	Topics	Lecture Hour
1	**Solid Waste Management:** Characteristics and Sources of Solid Waste, Environmental Issues Related to Solid Waste, Waste Management, Basics of Solid Waste Treatment Methods, Solid Waste Transformation through Biological and Thermochemical Methods, and Disposal Techniques.	6
2	**e-Waste Management:** Sources and Characteristics, Disposal and Recycling.	2
3	**Environmental Impact Assessment (EIA):** Introduction to Basic EIA Structure and Overview on Impacts of Air, Water, Biological and Socio-economical Aspects.	2

SOLID WASTE MANAGEMENT

References:

1. Introduction to Environmental Engineering by *M.L. Davis & D.A. Cornwell*
2. Integrated Solid Waste Management: Engineering Principles and Management Issues by *G.Tchobanoglous, H.Theisen, & S. Vigil,* McGraw-Hill Ed
3. Municipal Solid Waste Management Manual, Part I & II, *CPHEEO*, India

- Introduction
- Characteristics and Sources of Solid Waste
- Environmental Issues Related to Solid Waste

WHAT IS SOLID WASTE ?

- Solid wastes are all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted.
- The term *solid waste* here refers to all types of discarded materials, including heterogeneous masses of throwaways from the urban community and more homogeneous agricultural, industrial, and mineral wastes.
- It does not have any economic value from the point of view of the first owner.

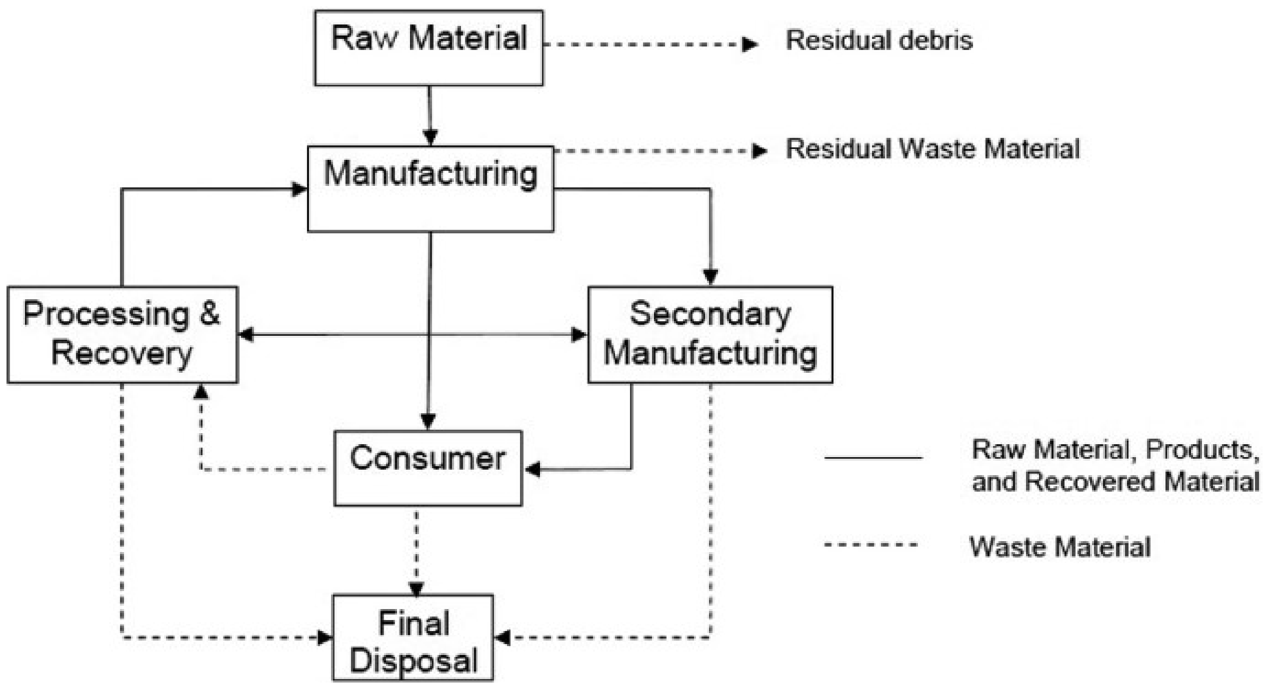
SOME TERMINOLOGIES OF SOLID WASTES

- **Refuse:** It is a general name given to all discarded materials except liquid waste. It includes all putrescible (decompose rapidly by bacteria) and non-putrescible (non-decomposable) wastes.
- **Garbage:** Putrescible wastes resulting from the growing, handling, processing, cooking, and consumption of food. E.g., Vegetables, fruits, bones, bread, etc.
- **Rubbish:** represents all non-putrescible wastes except ash. There are two categories of rubbish:
  a) Combustible: - organic in nature and includes items such as paper, cardboard, wood yard clippings, bedding, plastics, etc.
  b) Non-combustible: - are inorganic materials, which include metals, glass, ceramics, and other minerals.

SOME TERMINOLOGIES OF SOLID WASTES

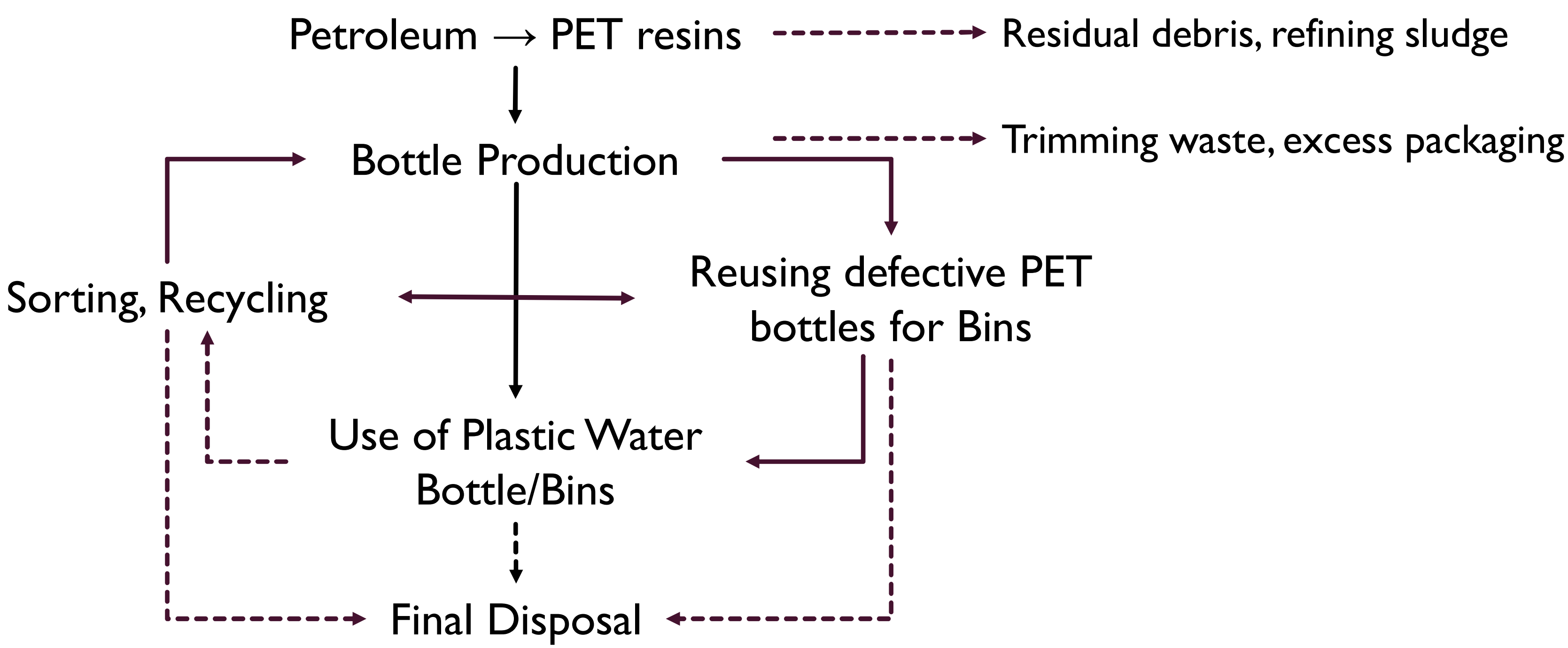
- **Scrap:** Wastes that have high metal content.
- **Debris:** These are bulky waste such as construction waste.
- **Biodegradable wastes:** These mainly refer to substances consisting of organic matter such as leftover food, vegetable and fruit peels, paper, textile, wood, etc. Due to the action of microorganisms, these wastes are degraded from complex to simpler compounds.
- **Non-biodegradable wastes:** They consist of inorganic materials such as plastic, glass, cans, metals, etc.

MATERIAL FLOW AND WASTE GENERATION



Source: Municipal Landfill Leachate Management. *Environmental Science and Engineering*. Springer

EXAMPLE: PLASTIC WATER BOTTLE



WHY SOLID WASTE: A CONSEQUENCE OF LIFE

- Waste disposal problems began when humans started living in communities, leading to waste accumulation as a consequence of life.
- The lack of any plan for the management of solid waste led to the Black Death, which killed half of 14th-century Europeans and triggered later deadly epidemics.
- The relation between public health and improper storage, collection, and disposal of solid wastes is quite clear.

ENVIRONMENTAL ISSUES RELATED TO SOLID WASTE

- **Water pollution**

  – Waste can obstruct both natural waterways and man-made drainage systems

  – Can cause both immediate and prolonged contamination of valuable water resources

- **Soil pollution**

  – Contaminants trapped in soil reduce its fertility and increase toxicity, affecting productivity

- **Air pollution**

  – Emissions occur due to wind dispersion and evaporation of volatile compounds

  – Methane accumulation may cause fire hazards or explosions

- **Health hazard**

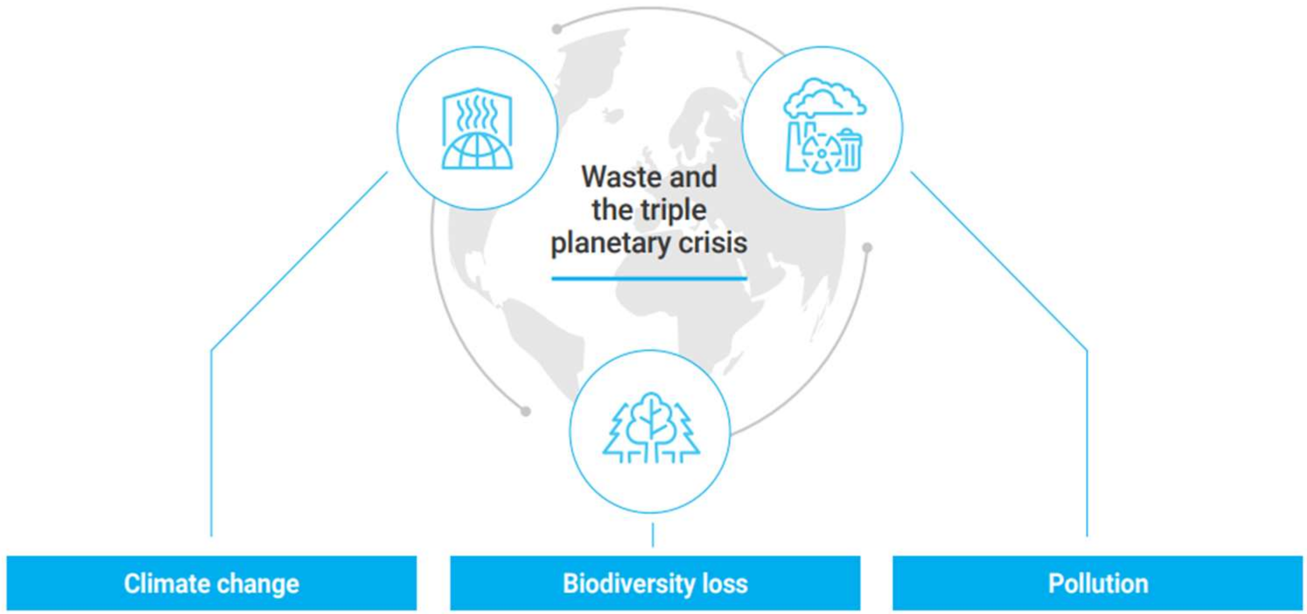
  – Pathogens may spread through air, water, or soil, posing serious public health risks

  – Unmanaged waste attracts pests like flies, rodents, and insects

- **Aesthetic and Social Impacts**

  – Poor waste management diminishes community appearance and hygiene

  – Leads to reduced property values and a decline in public morale and civic responsibility



Transporting, processing and disposing of waste generates CO_2 and other greenhouse gases and airborne pollutants that contribute to climate change.

