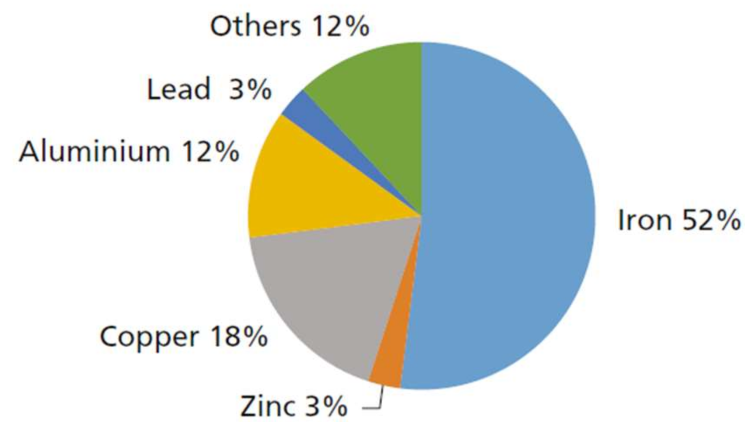
COMPOSITION OF E-WASTE

Graph 1: Components of e-waste



Source: Electricals and Electronics manufacturing in India, ASSOCHAM, NEC technologies, 2018

Graph 2: Metallic constituents of e-waste



Source: Electricals and Electronics manufacturing in India, ASSOCHAM, NEC technologies, 2018

COLLECTION & STORAGE

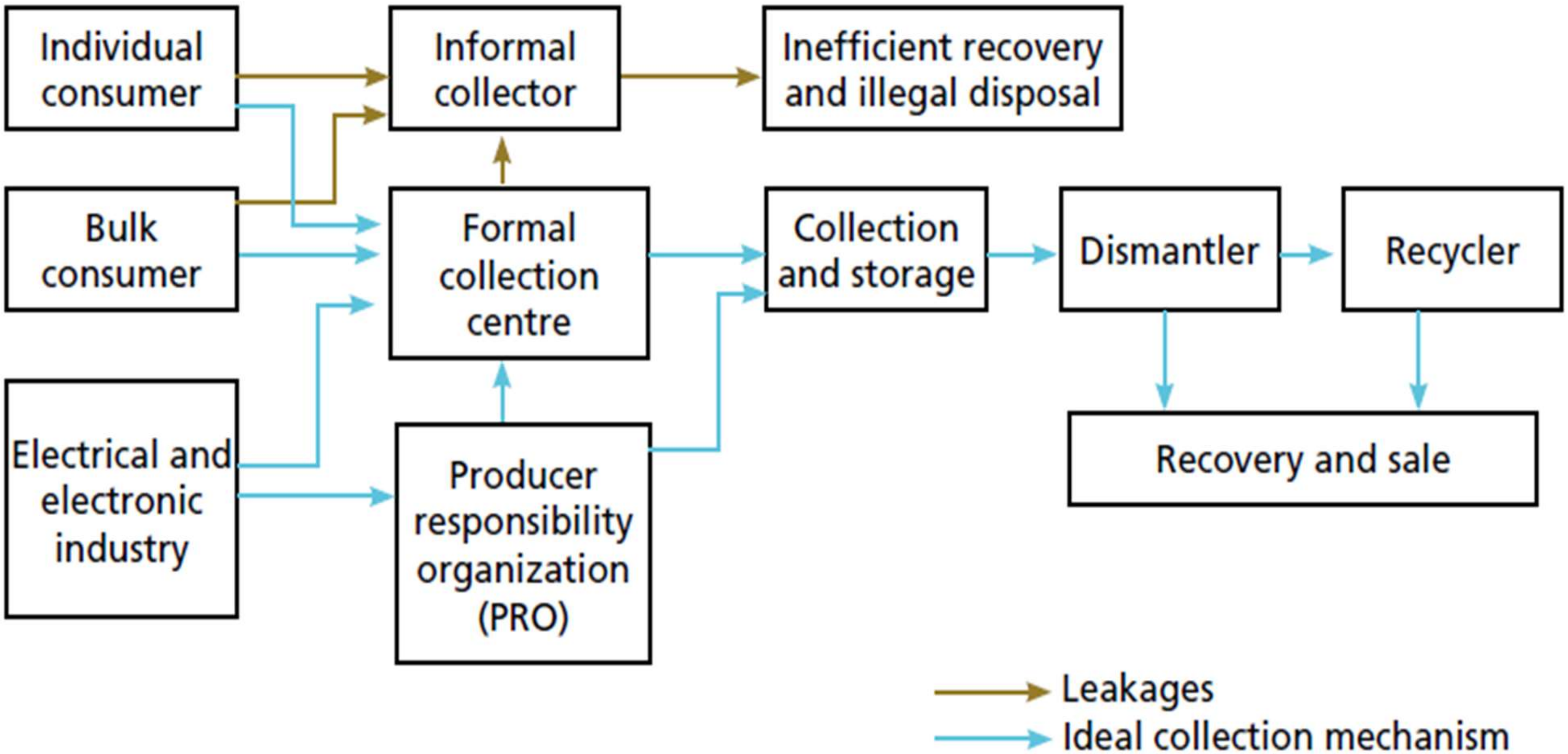
Collection

- Old electronics are gathered through recycling bins, drop-off centres, take-back programs, or on-demand pickups.
- Managed by local governments, businesses, or community events.
- Proper separation is crucial → bins for batteries, phones, computers, etc.
- Batteries need special handling (risk of fire, toxic leaks).

Safe Storage

- Collected e-waste is stored securely until processing.
- Special care for items like TVs and monitors containing lead.
- Earlier, glass from screens was recycled, but demand has declined → much remains in storage.
- Prevents environmental harm and exposure to hazardous substances.

Ideal collection flow of and leakages in e-waste management in India



Source: CSE. 2020

WHY RECYCLE?

Problem

- Landfilling → lead leaches into groundwater.
- Burning → toxic fumes released.
- Cadmium from one mobile battery can pollute 600 m^3 of water.

