Hand Book on

Waste Management

BETC151

For First Year BE, VTU, Belgaum

Course Title:	Waste Management		
Course Code:	**BETC151**	CIE Marks	50
Course Type (Theory/Practical /Integrated)	Theory	SEE Marks	50
		Total Marks	100
Teaching Hours/Week (L:T:P: S)	3:0:0:0	Exam Hours	3 hrs of Theory
Total Hours of Pedagogy	40 hours	Credits	03

Course objectives

- To learn broader understandings on various aspects of solid waste management practiced in industries.
- To learn recovery of products from solid waste to compost and biogas, incineration and energy recovery, hazardous waste management and treatment, and integrated waste management.

Module-1 (08)

INTRODUCTION TO SOLID WASTE MANAGEMENT:
Classification of solid wastes (source and type based), solid waste management (SWM), elements of SWM, ESSWM (environmentally sound solid waste management) and EST (environmentally sound technologies), factors affecting SWM, Indian scenario, progress in MSW (municipal solid waste) management in India. Indian and global scenario of e-waste,

Module-2 (08)

WASTE GENERATION ASPECTS:
Waste stream assessment (WSA), waste generation and composition, waste characteristics (physical and chemical), health and environmental effects (public health and environmental), comparative assessment of waste generation and composition of developing and developed nations, a case study results from an Indian city, handouts on solid waste compositions. E-waste generation.

Module-3 (08)

COLLECTION, STORAGE, TRANSPORT AND DISPOSAL OF WASTES:
Waste Collection, Storage and Transport: Collection components, storage-containers/collection vehicles, collection operation, transfer station, waste collection system design, record keeping, control, inventory and monitoring, implementing collection and transfer system, a case study. Waste Disposal: key issues in waste disposal, disposal options and selection criteria, sanitary landfill, landfill gas emission, leachate formation, environmental effects of landfill, landfill operation issues, a case study.

Module-4 (08)

WASTE PROCESSING TECHNIQUES & SOURCE REDUCTION, PRODUCT RECOVERY & RECYCLING:
Purpose of processing, mechanical volume and size reduction, component separation, drying and dewatering. Source Reduction, Product Recovery and Recycling: basics, purpose, implementation monitoring and evaluation of source reduction, significance of recycling, planning of a recycling programme, recycling programme elements, commonly recycled materials and processes, a case study.

Module-5 (08)

HAZARDOUS WASTE MANAGEMENT AND TREATMENT:
Identification and classification of hazardous waste, hazardous waste treatment, pollution prevention and waste minimization, hazardous wastes management in India. E-waste recycling.

Course outcome (Course Skill Set)
At the end of the course the student will be able to:

CO1	Apply the basics of solid waste management towards sustainable development
CO2	Apply technologies to process waste and dispose the same.
CO3	Design working models to convert waste to energy
CO4	Identify and classify hazardous waste and manage the hazard

Module 1

INTRODUCTION TO SOLID WASTE MANAGEMENT

1.1 Classification of solid wastes (source and type based),
1.2 Solid waste management (SWM);
  1.2.1 Elements of SWM,
  1.2.2. ESSWM (environmentally sound solid waste management) and EST (environmentally sound technologies),
  1.2.3 Factors affecting SWM,
1.3 Indian scenario; progress in MSW (municipal solid waste) management in India.
1.4 Indian and global scenario of e-waste,

1.1 CLASSIFICATION OF SOLID WASTE

- Solid wastes are the organic and inorganic waste materials such as product packaging, grass clippings, furniture, clothing, bottles, kitchen refuse, paper, appliances, paint cans, batteries, etc., produced in a society, which do not generally carry any value to the first user(s).
- Solid wastes, thus, encompass both a heterogeneous mass of wastes from the urban community as well as a more homogeneous accumulation of agricultural, industrial and mineral wastes.
- While wastes have little or no value in one setting or to the one who wants to dispose them, the discharged wastes may gain significant value in another setting.
- Knowledge of the sources and types of solid wastes as well as the information on composition and the rate at which wastes are generated/ disposed is, therefore, essential for the design and operation of the functional elements associated with the management of solid wastes.