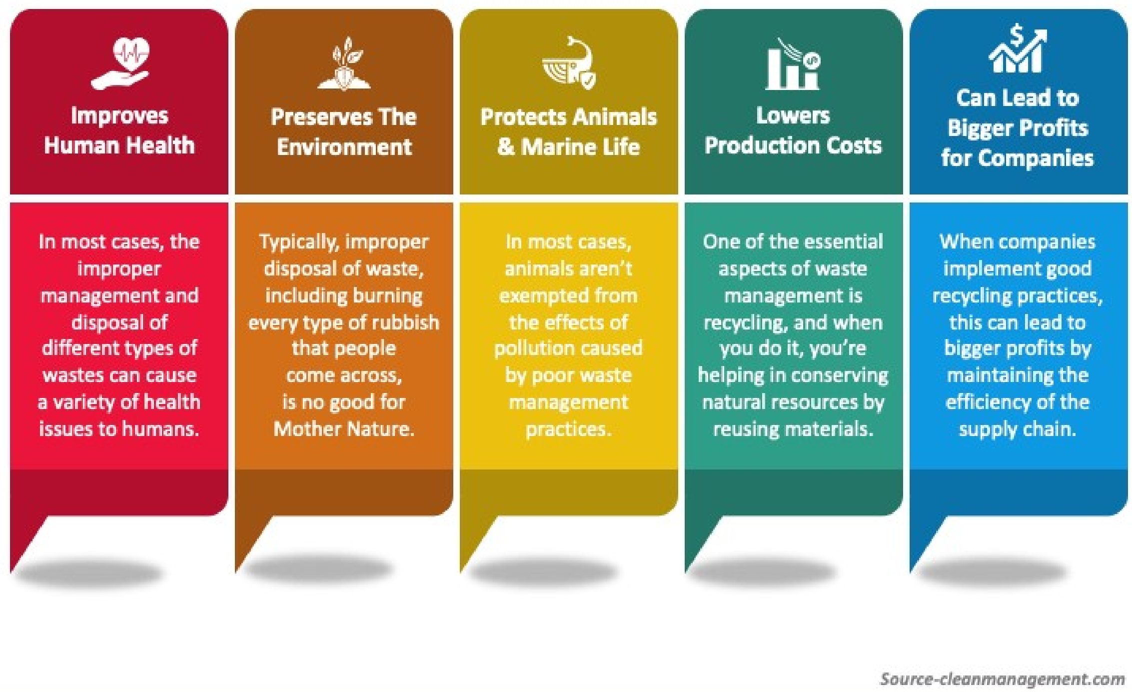
Improper waste disposal releases hazardous chemicals into soil, water, and air, causing lasting harm to ecosystems, reducing biodiversity, and contaminating the food chain.

Between 400,000 and 1 million people die every year as a result of diseases related to mismanaged waste that include diarrhoea, malaria, heart disease, and cancer.

Source: Beyond an Age of Waste - Global Waste Management Outlook, *UNEP* 2024.

WHAT IS SOLID WASTE MANAGEMENT?

Solid waste management may be defined as the discipline associated with the **control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes** in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, and that is also responsive to public attitudes.



SOURCES OF SOLID WASTE

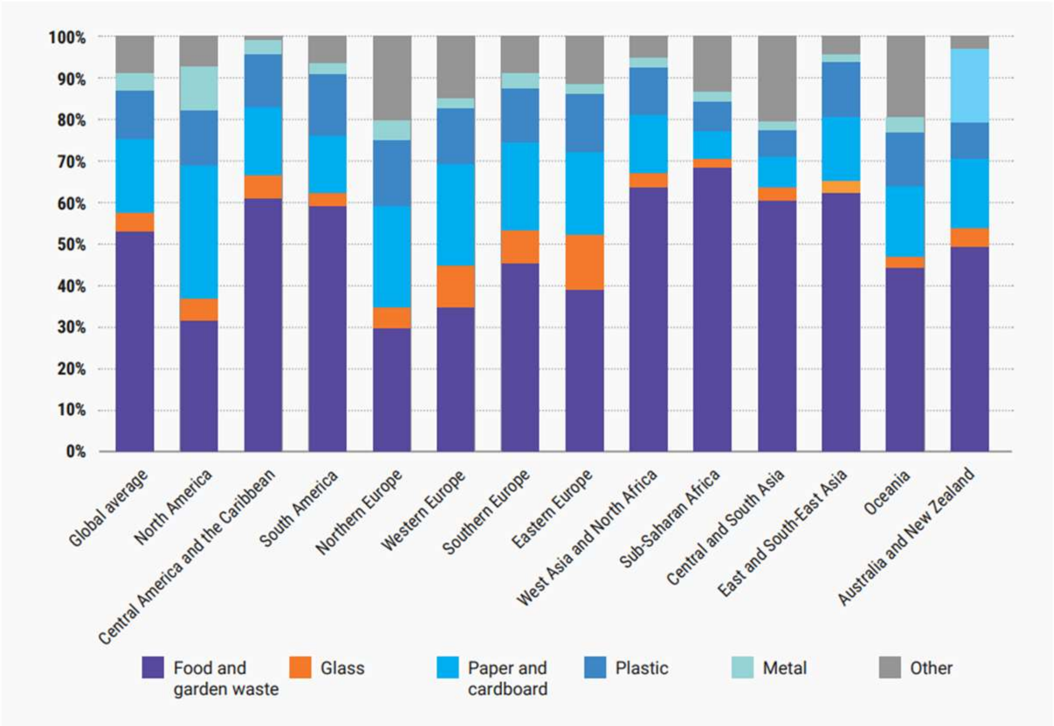
- **Residential Waste:** This type includes everyday items discarded by households, such as paper, plastics, food waste, textiles, packaging materials, yard waste, and household hazardous waste like batteries or cleaning products.
- **Commercial Waste:** Originating from commercial establishments such as offices, restaurants, shops, and warehouses, this waste type includes paper, packaging materials, food waste, and other discarded items.
- **Institutional Waste:** This mainly consists of paper, plastic, glass, etc., generated from educational, administrative, and government facilities such as schools, colleges, offices, prisons, etc.
- **Industrial Waste:** Generated by industrial processes and manufacturing activities, industrial waste comprises materials like scrap metal, chemicals, solvents, sludge, and other by-products from factories and production facilities.

SOURCES OF SOLID WASTE

- **Construction and Demolition Debris (C&D):** Generated from construction, renovation and demolition activities, C&D waste includes concrete, wood, bricks, asphalt, metals and other materials used in building structures.
- **Hazardous Waste:** Materials that pose a risk to human health or the environment due to their toxic, flammable, corrosive or reactive nature are considered hazardous. This category includes items like pesticides, certain chemicals and medical waste.
- **Electronic Waste (E-waste):** Discarded electronic devices and equipment, such as computers, televisions, smartphones and appliances, can contain hazardous materials like lead, mercury and other components that require specialized handling and disposal.
- **Agricultural Waste:** Generated from farming activities, agricultural waste includes crop residues, animal manure, pesticides and other waste produced in agricultural processes

COMPOSITION OF SOLID WASTES

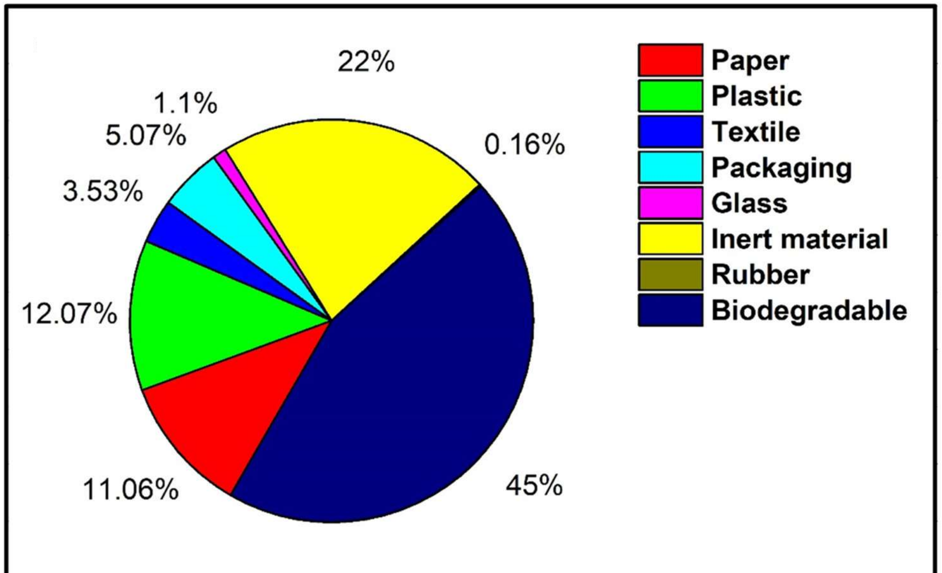
- Composition is the term used to describe the individual components that make up the solid waste stream and their relative distribution, usually by percent by weight.
- Information on the composition of solid waste is important in evaluating equipment needs, systems and management programs and plans.



Source: Beyond an Age of Waste - Global Waste Management Outlook, *UNEP* 2024.

MUNICIPAL SOLID WASTE (MSW)

- It refers to the waste arising from domestic, commercial, industrial, and institutional activities in an urban area.
- Compostable organics, inert debris, paper, plastics, leather, textile, glass, household hazardous, and metals are constituents of MSW.
- Generally, MSW in India consists of 40-55% of compostable organics.



Composition of Municipal Solid Waste in India

Source: CPCB Report (2015)

WASTE CHARACTERISTICS

- **Physical:** Information and data on the physical characteristics of solid wastes are important for the selection and operation of equipment and for the analysis and design of disposal facilities
- **Chemical:** Knowledge of the chemical compounds and their characteristics is essential for the proper understanding and behaviour of waste, as it moves through the waste management system
- **Biological:** Biodegradability helps in selecting eco-friendly treatment methods like composting and anaerobic digestion, reducing waste volume and enabling resource recovery.

PHYSICAL CHARACTERISTICS

Density (kg/m^3)

- Refers to the mass per unit volume of waste.
- **Density** (ρ) = **Mass / Volume**
- **Importance:** Affects design of collection bins, transportation capacity, and landfill volume.
- Typical MSW Density (India): 450–500 kg/m^3

Specific Gravity

- The specific gravity of a material is the ratio of its density to the density of water (in the case of solid and liquids) or air (in the case of gases).

TYPICAL DATA ON THE BULK DENSITY OF MSW

Components	Condition	Bulk Density (kg/m³)
Aluminum cans	Loose	30–44
	Flattened	150
Corrugated cardboard	Loose	210
Fines (dirt, etc.)	Loose	325–960
Food waste	Loose	130–490
	Baled	600–720
Glass bottles	Whole bottles	300–420
	Crushed	1080–1620
Magazines	Loose	480
Newsprint	Loose	12–33
	Baled	430–600
Office paper	Loose	240
	Baled	420–450

Components	Condition	Bulk Density (kg/m³)
Plastics	Mixed	42–130
	PETE, whole	18–24
	Baled	240–300
	HDPE, loose	14
	Flattened	40
Plastic bags	Baled	300–480
	Granulated	420–450
Steel cans	Unflattened	90
	Baled	510
Textiles	Loose	42–100
Yard waste	Mixed, loose	150–300
	Leaves, loose	30–150
	Grass, loose	210–300

PHYSICAL CHARACTERISTICS

2. Moistur Content (%)

- Percentage of water in the waste.
- **MC = [(Wet weight - Dry weight) / Wet weight] × 100**
- **Importance**: Influences weight, decomposition rate, and energy content of waste.
- Typical range of moisture content: 20 to 40%.
- High moisture requires careful handling in composting and incineration.