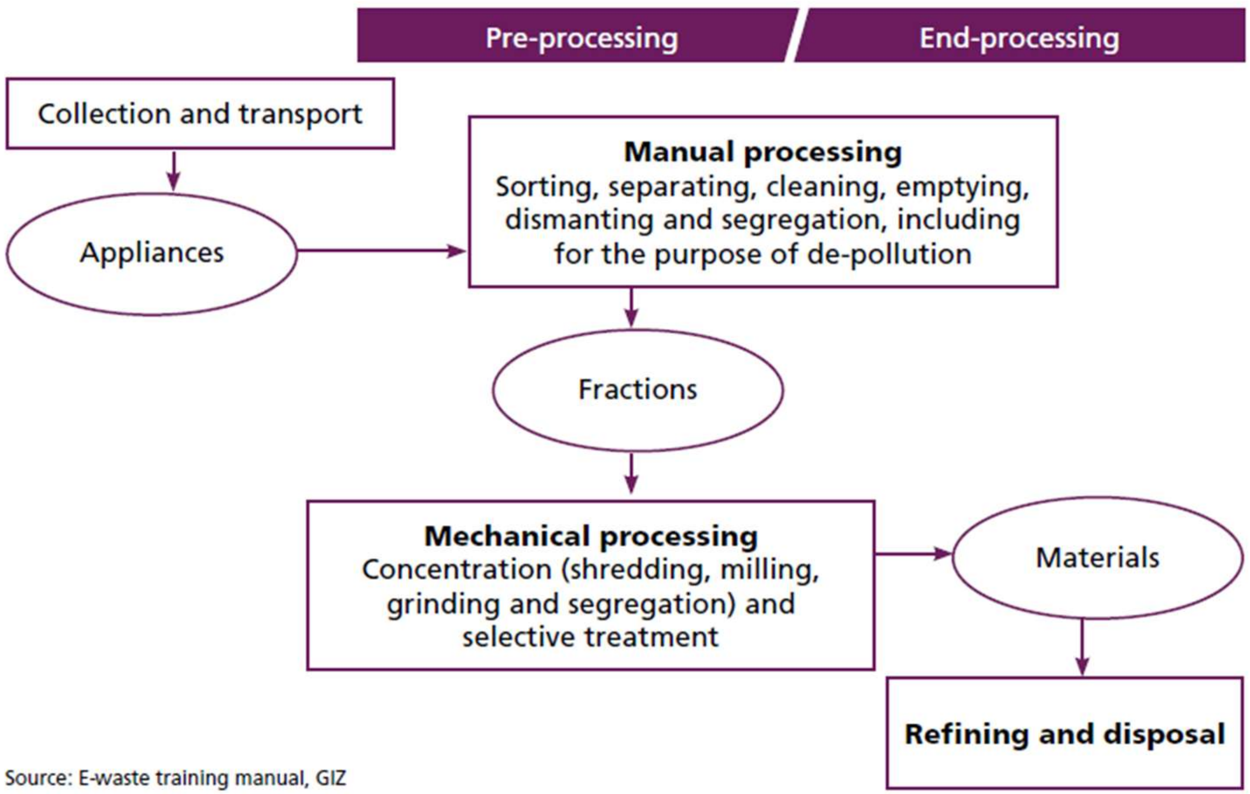
Recycling

- Safe recovery of valuable metals and components.
- Reduces hazardous disposal.
- Promotes circular economy.