3. Particle Size Distribution

- Size range of waste particles (fine to coarse).
- **Importance:** Affects sorting, shredding, and treatment methods (e.g., composting, landfill layering).

TYPICAL DATA ON THE MOISTURE CONTENT OF MSW

Component	**Moisture Content %**	
	Range	**Typical**
Food wastes	50 – 80	70
Paper	4 –10	6
Cardboard	4 – 8	5
Plastics	1 – 4	2
Textiles	6 – 15	10
Rubber	1 – 4	2
Leather	8 – 12	10
Garden trimmings	30 – 80	60

Component	**Moisture Content %**	
	Range	**Typical**
Misc. organics	10 – 60	25
Wood	15 – 40	20
Glass	1 – 4	2
Tin cans	2 – 4	3
Nonferrous metals	2 – 4	2
Ferrous metals	2 – 6	3
Dirt, ashes, brick	6 – 12	8
MSW	**15 – 40**	**20**

NUMERICAL

Q. Estimate the overall density and moisture content of a solid waste sample with the following composition based on 100 kg of sample.

Component	% By weight	Density (kg/m³)	M.C (%)
Food waste	17	290	70
Paper	43	90	6
Card board	10	50	5
Plastics	12	65	2
Garden trimmings	8	100	60
Wood	4	200	20
Tin cans	6	90	3
Total	100		

SOLUTION

Component	% By weight	Wet weight (kg)	Density (kg/m³)	Volume (m³)	M.C (%)	Dry weight (kg)
Food waste	17	17	290	0.06	70	5.1
Paper	43	43	90	0.48	6	40.42
Card board	10	10	50	0.2	5	9.5
Plastics	12	12	65	0.18	2	11.76
Garden trimmings	8	8	100	0.08	60	3.2
Wood	4	4	200	0.02	20	3.2
Tin cans	6	6	90	0.07	3	5.82
Total	**100**	**100**		**1.09**		**79**

SOLUTION

$$\text{Density } (\text{kg/m}^3) = \frac{100}{1.09}$$

$$= 91.74 \text{ kg/m}^3$$

$$\text{M.C } \% = \frac{100 - 79}{100} \times 100$$

$$= 21\%$$

CHEMICAL CHARACTERISTICS

Lipids:

- Source: Cooking oils and fats
- High energy (~38,000 kJ/kg), biodegradable but slow process

Carbohydrates:

- Source: Starch and cellulose-rich food waste
- Readily decompose into CO_2, H_2O , CH_4

Proteins

- Organic compounds made of C, H, O, N, and amino acids.
- Commonly found in food and garden waste.

CHEMICAL CHARACTERISTICS

Natural Fibers

- Include cellulose and lignin-based materials from plants.
- Present in paper, cotton, wood, and yard waste.
- Resistant to biodegradation but highly combustible.

Plastics:

- High heating value; contributes significantly to energy recovery
- Non-biodegradable; pose environmental disposal challenges

Non-combustibles:

- Includes metals, glass, ceramics
- Do not contribute to energy; require separate handling or recycling

CHEMICAL CHARACTERISTICS

Proximate analysis:

Proximate analysis for combustible components of MSW includes the following tests

a. Moisture (loss of moisture when heated to 105°C for 1h)
b. Volatile combustible matter (additional loss of weight on ignition at 950°C in a covered crucible)
c. Fixed carbon (combustible residue left after volatile matter is removed)
d. Ash (weight of residue after combustion in an open crucible)

Ultimate analysis:

- Ultimate analysis of a waste component typically involves the determination of the percent of C, H, O, N, S, and ash.
- The results of the ultimate analysis are used to characterize the chemical composition of the organic matter in municipal solid waste.

CHEMICAL CHARACTERISTICS

Fusion point of Ash:

- It is the temperature at which the ash (from the combustion of waste) forms a solid (clinker) by fusion and agglomeration, which provides information about softening and melting conditions.
- Typical fusing temperatures for the formation of clinker from solid waste range from 1100 to 1200°C.

Energy content of waste (Calorific value):

- The heat value of waste is the energy released when waste is burned.
- Directly proportional to the carbon content of waste; inversely proportional to ash and MC.
- Depends on the composition of the waste—plastics, paper, and food waste have high energy content, while inert materials have lower energy content.
- The potential of waste material for use as fuel for incineration requires a determination of its heating value (kJ/kg).

CHEMICAL CHARACTERISTICS

$$\text{Energy (Dry basis)} = \text{Energy (Discarded basis)} \times \frac{100}{100 - \%\,Moisture}$$

$$\text{Energy (Ash-free dry basis)} = \text{Energy (Discarded Basis)} \times \frac{100}{100 - \%\,Moisture - \%Ash}$$

If energy values are not available, approximate energy values for the individual waste material can be determined by using the equation known as the ***Modified Dulong formula***:

$$\text{kJ/kg} = 337\text{C} + 1419\ (\text{H} - \text{O}/8\ ) + 93\text{S} + 23\text{N}$$

H = Hydrogen in percent by weight
O = Oxygen in percent by weight
S = Sulfur in percent by weight
N = Nitrogen percent by weight

NUMERCALS

Q. Estimate the energy content of a solid waste sample on dry basis and ash –free dry basis with the composition given in below. Take the ash content is equal to 5%.

Component	% By weight	Energy (kJ/kg)	M.C (%)
Food waste	17	4650	70
Paper	43	16750	6
Card board	10	16300	5
Plastics	12	32600	2
Garden trimmings	8	6500	60
Wood	4	18600	20
Tin cans	6	700	3
Total	100		

SOLUTION

Component	Weight (kg)	Energy (kJ/kg)	Total energy (kJ)
Food waste	17	4650	79,050
Paper	43	16750	720,250
Card board	10	16300	163,000
Plastics	12	32600	391,200
Garden trimmings	8	6500	52,000
Wood	4	18600	74,400
Tin cans	6	700	4,200
Total	100		1,484,100

SOLUTION

$$\text{Energy (Discarded)} = \frac{1484100}{100}$$

$$= 14841 \text{ kJ/kg}$$

$$\text{M.C \%} = \frac{100 - 79}{100} \times 100$$

$$= 21\% \text{ (Previous Q)}$$

$$\text{Energy (Dry basis)} = \text{Energy (Discarded basis)} \times \frac{100}{100 \quad \% \, Moisture}$$

$$= 14841 \times \frac{100}{100 - 21}$$

$$= 18786 \text{ kJ/kg}$$

SOLUTION

$$\text{Energy (Ash-free dry basis)} = \text{Energy (Discarded Basis)} \times \frac{100}{100-\%\,Moisture-\,\%Ash}$$

$$=14841 \times \frac{100}{100-21-5}$$

$$= 20055.41\ \text{kJ/kg}$$

NUMERICAL

Q. A municipal solid waste sample has the following molecular composition: $C_{970}H_{2667.5}O_{1097.6}N_{15.2}S$.

Estimate the energy content (in kJ/kg) of the MSW sample using the modified Dulong formula.

Element	Moles	Atomic Weight	Mass (g) = Moles × Atomic Wt	% Weight = (Mass / Total) × 100
C	970	12	11640	36.24
H	2667.5	1	2667.5	8.31
O	1097.6	16	17561.6	54.7
N	15.2	14	212.8	0.66
S	1	32	32	0.0996
Total			**32113.9 g**	

$$\text{Energy (kJ/kg)} = 337C + 1419\,(H - O/8) + 93S + 23N$$

$$= 337(36.24) + 1419\left(8.31 - \frac{54.7}{8}\right) + 93(0.0996) + 23(0.66)$$

$$= \boxed{14331.04\ \mathrm{kJ/kg}}$$

SOLUTION

BIOLOGICAL CHARACTERISTICS

1. Biodegradability of organic waste components:

- Volatile solids (VS) content, determined by ignition at 550°C, is often used as a measure of the biodegradability of the organic fraction of solid waste
- Using VS to represent the biodegradability of the organic fraction in solid waste can be misleading, as some materials—like newsprint and certain plant trimmings—are highly volatile but poorly biodegradable.
- Alternatively, the lignin content of waste can be used as a surrogate indicator to estimate its biodegradable fraction:

$$BF = 0.83 - 0.028\,LC$$

BF = biodegradable fraction expressed on a VS basis

LC = lignin content expressed as a percent of dry weight

BIOLOGICAL CHARACTERISTICS

Fly breeding:

- In warm climates, fly breeding becomes a significant concern during on-site waste storage.
- The presence of decaying organic matter, moisture, and warmth creates an ideal environment for fly breeding, making solid waste a potential breeding ground.

Odor:

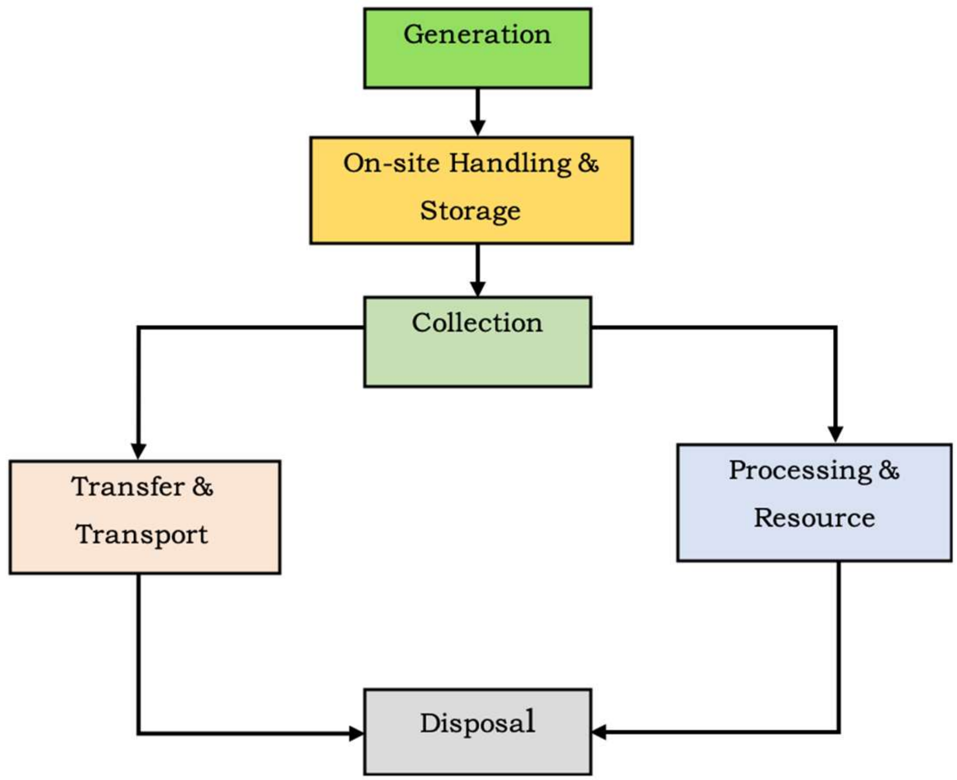
- Odor usually signals anaerobic decomposition of easily degradable organic matter present in solid waste.

- **Solid Waste Management**

FUNCTIONAL ELEMENTS OF SWM

The activities involved with the management of solid wastes from the point of generation to final disposal have been grouped into six functional elements:

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



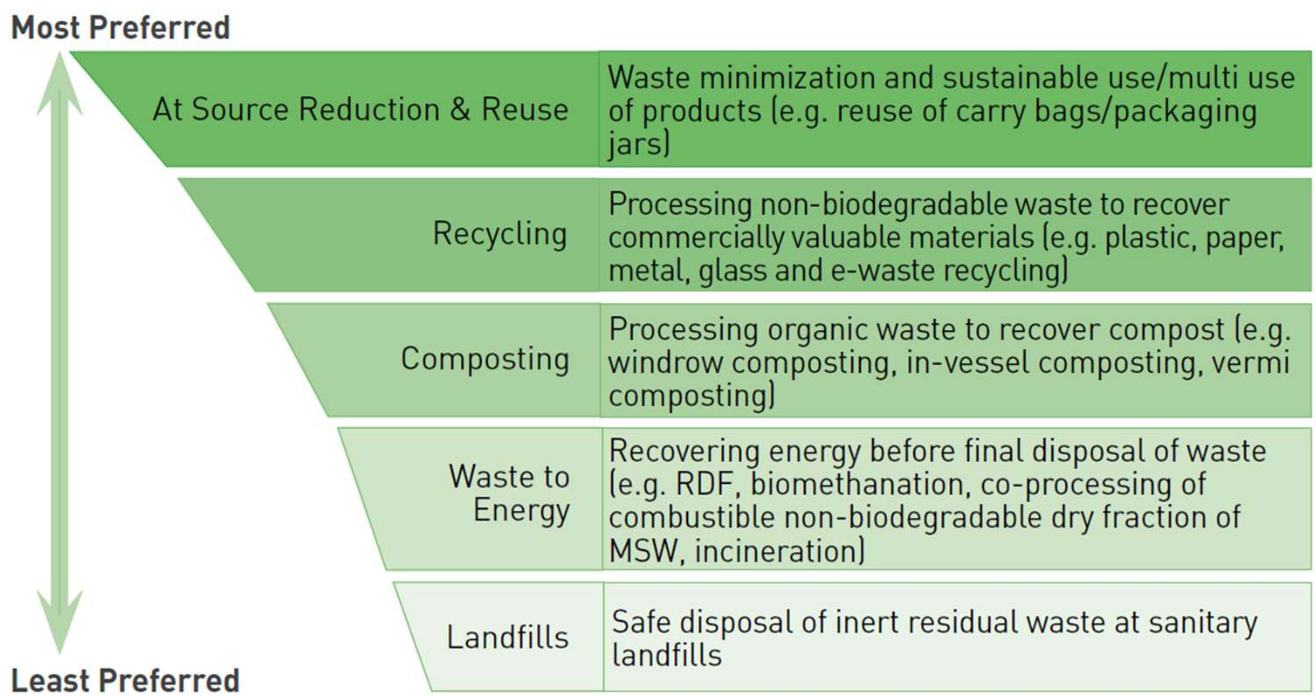
Functional element	Description
Waste generation	It is the production of waste materials from residential, commercial, and industrial activities. It involves identifying the sources, amounts, and types of waste to plan effective management strategies.
On- site handling, Storage, and processing	These are activities related to the handling, storage, and initial processing of solid waste at or close to its point of origin.
Collection	These activities associated with the gathering of solid wastes and the hauling of wastes after collection to the location where the collection vehicle is emptied.
Transfer and transport	Activities involving: 1)Transferring waste from smaller collection vehicles to larger transport systems, and 2)Transporting the waste, typically over long distances to the treatment or final disposal site.
Processing and recovery	The techniques, equipment, and facilities used to enhance the efficiency of other solid waste management functions and to recover usable materials, energy, or conversion products from solid waste.
Disposal	Disposal is the ultimate fate of all solid wastes, be they residential wastes, semi-solid wastes from municipal and industrial treatment plants, incinerator residues, composts or other substances that have no further use to the society.

GUIDING PRINCIPLES FOR MSW MANAGEMENT

- The Integrated Solid Waste Management System
- Extended Producer Responsibility
- Decentralized Waste Management Systems
- Integration of the Informal Sector

GUIDING PRINCIPLES FOR MSW MANAGEMENT

- **Integrated Solid Waste Management (ISWM)**
  - It promotes a waste management hierarchy focused on minimizing disposal and maximizing resource efficiency and conservation.
  - It prioritizes waste management options based on their environmental, economic, and energy impacts.



Source: Municipal Solid Waste Management Manual, Part II: The manual, *CPHEEO* (2016)

GUIDING PRINCIPLES FOR MSW MANAGEMENT

- **Extended Producer Responsibility (EPR)** ensures that producers are accountable for post-consumer waste, promoting recycling, reuse, and safe disposal, especially for hazardous and e-waste.
- **Decentralized Waste Management Systems** reduce the load on centralized infrastructure, lower transportation costs, and enable community-driven, locally adaptable solutions.
- **Integration of the Informal Sector** recognizes and empowers waste pickers and recyclers, creating livelihoods and strengthening the circular economy through formal inclusion and capacity building.

THE 4 RS - REDUCE, REUSE, RECYCLE AND RECOVER

Reduce: Minimizing Resource Use at the Source

- Use fewer materials per product without compromising function or quality.
  E.g., refillable containers instead of single-use packaging; rechargeable batteries over disposable ones.
- Extend product lifespan to delay replacement.
  E.g., durable plastic furniture vs. low-cost wooden items; synthetic fabrics over natural ones.
- Avoid or minimize the need for products where possible.
  E.g., digital media replacing printed material; gas pipelines instead of gas cylinders.
- While disposables offer convenience and hygiene, they significantly increase resource use and waste generation.

THE 4 RS - REDUCE, REUSE, RECYCLE AND RECOVER

Reuse: Giving Products a Second Life

- Repurpose plastic, metal, and glass containers for household storage.

E.g., Old glass jars can be repurposed in a variety of different ways, from storing dry goods in your pantry to using them as reservoirs for candles.

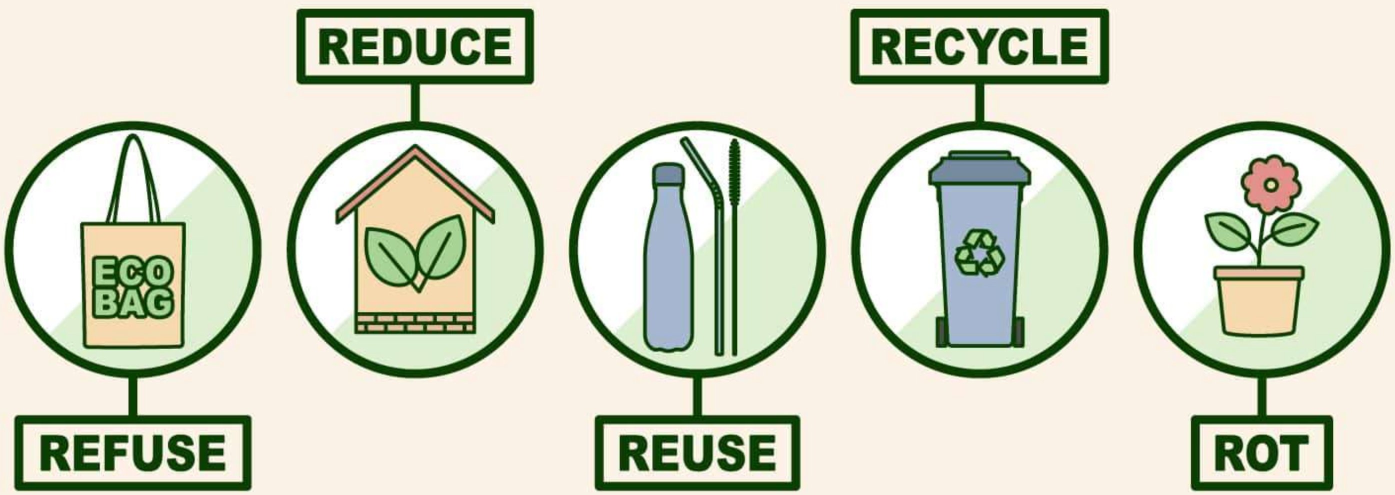
Recycle: Transforming Waste into Resources

- Separate and process materials into new products.
- Common recyclables: plastics, paper, metals (steel/aluminum), glass, and organic waste (through composting).

Recover: Extracting Value from Mixed Waste

- In cases of unsegregated waste, valuable materials are recovered at centralized processing facilities.

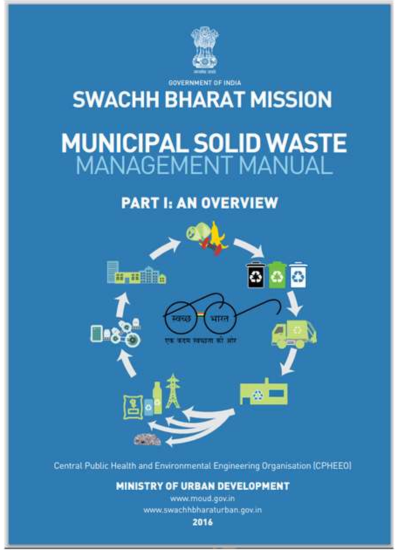
The 5 R's of
ZERO WASTE

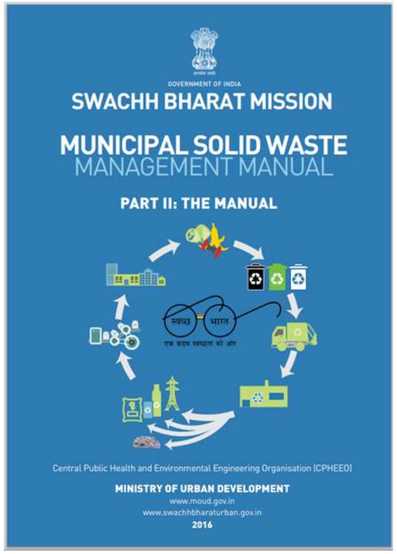


- **Solid Waste Management Rules**

GOVERNMENT INITIATIVES FOR STRENGTHENING WASTE MANAGEMENT

- The Government of India introduced the Solid Waste Management (SWM) Rules, 2016 to improve and standardize waste management practices.
- The Central Pollution Control Board (CPCB) developed criteria for selecting waste processing technologies in line with National Green Tribunal (NGT) guidelines.
- The Ministry of Urban Development released a step-by-step manual (CPHEEO, 2016) to guide local authorities in establishing effective solid waste management systems.





KEY FEATURES OF SOLID WASTE MANAGEMENT RULES, 2016

Scope Extended

- Applicable to: Every individual, residential and commercial establishment, institutional premises, bulk generators, railways, airports, industries, and street vendors.
- Covers urban and rural areas (including census towns, not just municipalities).

Waste Segregation at Source

- Waste generators must segregate waste into:
  - Biodegradable
  - Non-biodegradable
  - Domestic hazardous waste
- Segregated waste must be handed over to authorized waste collectors.

KEY FEATURES OF SOLID WASTE MANAGEMENT RULES, 2016

Responsibilities of Generators

- Bulk generators (e.g., hotels, schools, offices) must:
  - Process and dispose of biodegradable waste onsite (e.g., composting).
  - Ensure no littering and segregated disposal.

Duties of Local Bodies (ULBs)

- Set up waste processing and disposal facilities.
- Promote waste segregation, door-to-door collection, and transport of segregated waste.
- Impose user fees and spot fines for littering and non-compliance.

KEY FEATURES OF SOLID WASTE MANAGEMENT RULES, 2016

Role of Manufacturers and Brand Owners

- Extended Producer Responsibility (EPR):
  - Manufacturers of disposable products (plastic, glass, metal) must establish collection systems.
  - Ensure recycling or safe disposal of products after use.

Waste Processing Emphasis

- Priority for:
  - Composting of biodegradable waste.
  - Waste-to-energy (WTE) for combustible non-recyclables.

Prohibition of Littering and Burning

- Burning of waste (in open or landfill) is strictly banned.
- Penalties for littering and non-segregation of waste.

KEY FEATURES OF SOLID WASTE MANAGEMENT RULES, 2016

Landfilling Guidelines

- Only non-recyclable, non-biodegradable, and non-combustible inert waste allowed.
- Landfills must be scientifically designed with leachate and gas management systems.

Involvement of the Informal Sector

- Integration of waste pickers and ragpickers into the formal waste management system by Urban Local Bodies (ULBs).

Time-bound Implementation

- Timelines specified for setting up infrastructure and compliance by stakeholders (e.g., ULBs given 2 years for waste processing facility setup).