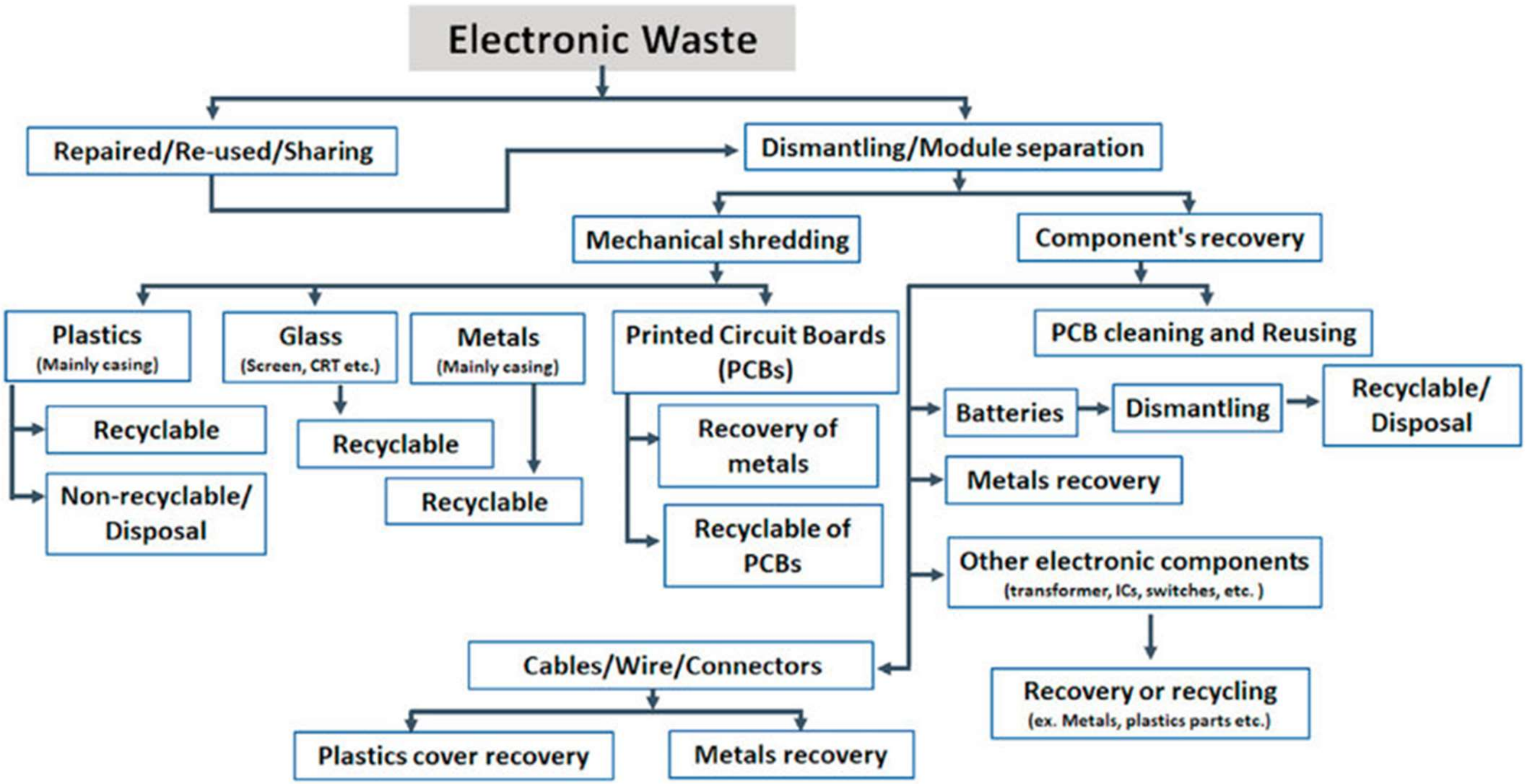
Benefits

- **Economic:** Raw material value ≈ **€55 billion (2016)**, greater than the GDP of many countries.
- **Environmental:** Prevents contamination of soil, water, and wildlife habitats.
- **Sustainability:** Extends resource life, reduces mining pressure.

PROCESS FLOW OF E-WASTE RECYCLING



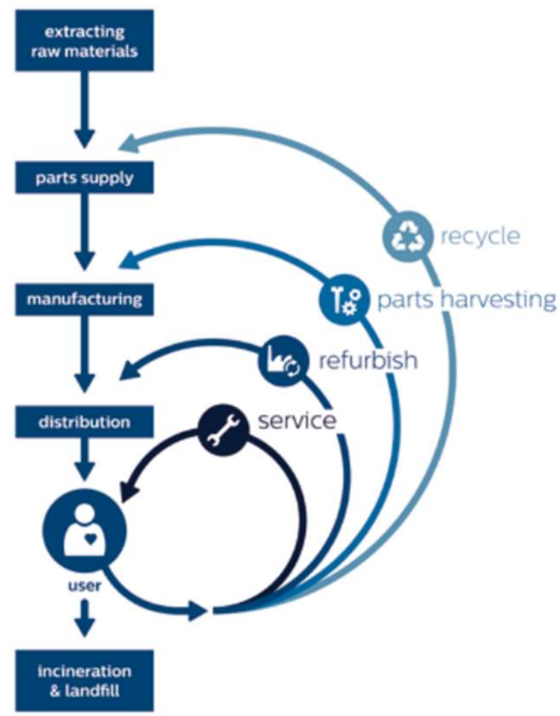
Source: E-waste training manual, GIZ


Electronic Waste
Repaired/Re-used/Sharing
Dismantling/Module separation
Mechanical shredding
Component's recovery
Plastics
(Mainly casing)
Glass
(Screen, CRT etc.)
Metals
(Mainly casing)
Printed Circuit Boards (PCBs)
PCB cleaning and Reusing
Recyclable
Non-recyclable/ Disposal
Recyclable
Recyclable
Recovery of metals
Recyclable of PCBs
Batteries
Dismantling
Recyclable/ Disposal
Metals recovery
Other electronic components
(transformer, ICs, switches, etc.)
Recovery or recycling
(ex. Metals, plastics parts etc.)
Cables/Wire/Connectors
Plastics cover recovery
Metals recovery

RECYCLING PROCESS

- ***Separation:*** Metals are separated from other materials using magnetics, sink-float, or hand sorting.
- ***Pretreatment & Processing:*** Materials undergo pretreatment, melting, refining, etc., for recovery.
- ***Reusable Components:*** Directly reintroduced into production lines
- ***Metals:*** Steel, copper, and others go to smelting plants for new product manufacturing.
- ***Plastics:*** Melted and remoulded into new items.

Circular Economy Impact: Reduces mining of raw materials, conserves energy, and ensures environmental sustainability.



Authorized recyclers in India and their processing capacities

0.78 million MT

Total recycling capacity of these units

State	Number of authorized dismantlers and recyclers	State-wise capacity (mTA)
Goa	1	103
Jammu and Kashmir	1	165
Andhra Pradesh	1	480
Chhattisgarh	1	600
Himachal Pradesh	1	1,000
West Bengal	3	1,860
Odisha	3	3,680
Punjab	3	4,850
Madhya Pradesh	2	9,600
Uttarakhand	4	19,250
Telangana	11	41,493
Gujarat	16	49,053
Karnataka	71	52,722
Maharashtra	75	78,179
Haryana	28	87,378
Rajasthan	26	90,769
Tamil Nadu	24	97,271
Uttar Pradesh	41	243,627
Total	312	782,080

Source: CSE, 2020

India's formal and informal e-waste management sectors

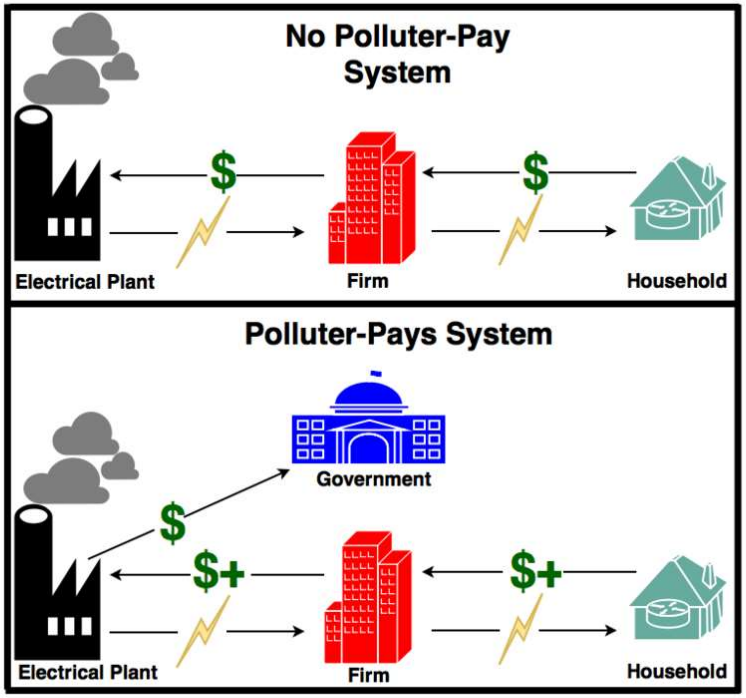
Parameter	Informal sector	Formal sector
Percentage of e-waste processed	90	10
General practices of e-waste processing	Rudimentary methods: Incineration, breaking, dismantling, dumping, etc.	Industrial recycling and dismantling using technically advanced methods
Current stakeholders	Dealers or retailers, unorganized recycling sector (local pawn shops, recyclers, dismantlers, etc.) contractual labour, localized vendors (kabadis)	Government, consumers, retailers, industries or organizations, registered processing units, NGOs and manufacturers
Binding laws	Not bound by any laws or regulations	Environmental laws, E-waste (Management) Rules, labour laws, etc.
Major functions	Collection, disassembly, extraction and dumping	Disassembly, extraction, recycling, treatment and segregation