- **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

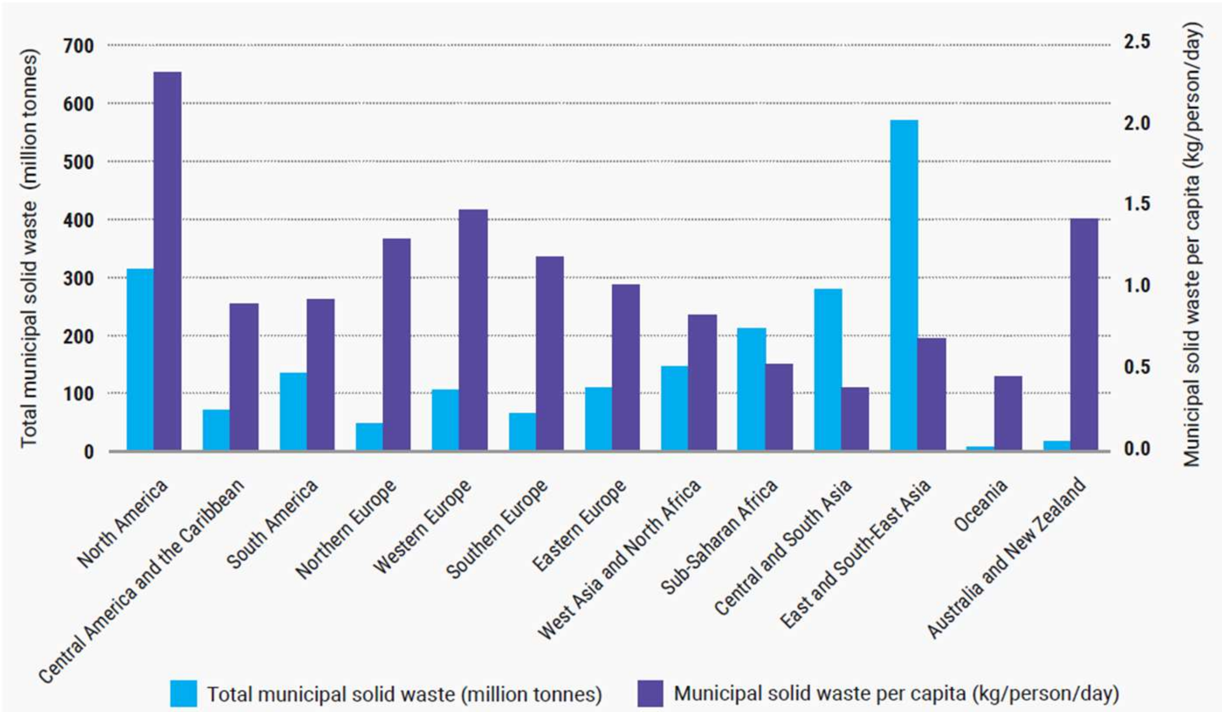
SOLID WASTE GENERATION

- Solid waste generation refers to the creation of waste materials by residential, commercial, and industrial activities.
- This function involves understanding the sources, quantities, and composition of waste to develop appropriate waste management strategies.
- The characteristics, quantities, volume and composition of solid waste generated may differ from one country to another and between urban and rural areas.
- It depends mainly upon the customs, climate, living conditions and economic standard of the area.

$$\boxed{\textbf{Waste Generation} = \textbf{Population} \times \textbf{Per Capita Waste Generation Rate}}$$

MSW GENERATION BY REGION: TOTAL MSW AND MSW PER CAPITA

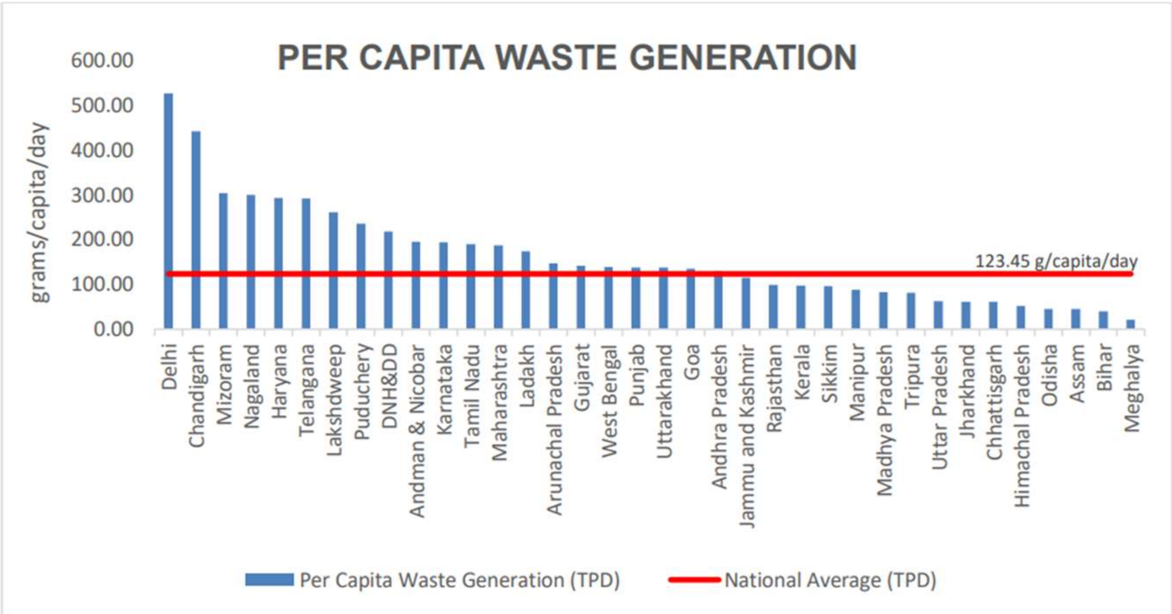
- Total MSW can be high even if per capita waste is low, especially in densely populated regions like Central and South Asia.
- North America and South Asia generate similar total waste, but North America has a much higher waste per person.
- Rapidly growing middle-income countries are facing rising waste challenges due to limited waste management infrastructure.



Source: Beyond an Age of Waste - Global Waste Management Outlook, *UNEP* 2024.

WASTE GENERATION RATES IN INDIA

- The quantity of waste from various cities was accurately measured by NEERI.
- On the basis of quantity transported per trip and the number of trips made per day the daily quantity was determined.
- The quantity of waste produced is lesser than that in developed countries and is normally observed to vary between 0.1-0.6 kg/capita/day.



Source: Annual Report on Solid Waste Management, 2021-2022, CPCB.

NUMERICAL

Q.

a. A residential academic campus has a population of 25,000 people, of which 10,000 are students. The students generate waste at 0.3 kg/cap/d, and the permanent residents generate 0.5 kg/cap/d. Determine the total waste generated per day during the academic session.

b. During vacation time, half the students leave campus. What is the total waste generation rate/day during the vacation period?

SOLUTION

a. **Total waste generated per day during academic session:**

Total population = 25,000

No. of students = 10,000

No. of permanent residents = 25,000 − 10,000 = 15,000

Waste (students) $= 10{,}000 \times 0.3 = 3{,}000$ kg/day

Waste (residents) $= 15{,}000 \times 0.5 = 7{,}500$ kg/day

Total waste $= 3{,}000 + 7{,}500 = 10{,}500$ kg/day

SOLUTION

b. Total waste during vacation:

Remaining students during vacation = $10{,}000 \times 0.5 = 5{,}000$

Permanent residents remain the same = 15,000

Waste (students) $= 5{,}000 \times 0.3 = 1{,}500$ kg/day

Waste (residents) $= 15{,}000 \times 0.5 = 7{,}500$ kg/day

Total waste $= 1{,}500 + 7{,}500 = 9{,}000$ kg/day

VARIATION IN SOLID WASTE GENERATION

- Income and extent of resource consumption (degree of development or economic conditions)
- Extent of materials recovery and conservation measures (the 4 Rs)
- Geographic location
  - Population size (total SW gen rate not per capita)
  - Geographic (climate) conditions
  - Number of persons/dwelling
- Public attitude
- Legislation
- Seasonal variations
  - Winter vs. summer or monsoon vs. other
  - Locations with Fluctuating Populations
    - Tourist or pilgrimage sites experience significant variation in waste generation between peak and off-seasons.
    - Educational campuses produce less waste during vacation periods compared to the regular academic year.

- **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

ONSITE HANDLING

- Refers to the activities involved in handling waste at the point of generation until it is placed in designated storage containers for collection.

Importance of On-site Handling:

- Reduces waste volume through basic pre-treatment or compaction.
- Alters physical form to ease handling and storage (e.g., shredding, grinding, folding).
- Enables recovery of useful or recyclable materials at source.
- Facilitates segregation, as mandated by SWM Rules, 2016, improving efficiency in downstream management.

Why Source Segregation Matters:

- Minimizes contamination, making collection, transport, and processing more efficient.
- Enhances recovery and recycling of materials, reducing the use of virgin resources.
- Supports climate action goals by lowering emissions from mixed waste processing.

STORAGE

- Storage is an important element in the SWM, always accompanied by separation process.
- It depends on the quality and quantity of waste generated.
- Storage containers should be:
  - Waterproof, rust-resistant, washable, and preferably made of galvanized iron or durable plastic.
  - Fitted with tight lids, lightweight, with side handles, and easy to lift when full.
  - Placed on a raised platform (30 cm above ground), preferably in a shaded/cool area.
- Plastic liners help control odor, flies, and reduce cleaning needs.
- Bulk containers are ideal for high-waste-generating establishments (hotels, restaurants, malls, etc.).
- Litter bins should be placed in public spaces (25m–250m apart) and used for segregated collection (wet/dry).

- **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

COLLECTION SYSTEMS

- A municipality's responsibilities begin with collection.
- 50 to 70% of SWM budget spent on collection.
- Labor and equipment are used intensively
- Bulk of SWM problems for most cities are due to inefficiencies in collection

Importance of Waste Collection:

- Ensures public health and hygiene.
- Maintains cleanliness and aesthetics in towns and cities.
- Segregated collection (wet, dry, domestic hazardous) improves resource recovery and efficient treatment (e.g., better compost quality from pure organic waste).

TYPES OF COLLECTION

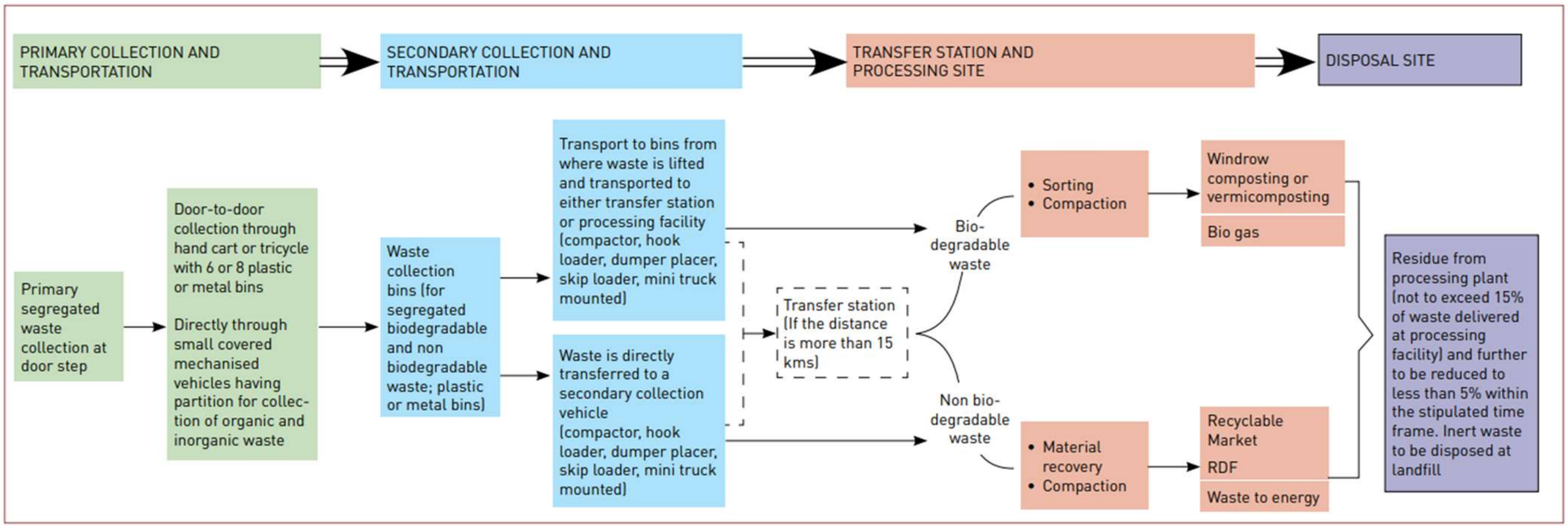
Primary Collection:

- Process of collecting, lifting and removal of segregated solid waste from source of its generation (households, shops, institutions, etc.).
- Waste is transported to local storage depots, transfer stations, or directly to processing/disposal sites.
- Must ensure separate collection of waste streams.

Secondary Collection:

- Collection of waste from community bins, storage depots, or transfer stations for transportation to processing/disposal site.
- Segregated waste must be stored in separate covered bins and kept separate throughout transportation and processing.

FLOW CHART FOR HOUSEHOLD WASTE COLLECTION, TRANSPORTATION AND DISPOSAL



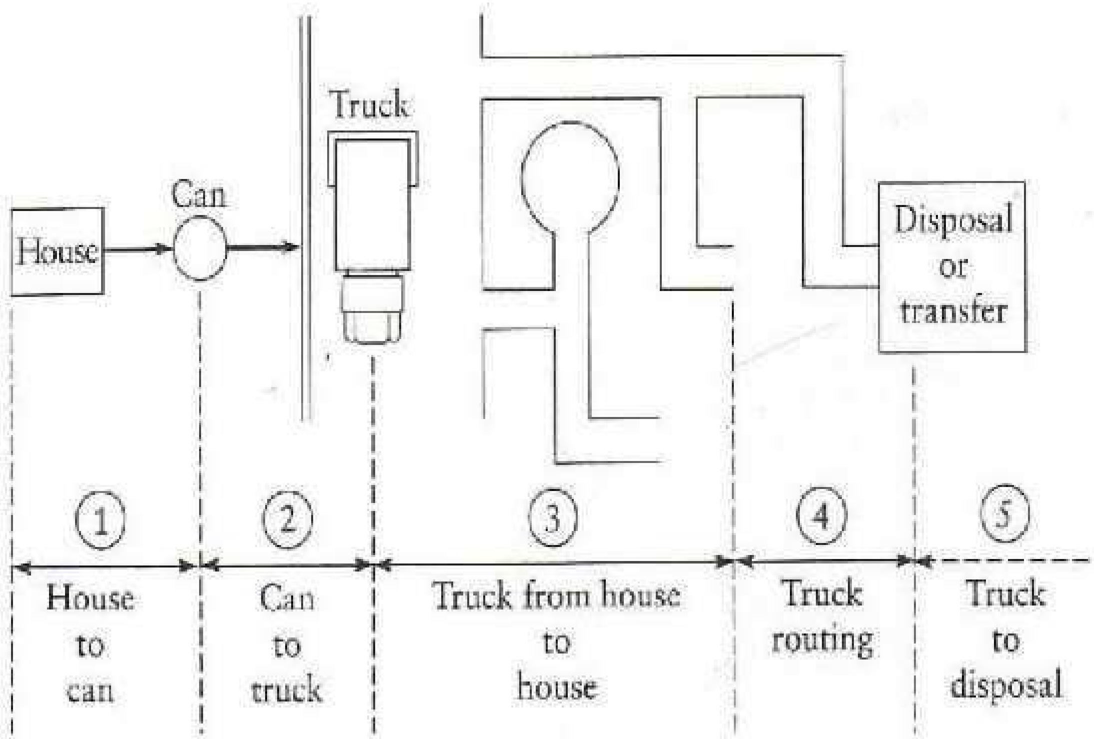
- The compactor is an appropriate vehicle for collecting biodegradable and recyclable component of MSW
- Skip loaders/ Hook loaders are preferred for collecting inert waste or Construction and Demolition waste
- Waste may be transferred to the transfer station if the processing site is located at least 15 kms away from the city

Source: Municipal Solid Waste Management manual, Part II: The manual, *CPHEEO* (2016)

OPERATIONAL BEST PRACTICES

- Daily clearance of bins/storage points to prevent overflow and littering.
- Vehicles must be: Compatible with storage/transfer station equipment.
- Covered to avoid public visibility.
- Leak-proof to prevent spillage and leachate.
- Capable of transporting segregated waste directly to recovery/processing facilities.

PHASES IN COLLECTION



NUMERICAL

Q. A community of 25,000 people is to be provided with community bins. Assume a per capita generation rate of 0.6 kg/cap-day and a bulk density of 300 kg/m^3. What should the total container capacity (m^3) be if the collection frequency is (a) once a day and (b) once in two days?

SOLUTION

Total waste/day = $25000 \times 0.6 = 15000$ kg/day

Volume = Weight/Density = $15000/300 = 50\ m^3$ per day

Container Capacity

- **Once a day collection**: Required = $50\ m^3$
- **Once in two days**: Required = $50 \times 2 = 100\ m^3$

NUMERICAL

Q. From the following data, estimate the waste generation rate per day for a residential area consisting of 1200 houses. The observation location receives all the waste collected for disposal. The observation period is one week. Also, estimate the per capita generation rate assuming 4 persons per house.

Vehicle Type	**No. of Loads**	**Volume of Vehicle (m^3)**	**Specific Weight of Solid Waste (kg/m^3)**
Compactor Truck	10	15.30	296.5
Flat Bed Load	08	1.53	133.4
Private Cars/Trucks	25	0.23	88.9

SOLUTION

- Residential area with 1200 houses, 4 persons/house
- Total population = $1200 \times 4 = 4800$ persons
- Observation period = 1 week (7 days)

Vehicle Type	**No. of Loads**	**Volume per Load (m^3)**	**Specific Weight (kg/m^3)**
Compactor Truck	10	15.30	296.5
Flat Bed Load	8	1.53	133.4
Private Cars	25	0.23	88.9

SOLUTION

Total Waste (kg) = No. of loads × Volume × Specific Weight

- Compactor Truck
  $= 10 \times 15.30 \times 296.5 = 45{,}364.5$ kg
- Flat Bed Load
  $= 8 \times 1.53 \times 133.4 = 1{,}632.43$ kg
- Private Cars
  $= 25 \times 0.23 \times 88.9 = 510.88$ kg

Total Waste (kg/week)=$45{,}364.5+1{,}632.43+510.88=47{,}507.81$ kg

SOLUTION

Daily Waste Generation Rate

- Waste per day=47,507.81/7=6,786.83 kg/ per day

Per Capita Generation Rate

- Per Capita Generation=6,786.83/4800=1.41 kg/capita/day

- **Solid Waste Management**
  1. Waste generation
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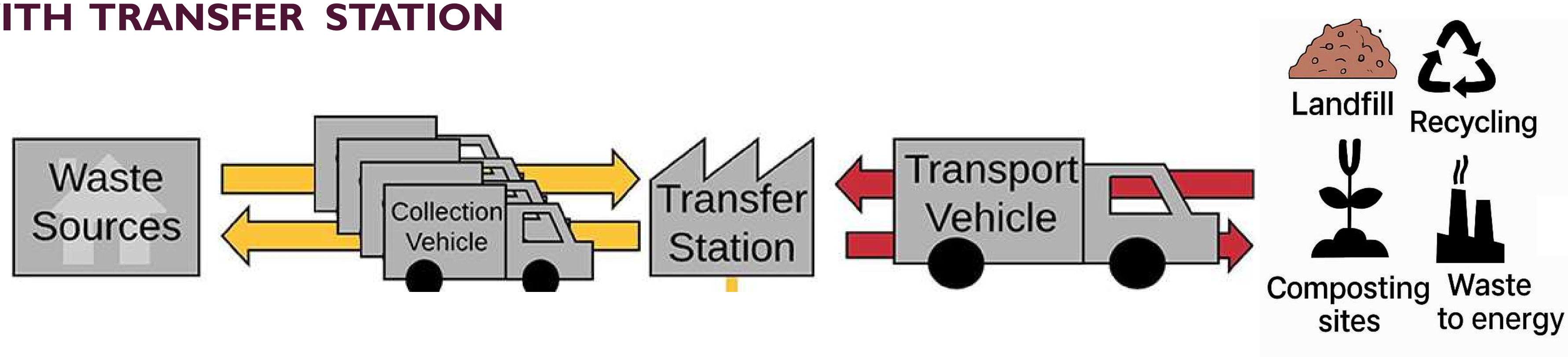
TRANSFER STATIONS

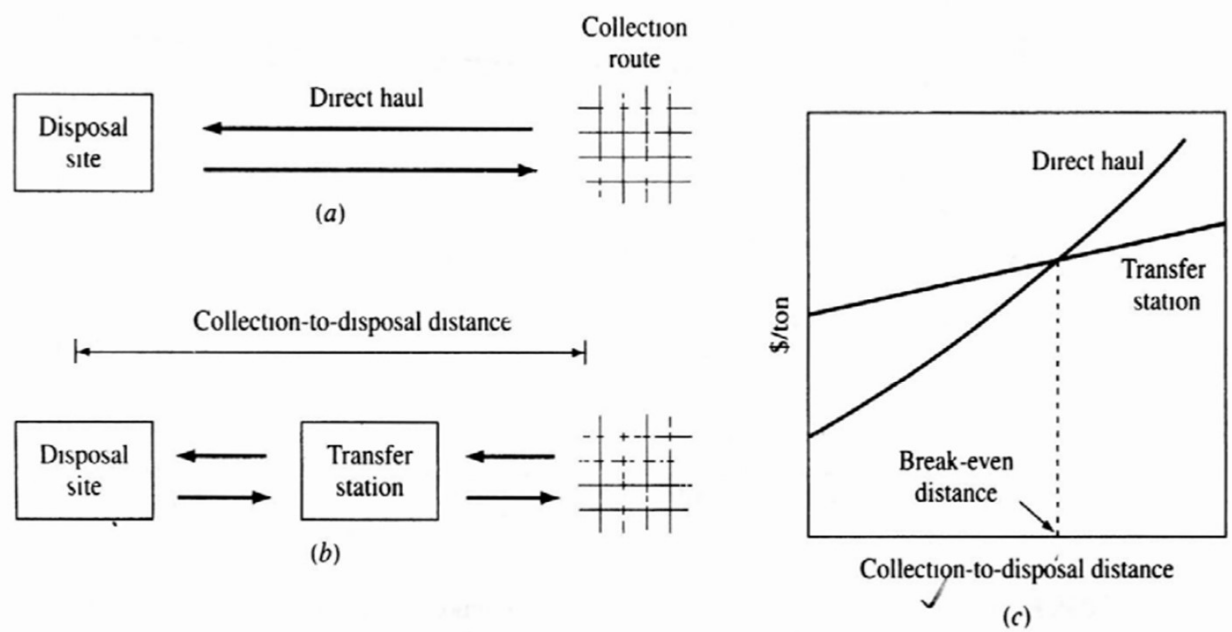
- A transfer station is an intermediate station between the disposal/processing facilities and the collection point in order to increase the efficiency of the system.
- Allows collection vehicles to offload waste quickly and return to routes.
- Larger vehicles transport bulk waste to distant disposal/processing facilities.
- Improves operational efficiency and reduces fuel and labor costs.
- Minimizes time spent by the collection crew on travel to disposal/processing facilities.
- Helps reduce traffic congestion and vehicle wear & tear.

WITHOUT TRANSFER STATION

WITH TRANSFER STATION



TRANSFER STATIONS: VIABILITY



The cost curve for a direct-haul system (*a*) starts lower but rises more steeply than the cost curve when a transfer station is included (*b*). At some distance, where the curves cross, the transfer station option becomes more cost effective (*c*).