Source: ASSOCHAM and NEC Technologies report, Electrical and Electronics manufacturing in India 2018

E-WASTE MANAGEMENT TOOLS

1. Policy and Regulatory Tools

- **Extended Producer Responsibility (EPR):** Mandates producers to **take back**, **recycle**, or **dispose** of e-waste safely.
- **Polluter Pays Principle:** Ensures that generators of e-waste **bear the costs** of management.
- **Legislation and Standards:** National e-waste rules (like India's **E-Waste Management Rules**, **EU WEEE Directive**).
- **Certification Schemes:** e.g., **R2** (Responsible Recycling), **e-Stewards** for recyclers.



E-WASTE MANAGEMENT TOOLS

2. Collection and Tracking Tools

- **Take-back Programs:** Manufacturer- or retailer-run collection centres.
- **Deposit-Refund Systems:** Consumers pay a small deposit when purchasing electronics, refunded upon return.
- **Digital Tracking Systems:** Barcodes, RFID, and blockchain to track e-waste flows.
- **Reverse Logistics Platforms:** Organised return of used devices through collection networks.

E-WASTE MANAGEMENT TOOLS

3. Technical and Recycling Tool

- **Manual Dismantling:** For safe separation of reusable components.
- **Mechanical Separation:** Shredding, magnetic separation, and eddy current separation to extract metals/plastics.
- **Pyro-metallurgical Processing:** Smelting for metal recovery.
- **Hydro-metallurgical Processing:** Acid leaching and solvent extraction to recover precious metals.
- **Bioleaching (Biotechnological Tool):** Using microbes to recover metals like copper and gold.
- **Plasma Arc Technology:** High-temperature treatment to break down hazardous materials.

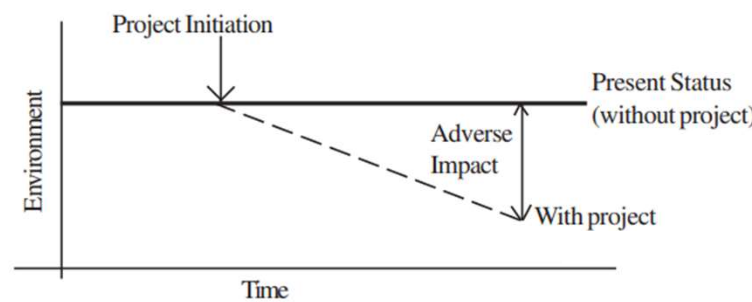
ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

References:

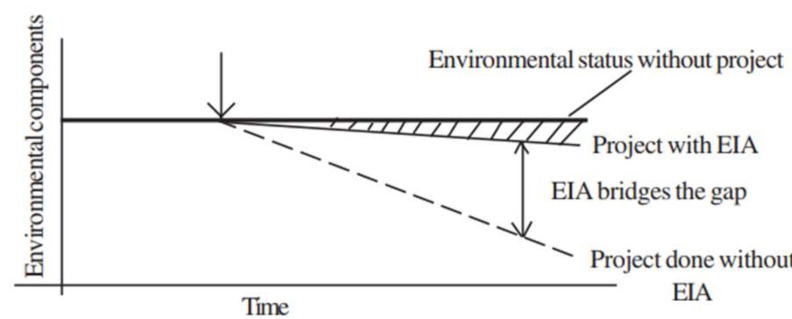
1. Environmental Impact Assessment - Theory and Practice by *Peter Wathern*
2. Understanding EIA by the Centre for Science and Environment
3. Environmental Impact Assessment Training Manual by the International Institute for Sustainable Development

WHAT IS ENVIRONMENTAL IMPACT ASSESSMENT (EIA)?

- UNEP defines Environmental Impact Assessment (EIA) as a tool used to identify the environmental, social and economic impacts of a project prior to decision-making.
- It aims to predict environmental impacts at an early stage in project planning and design, find ways and means to reduce adverse impacts, shape projects to suit the local environment and present the predictions and options to decision-makers.
- It takes into consideration not only technical and economic considerations but also traditional aspects like impact on local people, biodiversity, etc.



Anticipated environmental impact of developmental project.