- **Solid Waste Management**
  1. Waste generation
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  5. **Processing and recovery,**
  6. Disposal

SEPARATION, PROCESSING AND TRANSFORMATION

Goals

- Recover usable materials and energy from the waste stream
- Transform waste through physical, chemical, or biological means
- Improve efficiency of downstream treatment and disposal methods
- Enhance the quality of recovered products (e.g., compost, recyclables, fuel)
- Reduce the volume and weight of waste before final disposal

SEPARATION/PHYSICAL TRANSFORMATION

Component Separation

- Involves manual or mechanical sorting of waste into distinct material types (e.g., plastics, metals, paper, glass).
- Enhances recovery of recyclables and reduces the amount of waste requiring further treatment or disposal.

Mechanical Size Reduction

- Reduces the particle size of waste using equipment like shredders, grinders, or crushers.
- Facilitates uniform mixing, better combustion, or efficient composting in further processing steps.
- Also aids in separating embedded components (e.g., separating metal parts from composite waste).

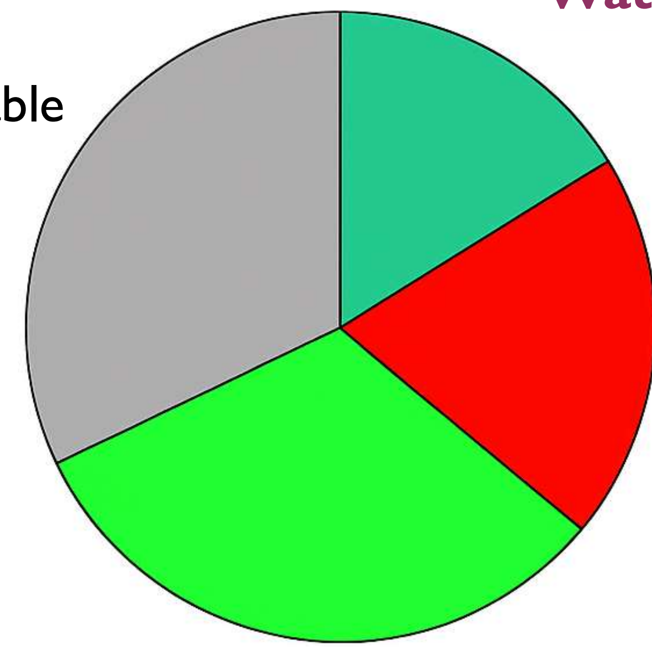
BIOLOGICAL TREATMENT

- Conversion of organic substrate in the waste to a more stabilized form through the use of biological organisms.

- It is generally of two types:

➢ **Aerobic composting:** It is the composting process in which aerobic microorganisms feed on the organic matter, converting it to new cell tissue and gases.

➢ **Anaerobic digestion:** It is the anaerobic fermentation process, where microorganisms break down organic matter in the absence of oxygen.


Biological Volatile Solids (BVS)
(Organic fraction of biodegradable components "destroyed" during treatment)
Water
Inorganic
Residual Volatile Solids (RVS)
(Organic fraction of Biodegradable components that remains after treatment + plastic)

COMPOSTING TECHNIQUES

- **Compost:** It is the end material after microbial degradation of organic matter in solid waste
- Generally applied to food and garden waste
- There are two principal methods of aerobic composting:
- **Agitated** – the material is agitated periodically to introduce air
- **Static** – the material remains static and air is blown

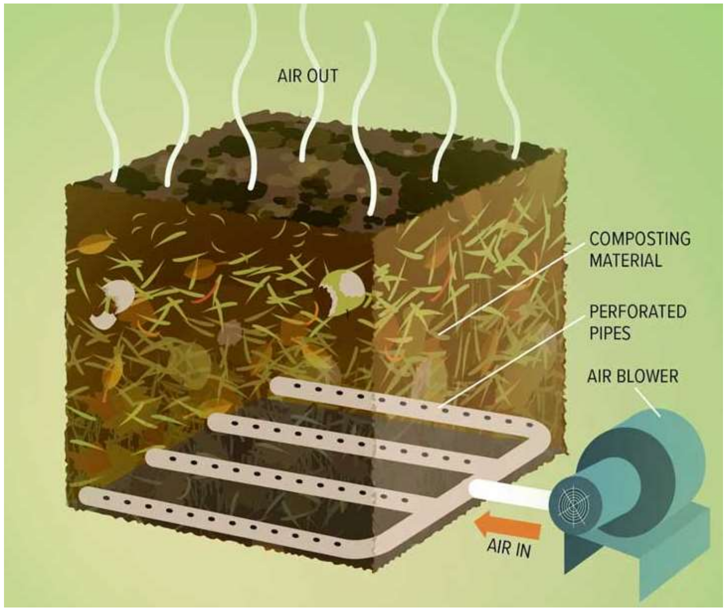
WINDROW COMPOSTING

- Organic waste is arranged in long, narrow piles (about 3 m high and 5 m wide).
- The piles are aerated by turning them regularly, usually once or twice per week, to maintain oxygen levels.
- Heat is naturally generated within the piles due to microbial activity during decomposition.
- Organic matter breaks down into CO_2 and biomass.
- The process can emit unpleasant gases such as NH_3 and H_2S.
- Active composting is typically completed in 1 to 3 weeks.
- The compost is then cured without further mixing for an additional 3 to 4 weeks to stabilize and mature.

Source: www.texasdisposal.com/blog/types-of-composting/

AERATED STATIC PILE COMPOSTING

- No manual turning; air is blown through perforated pipes (steel/PVC)
- Automated blower system controlled by timers or temperature sensors
- Requires proper C:N ratio and moisture for optimal decomposition
- Active composting: 3–5 weeks → followed by 4 weeks curing
- The system allows for better odor control and faster decomposition compared to passive methods.
- Suitable for large volumes of organic waste and limited space, making it ideal for large-scale/commercial setups.



Source: www.texasdisposal.com/blog/types-of-composting/

MECHANICAL OR IN-VESSEL SYSTEMS

- An industrial composting method where organic waste is processed inside a closed, engineered reactor vessel.
- Typically designed as plug flow systems, ensuring consistent movement and processing of material.
- Offers a rapid active composting phase (4–7 days) due to controlled internal conditions.
- Provides precise control over moisture, oxygen, temperature, and odour for efficient decomposition.
- Lower labor requirements and smaller land footprint make it suitable for urban or space-constrained setups.
- Requires 4–12 weeks of curing after processing
- More expensive due to mechanical setup and system design.

Source: www.texasdisposal.com/blog/types-of-composting/

OXYGEN REQUIREMENT IN COMPOSTING SYSTEMS

- The oxygen demand is estimated using stoichiometric equations based on the decomposition of organic matter.

$$C_aH_bO_cN_d + \left(\frac{4a+b-2c-3d}{4}\right)O_2 \rightarrow a\,CO_2 + \left(\frac{b-3d}{2}\right)H_2O + d\,NH_3$$

- In forced aeration systems (e.g., aerated static piles, in-vessel composting), the total air requirement and air flow rate are critical design parameters.
- In windrow composting, air is introduced passively through regular turning and mixing of the material.
- Odour issues may arise if anaerobic zones develop, which highlights the importance of proper aeration and consistent mixing.

NUMERICAL

Q. Determine the amount of air required to compost 1 tonne of organic solid waste using an in-vessel composting system with forced aeration. Use the following data and assumptions:

- Waste composition: $\mathbf{C_{60}H_{94}O_{38}N}$
- Moisture content of the organic fraction: 25%
- Volatile solids (VS) = 93% of total solids (TS)
- Biodegradable volatile solids (BVS) = 60% of VS
- BVS conversion efficiency = 95%
- Oxygen demand distribution over 5 days: Day 1: 20%, Day 2: 35%, Day 3: 25%, Day 4: 15%, Day 5: 5%
- Air contains 23% oxygen by weight
- Density of air = 1.2928 kg/m^3
- Apply a safety factor of 2 to ensure sufficient oxygen supply.

Also determine the peak day air flowrate.

Parameter	Value
Waste composition	$C_{60}H_{94}O_{38}N$
Moisture content (MC)	25%
Total solids (TS)	= 1 – MC = **0.75**
Volatile solids (VS)	= 0.93 × TS = 0.93 × 0.75 = **0.6975**
BVS (biodegradable volatile solids)	= 60% of VS = 0.6 × 0.6975 = **0.4185**
BVS conversion efficiency	95% = 0.95
Waste mass =	**1 tonne = 1000 kg**
Air contains O_2 =	23% by weight
Density of air =	1.2928 kg/m³
Safety factor =	2 (double the oxygen supplied)
Composting duration =	5 days
Daily oxygen demand split =	20%, 35%, 25%, 15%, 5%

SOLUTION

SOLUTION

- Mass of BVS $=1000\ \text{kg}\times 0.4185\times 0.95=397.575\ \text{kg}$
- O_2 required for $C_{60}H_{94}O_{38}N$

$$O_2\ \text{mol} = \frac{4a+b-2c-3d}{4} = \frac{4(60)+94-2(38)-3(1)}{4}$$
$$= 63.75\ \text{mol}\ O_2/molwaste$$

- Molar mass of $C_{60}H_{94}O_{38}N$:

$$M = 60(12)+94(1)+38(16)+14 = 1436\ \text{g/mol}$$

- Mass of O_2 required:

$$\left(\frac{\text{mass BVS}}{\text{moles BVS}}\right) = \left(\frac{\text{mass } O_2}{\text{moles } O_2}\right)$$

$$\frac{397.575}{1\times 1436} = \frac{X}{63.75\times 32}$$

- Mass of $O_2 = 564.8\ \text{kg}\ O_2$

- Apply safety factor

  Adjusted O_2 mass $= 564.8 \times 2 = 1129.6 \text{ kg } O_2$

- Convert to air mass (23% O_2)

  Air mass = $$\frac{1129.\ 6}{0.23} \approx 4911.3 \text{ kg}$$

- Convert to air volume

  $$\frac{4911.3}{1.2928} \approx 3799 \text{ m}^3$$

- Total air volume needed for 1 tonne of waste:

  Total air = $3799 \text{ m}^3 / 5 \text{ days}$

- Design for Peak Day (Day 2 = 35%)