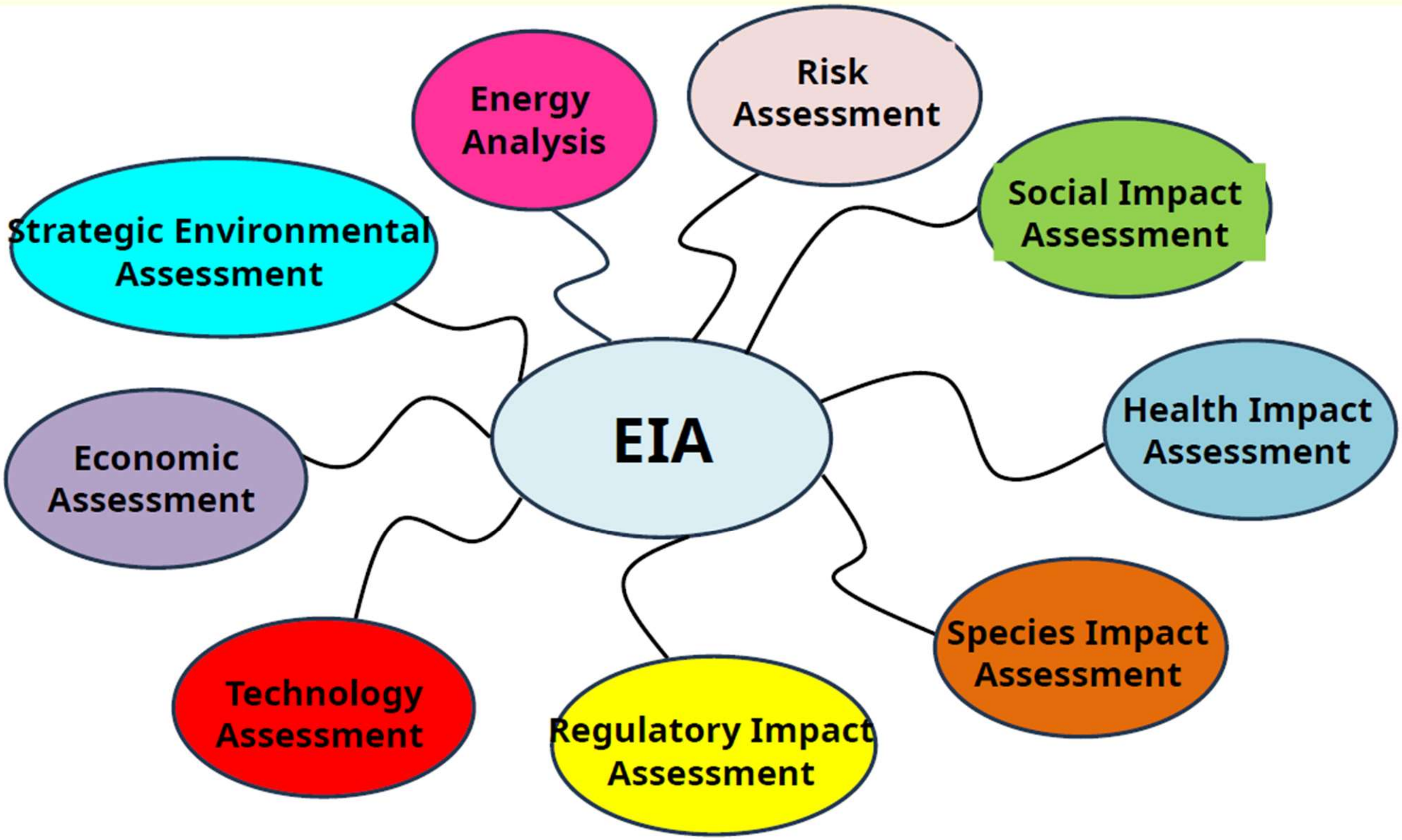


Environmental impact rectification after EIA

IMPORTANCE

- EIA links environment with development for environmentally safe and sustainable development.
- EIA provides a cost-effective method to eliminate or minimize the adverse impact of developmental projects.
- EIA enables the decision makers to analyse the effect of developmental activities on the environment well before the developmental project is implemented.
- EIA encourages the adaptation of mitigation strategies in the developmental plan.
- EIA makes sure that the developmental plan is environmentally sound and within the limits of the capacity of assimilation and regeneration of the ecosystem.

Key aspects included in EIA



PRINCIPLES OF EIA

Participation: The process should provide appropriate opportunities to inform and involve the interested and affected publics.

Transparency: The process should have clear, easily understood requirements for EIA content, ensuring public access to the information.

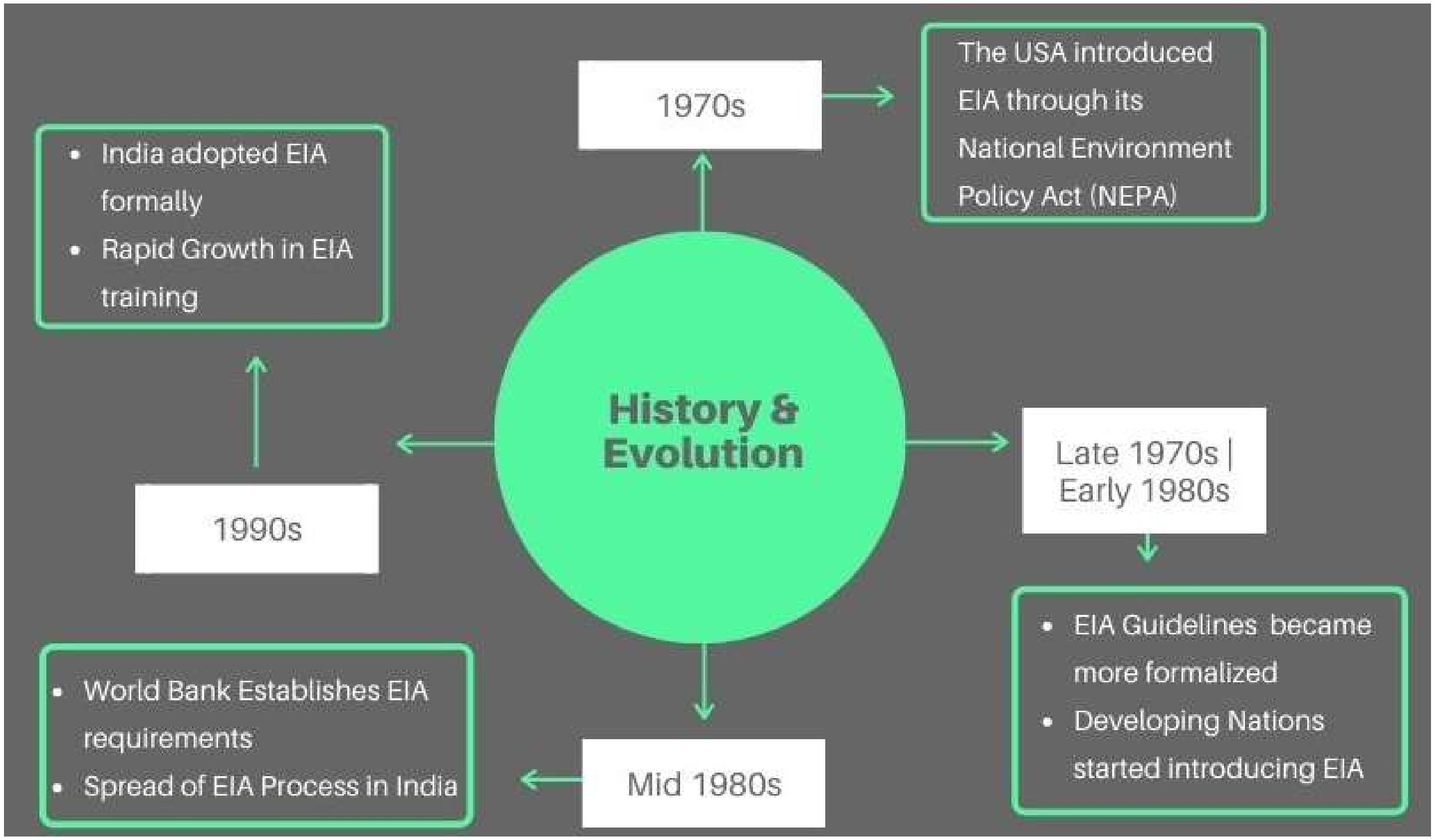
Cost-effective: The process should impose the minimum cost burdens in terms of time and finance on proponents.

Accountability: The decision maker should inform decision-making and result in appropriate levels of environmental protection and community well-being.

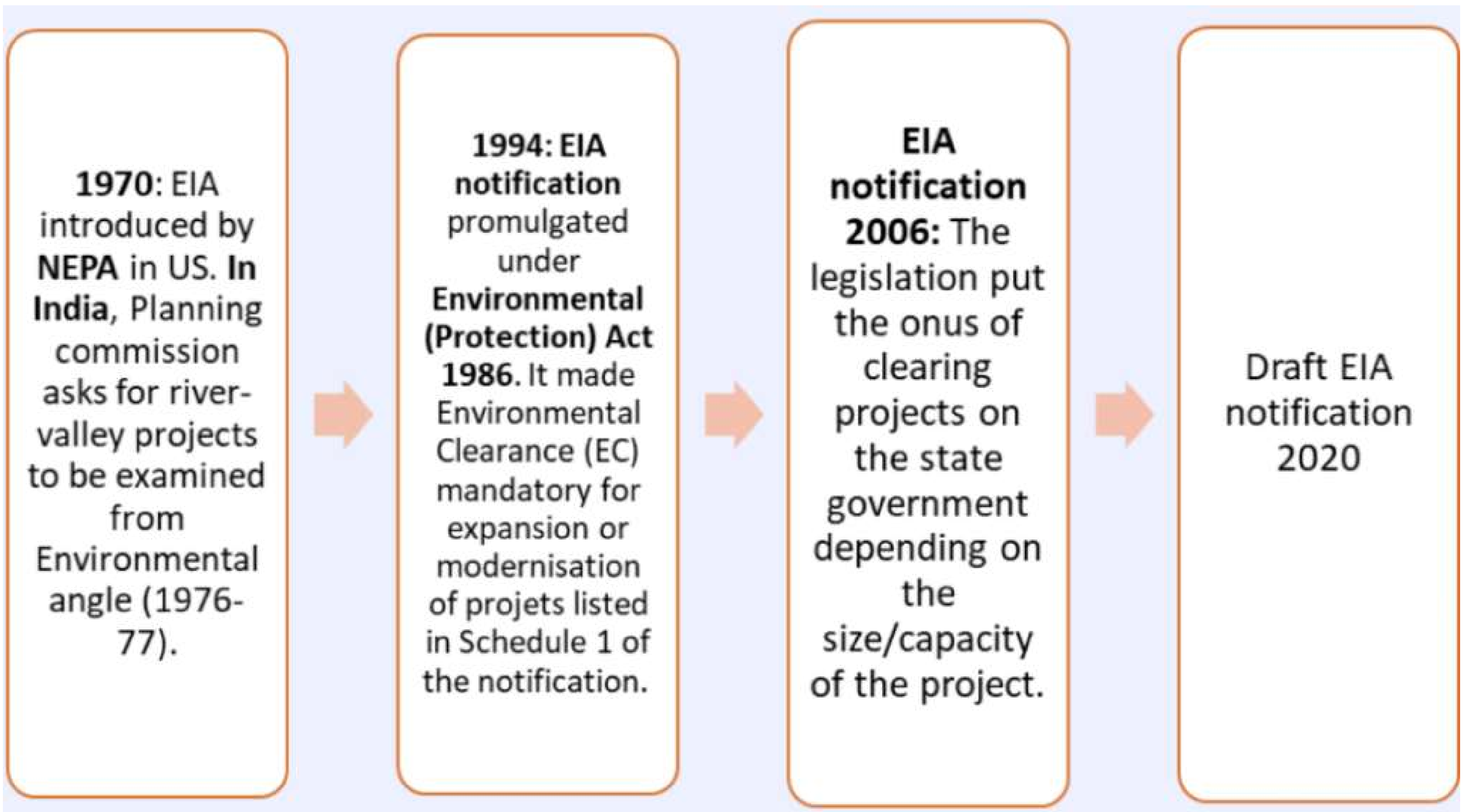
Credibility: The process should be carried out with professionalism, fairness, impartiality and balance and be subject to independent checks and verification.

Efficient: The process should achieve the objectives of EIA within the limits of available information, time, resources and methodology.

HISTORY AND EVOLUTION



STATUS OF EIA IN INDIA



CATEGORIZATION OF PROJECTS AND ACTIVITIES

- **Category A projects** require mandatory environmental clearance and thus they do not undergo the screening process.
- **Category B projects** undergo a screening process and are classified into two types.
  - **Category B1 projects (Mandatorily requires EIA).**
  - **Category B2 projects (Do not require EIA).**
- Thus, Category A and Category B1 projects undergo the complete EIA process, whereas Category B2 projects are excluded from the complete EIA process.