  Peak air flowrate $= 3799 \times 0.35 = 1329.7 \text{ m}^3/\text{day}$

SOLUTION

ADVANTAGES

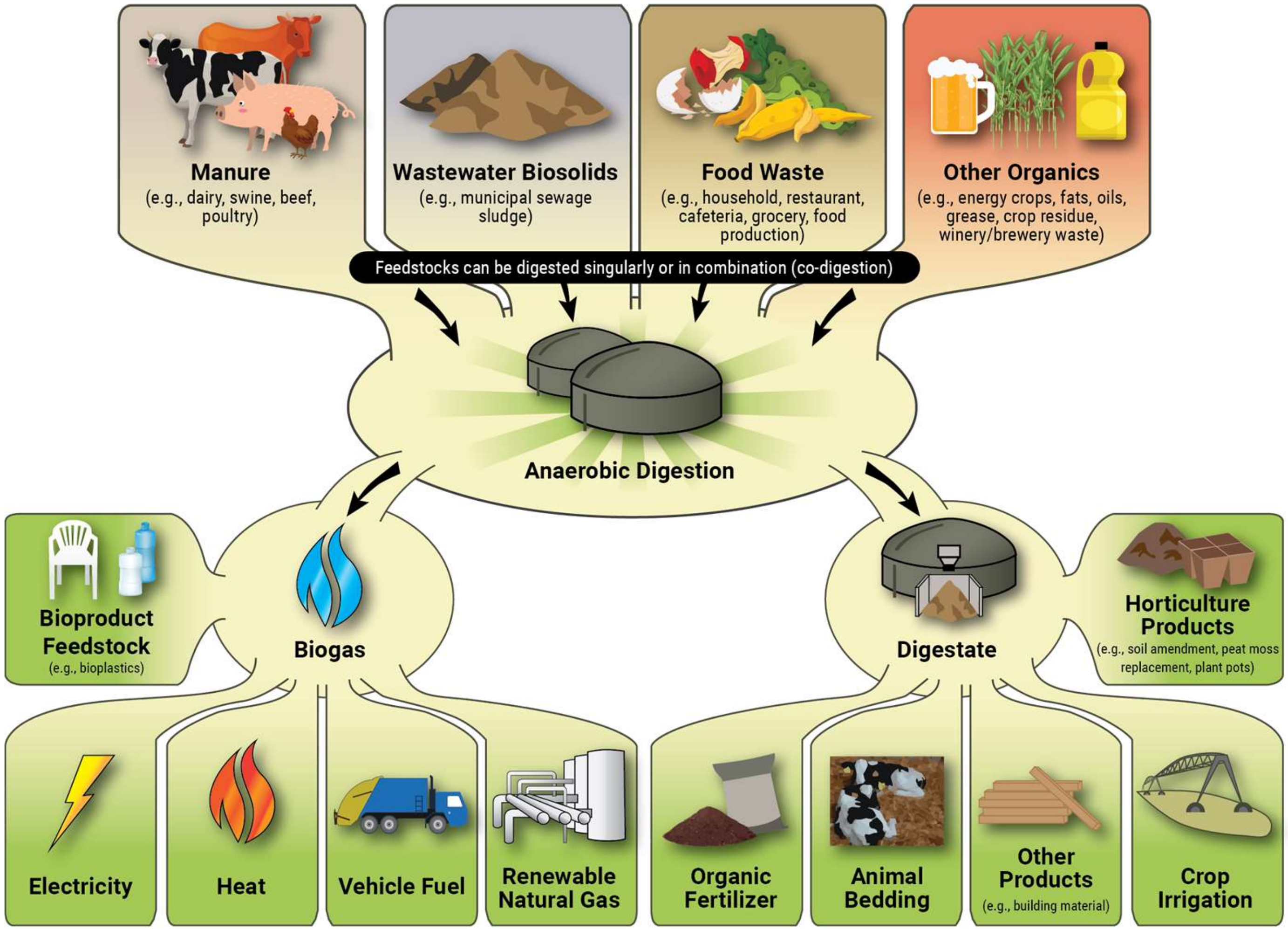
- Natural process where the end material is biologically stable
- High temperature destroys pathogens, insects, etc.
- Preserves essential nutrients like nitrogen (N), phosphorus (P), potassium (K), and trace elements, making the compost highly beneficial for soil.
- Has a low C:N ratio, indicating high nitrogen availability which supports faster decomposition and better plant nutrition.
- Produces a soil-enriching product that promotes healthy plant growth and enhances soil fertility.
- Boosts the cation exchange capacity of soil, improving its ability to retain and supply nutrients to plants.
- Enhances the water retention and nutrient-holding capacity of the soil due to the increased organic matter content.
- Reduces landfill burden by diverting biodegradable waste and converting it into a useful resource.

FACTORS AFFECTING COMPOSTING

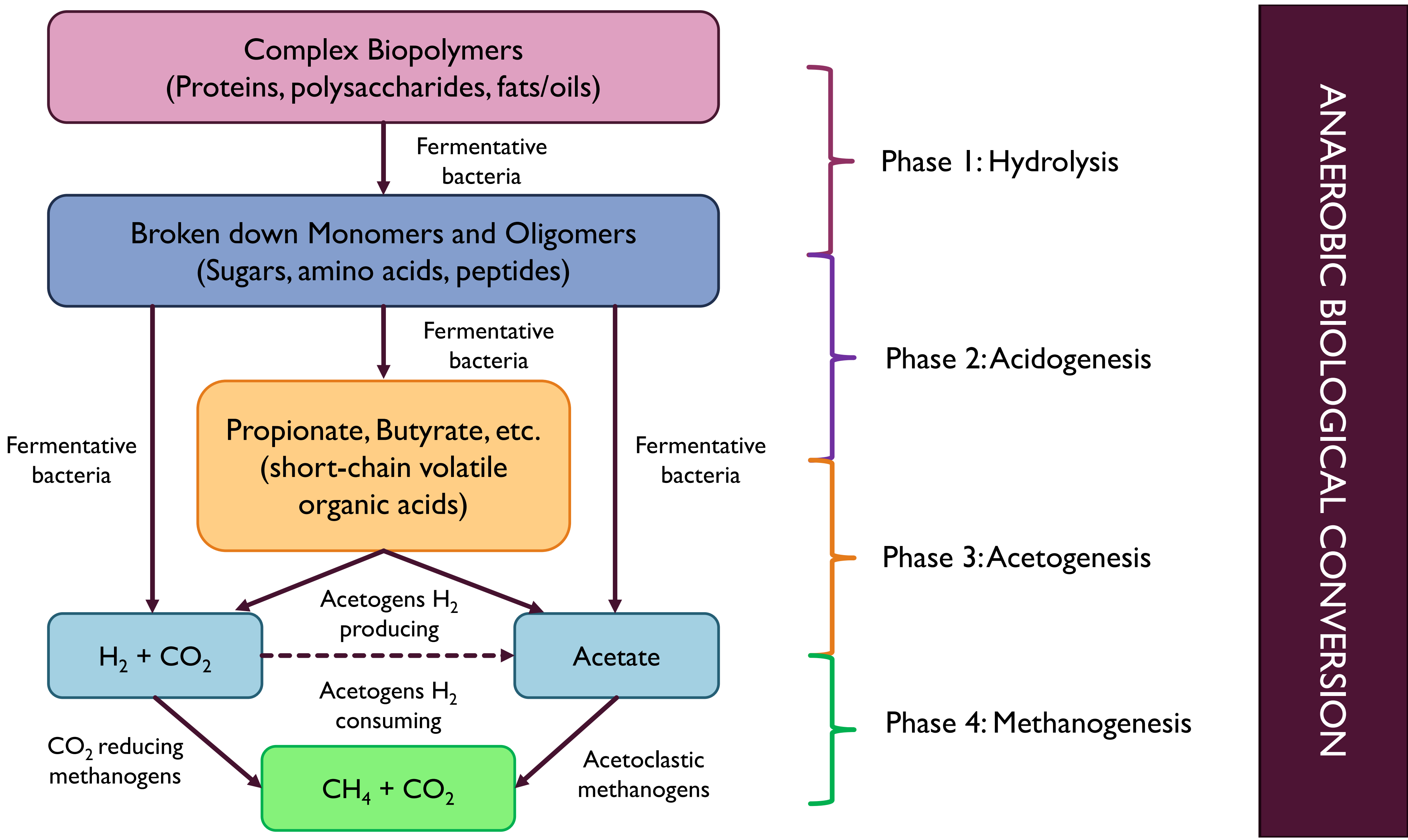
- Particle size
- Temperature, pH
- Nutrient (CHONPS) availability
  - Trace metals like Ca, Cu, Co, Mg, Mn ….
  - Ideal C:N ratio =25 to 35 (Combine low C:N material with high C:N material to create ideal mix)
- Moisture content (50 to 60%, optimum – 55%)
- Organic content
- Seed (bacteria, fungi, earthworms, beetles, etc.)
- Air or O_2 availability: degree of mixing or turning

ANAEROBIC DIGESTION

- Anaerobic digestion is a process through which bacteria break down organic matter in the absence of oxygen.
- These reactors contain complex microbial communities that break down (or digest) the waste and produce resultant biogas and digestate.
- To maintain an anaerobic treatment system, the non-methanogenic and methanogenic bacteria must be in a state of dynamic equilibrium
- Ideal conditions for digestion include:
  - pH = 6.5 – 7.5
  - need lots of alkalinity of 1,000 – 5,000 mg/L as $CaCO_3$ (pH should not drop below 6.2 as methanogenic bacteria can not function below this point)
  - A sufficient amount of nutrients (N and P) needs to be present
  - Optimal temperatures: Mesophilic 30 – 38 °C, and Thermophilic 55 – 60 °C



Source: www.epa.gov/agstar/how-does-anaerobic-digestion-work


Complex Biopolymers
(Proteins, polysaccharides, fats/oils)
Fermentative bacteria
Broken down Monomers and Oligomers
(Sugars, amino acids, peptides)
Fermentative bacteria
Propionate, Butyrate, etc. (short-chain volatile organic acids)
Fermentative bacteria
Fermentative bacteria
Acetogens H_2 producing
H_2 + CO_2
Acetate
Acetogens H_2 consuming
CO_2 reducing methanogens
CH_4 + CO_2
Acetoclastic methanogens
Phase 1: Hydrolysis
Phase 2: Acidogenesis
Phase 3: Acetogenesis
Phase 4: Methanogenesis
ANAEROBIC BIOLOGICAL CONVERSION

ANAEOBIC DIGESTION REACTION

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right)H_2O \rightarrow$$

$$\left(\frac{4a+b-2c-3d}{8}\right)CH_4 + \left(\frac{4a-b+2c+3d}{8}\right)CO_2 + dNH_3$$

NUMERICAL

Q. Determine the percentage composition of methane and carbon dioxide produced from the anaerobic digestion of 100 kg of MSW, given the following conditions:

- The MSW contains 78% organic matter, including water.
- The moisture content of the organic fraction is 25%.
- The empirical formula of the organic matter is $\mathbf{C_{60}H_{94.3}O_{37.8}N}$
- Take density of CH_4= 0.7167 kg/m³ and CO_2= 1.9768 kg/m³

- Waste to be decomposed (mass of organic) $= 100 \times 0.78 = 78 \text{ kg}$
- Mass of dry solids $= 78 \times 0.75 = 58.5 \text{ kg}$
- Moles of gas produced for

$$\text{moles } CH_4 = \left(\frac{4a + b - 2c - 3d}{8}\right) = \left(\frac{4(60) + 94.3 - 2(37.8) - 3}{8}\right) = 32 \text{ moles}$$

$$\text{moles } CO_2 = \left(\frac{4(60) - 94.3 + 2(37.8) - 3}{8}\right) = 28 \text{ moles}$$

- Mass:

$$\text{molar mass } CH_4 = (32 \text{ mole})(12 + 4(1)) = 512 \text{ g}$$

$$\text{molar mass } CO_2 = (28 \text{ mole})(12 + 2(16)) = 1232 \text{ g}$$

$$\text{molar mass MSW} = (1 \text{ mole})(12(60) + 94.3(1) + 37.8(16) + 14) = 1433 \text{ g}$$

$$\text{mass of } CH_4 = \left(\frac{58.5 \text{ kg}}{1433}\right)(512) = 20.9 \text{ kg}$$

$$\text{mass of } CO_2 = \left(\frac{58.5 \text{ kg}}{1433}\right)(1232) = 50.4 \text{ kg}$$

SOLUTION

- Volume of gas produced for

$$\text{volume of } CH_4 = \left(\frac{20.9}{0.7167}\right) = 29.2\ \text{m}^3/100\ \text{kg organic}$$

$$\text{volume of } CO_2 = \left(\frac{50.4}{1.9768}\right) = 25.5\ \text{m}^3/100\ \text{kg organic}$$

- Total gas produced:

$$\text{total gas} = (29.2 + 25.5) = 54.7\ \text{m}^3$$

$$\%\,CH_4 = \left(\frac{29.2}{54.7}\right)\ 100 = 53.4\,\%$$

$$\%\,CO_2 = 46.4\,\%$$

- Methane produced per kg of solid waste:

$$= \left(\frac{29.2}{100}\right) = 0.29\ \text{m}^3/\text{kg}$$

SOLUTION

TYPES OF ANAEROBIC DIGESTERS

1. Batch Digesters

- Simple, low-tech systems; suitable for developing countries
- Require large area; produce lower CH_4 yields
- Easier to operate but less efficient
- Cost-effective but slow process

2. Two-Stage Digesters

- Stage 1: Acidogenic microbes break down waste; helps buffering
- Stage 2: Methanogens convert acids into biogas
- Provides a stable, constant feed and higher gas production
- High setup cost, but more efficient and controlled

ADVANTAGES

- Produces biogas (mainly methane) that can be used for electricity, heating, or as fuel.
- Generates digestate, a nutrient-rich byproduct that can be used as a biofertilizer to improve soil health.
- Reduces greenhouse gas emissions by capturing methane that would otherwise escape from untreated waste.
- Operates in sealed, controlled systems, minimizing odour, pests, and pathogen spread.
- Effectively reduces the volume of organic waste, lowering landfill burden.
- Well-suited for treating high-moisture wastes like food scraps, sewage sludge, and animal manure.
- Supports resource recovery and aligns with sustainable waste management goals.