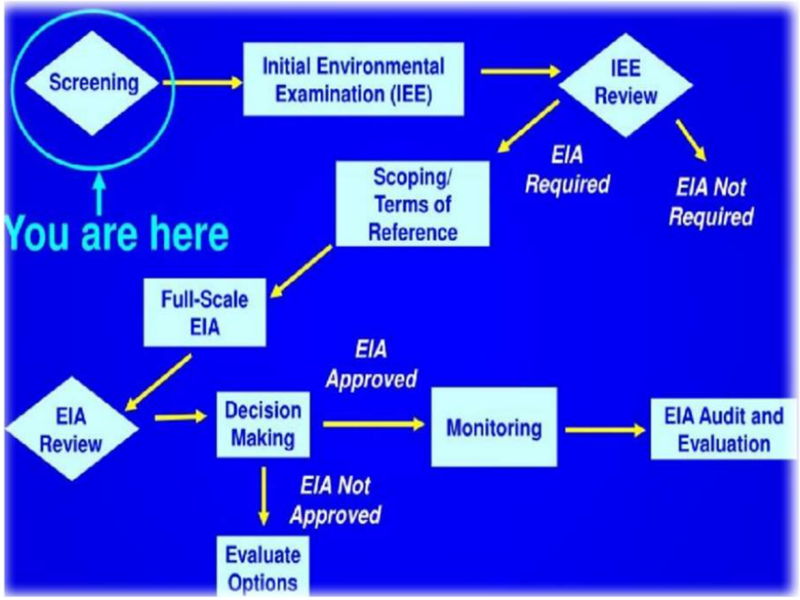
All projects or activities included as Category ‘A’ in the Schedule, including expansion and modernization of existing projects or activities and change in product mix, shall require prior environmental clearance from the Central Government in the Ministry of Environment and Forests (MoEF) on the recommendations of an Expert Appraisal Committee (EAC) to be constituted by the Central Government for the purposes of this notification;

All projects or activities included as Category ‘B’ in the Schedule, including expansion and modernization of existing projects or activities as specified in sub paragraph (ii) of paragraph 2, or change in product mix as specified in sub paragraph (iii) of paragraph 2, but excluding those which fulfill the General Conditions (GC) stipulated in the Schedule, *will* require prior environmental clearance from the State/Union territory Environment Impact Assessment Authority (SEIAA). The SEIAA shall base its decision on the recommendations of a State or Union territory level Expert Appraisal Committee (SEAC) as to be constituted for in this notification. In the absence of a duly constituted SEIAA or SEAC, a Category ‘B’ project shall be considered at the Central Level as a Category ‘B’ project;

STAGES IN OBTAINING ENVIRONMENTAL CLEARANCE (EC) FOR NEW PROJECTS

The environmental clearance process for new projects will comprise a maximum of four stages, all of which may not apply to particular cases as set forth below in this notification. These **four stages** in sequential order are:-

- ***Stage (1)*** Screening (Only for Category 'B' projects and activities)
- ***Stage (2)*** Scoping
- ***Stage (3)*** Public Consultation
- ***Stage (4)*** Appraisal



EIA PROCESS

EIA involves the steps mentioned below. However, the EIA process is cyclical with interaction between the various steps.

1. **Screening:** It is the process used to determine whether a proposed project or activity requires an EIA and, if so, what level of environmental review is necessary.
2. **Scoping:** A process of interaction between government agencies and project proponents. The project's potential impacts, zone of impacts, mitigation possibilities and need for monitoring.
3. **Collection of baseline data:** Baseline data is the environmental status of the study area.
4. **Impact prediction:** Positive and negative, reversible and irreversible and temporary and permanent impacts need to be predicted, which presupposes a good understanding of the project by the assessment agency.

   It is a way of mapping the environmental consequences of the significant aspects of the project and its alternatives. The

THE FOLLOWING IMPACTS OF THE PROJECT SHOULD BE ASSESSED:

1. Air

- Changes in ambient levels and ground level concentrations due to total emissions from point, line, and area sources.
- Effects on soils, materials, vegetation, and human health.

2. Water

- Changes in quality, Sediment transport, and Saltwater intrusion.

3. Biological

- Deforestation and the shrinkage of animal habitat
- Impact on flora and fauna
- Impact on rare and endangered species, endemic species, and migratory routes of animals.

4. Land

- Changes in the land use and drainage pattern.
- Changes in land quality, including effects of waste disposal.
- Changes in shoreline/riverbank, and their stability.

5. Noise

- Changes in ambient levels due to noise generated from equipment and the movement of vehicles
- Effect on fauna and human health

6. Socio-Economic

- Impact on the local community
- Impact on economic status
- Impact on human health
- Impact of increased traffic

EIA PROCESS

5. **Mitigation measures and EIA report:** The EIA report should include the actions and steps for preventing, minimizing or bypassing the impacts or else the level of compensation for probable environmental damage or loss.

6. **Public hearing:** On completion of the EIA report, public and environmental groups living close to project site may be informed and consulted.

   Anyone likely to be affected by the proposed project is entitled to have access to the Executive Summary of the EIA. The affected persons may include:

   - local residents;
   - local associations;
   - Environmental groups active in the area
   - any other person located at the project site/sites of displacement

   They are to be given an opportunity to make oral/written suggestions to the SPCB.

EIA PROCESS

7. **Decision making:** Impact Assessment Authority, along with the experts, consults with the project-in-charge and the consultant to take the final decision, keeping in mind EIA and EMP (Environment Management Plan).

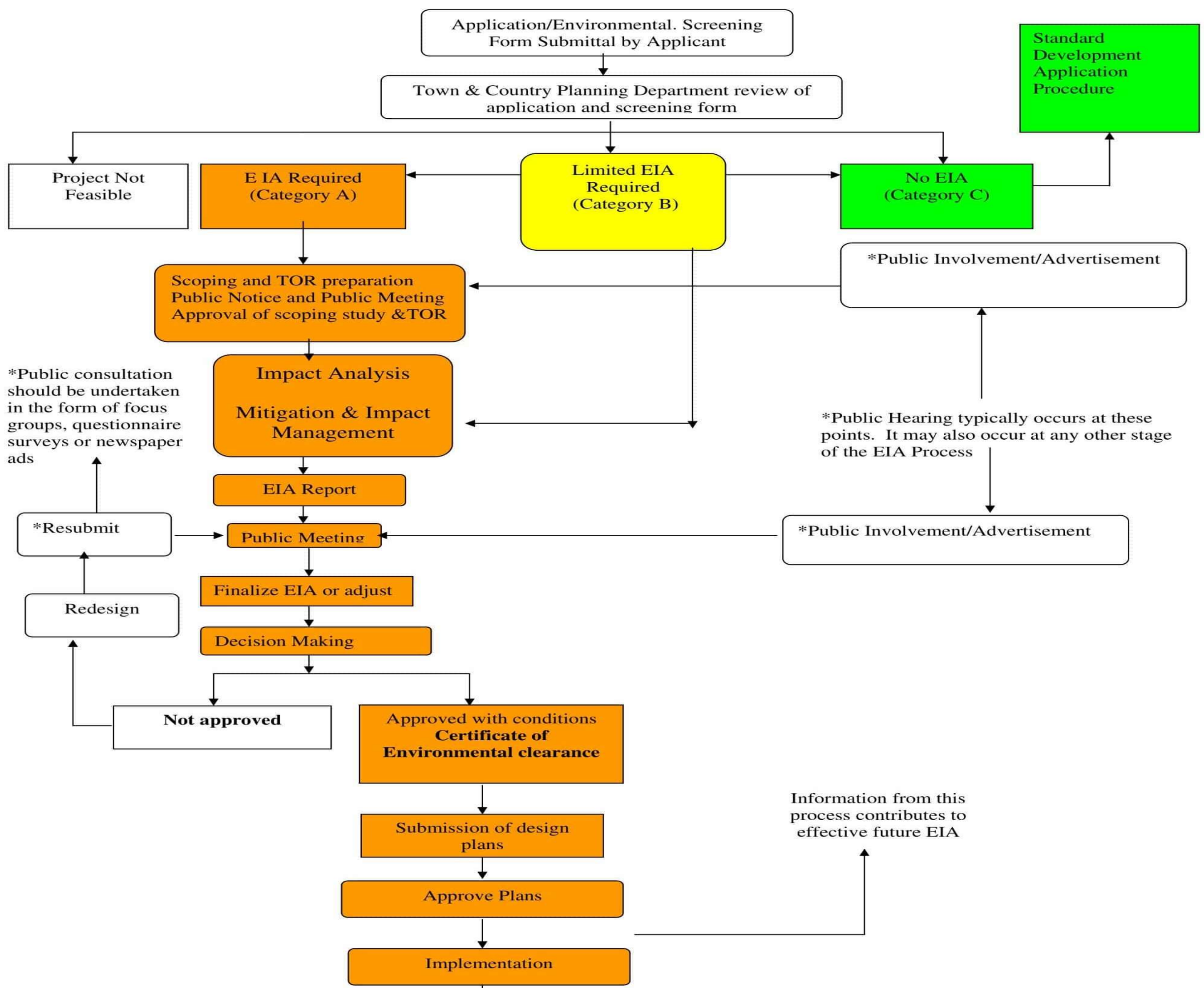
8. **Monitoring and implementation of environmental management plan:** The various phases of implementation of the project are monitored.

9. **Assessment of Alternatives, Delineation of Mitigation Measures and Environmental Impact Assessment Report:** For every project, possible alternatives should be identified, and environmental attributes compared. Alternatives should cover both project location and process technologies.

   Once alternatives have been reviewed, a mitigation plan should be drawn up for the selected option and is supplemented with an EMP to guide the proponent towards environmental improvements.

10. **Risk assessment:** Inventory analysis, hazard probability, and index also form part of EIA procedures.

Generalized EIA Process Flowchart



STAKEHOLDERS OF EIA

EIA applies to public and private sections. The six main players

(i) Those who propose the project

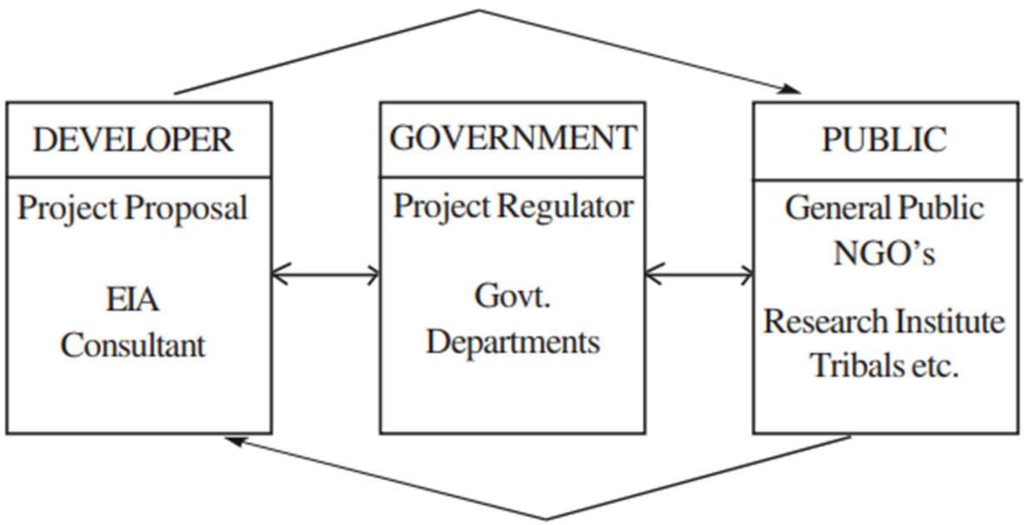
(ii) The environmental consultant who prepare EIA on behalf of project proponent.

(iii) Pollution Control Board (State or National).

(iv) Public has the right to express their opinion.

(v) The Impact Assessment Agency.

(vi) Regional centre of the Ministry of Environment and Forest.



Participants for EIA