1.1.1 Solid wastes are classified on the basis of source of generation and type

Source-based classification:

The sources of solid wastes have been consistent, dependent on sectors and activities and these include the following:

- **Residential:** This refers to wastes from dwellings, apartments, etc., and consists of leftover food, vegetable peels, plastic, clothes, ashes, etc.
- **Commercial:** This refers to wastes consisting of leftover food, glasses, metals, ashes, etc., generated from stores, restaurants, markets, hotels, motels, auto-repair shops, medical facilities, etc.
- **Institutional**: This mainly consists of paper, plastic, glasses, etc., generated from educational, administrative and public buildings such as schools, colleges, offices, prisons, etc.

- **Municipal**: This includes dust, leafy matter, building debris, treatment plant residual sludge, etc., generated from various municipal activities like construction and demolition, street cleaning, landscaping, etc.
- **Industrial**: This mainly consists of process wastes, ashes, demolition and construction wastes, hazardous wastes, etc., due to industrial activities.
- **Agricultural**: This mainly consists of spoiled food grains and vegetables, agricultural remains, litter, etc., generated from fields, orchards, vineyards, farms, etc.
- **Open areas**: this includes wastes from areas such as Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreational areas, etc.

Type-based classification: Classification of wastes based on types, i.e., physical, chemical, and biological characteristics of wastes

- Garbage
- Ashes and residues
- Combustible and non-combustible wastes:
- Bulky wastes
- Street wastes
- Biodegradable and non-biodegradable wastes:
- Dead animals
- Abandoned vehicles:
- Construction and demolition wastes:
- Hazardous wastes:
- Sewage wastes:

Fig 1: Types of Solid Waste

1.2 SOLID WASTE MANAGEMENT (SWM)

- Solid waste management (SWM) is associated with the control of waste generation, its storage, collection, transfer and transport, processing and disposal in a manner that is in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, public attitude and other environmental considerations.

1.2.1 Elements of SWM system

A SWM system refers to a combination of various functional elements associated with the management of solid wastes. The system, when put in place, facilitates the collection and disposal of solid wastes in the community at minimal costs, while preserving public health and ensuring little or minimal adverse impact on the environment. The functional elements that constitute the system are:

- **Waste generation:** Wastes are generated at the start of any process, and thereafter, at every stage as raw materials are converted into goods for consumption. The source of waste generation, determines quantity, composition and waste characteristics.
- **Waste storage:** Storage is a key functional element because collection of wastes never takes place at the source or at the time of their generation... Onsite storage is of primary importance due to aesthetic consideration, public health and economics involved. Some of the options for storage are plastic containers, conventional dustbins (of households), used oil drums, large storage bins (for institutions and commercial areas or servicing depots), etc.
- **Waste collection:** This includes gathering of wastes and hauling them to the location, where the collection vehicle is emptied, which may be a transfer station, a processing plant or a disposal site. Collection depends on the number of containers, frequency of collection, types of collection services and routes.
- **Transfer and transport:** This functional element involves: the transfer of wastes from smaller collection vehicles, where necessary to overcome the problem of narrow access lanes, to larger ones at transfer stations; the subsequent transport of the wastes, usually over long distances, to disposal sites.
- **Processing**: Processing is required to alter the physical and chemical characteristics of wastes for energy and resource recovery and recycling. The important processing techniques include compaction, thermal volume reduction, and manual separation of waste components, incineration and composting.

- **Recovery and recycling**: This includes various techniques, equipment and facilities used to improve both the efficiency of disposal system and recovery of usable material and energy.
- **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. Thus, land use planning becomes a primary determinant in the selection, design and operation of landfill operations. A modern sanitary landfill is a method of disposing solid waste without creating a nuisance and hazard to public health.

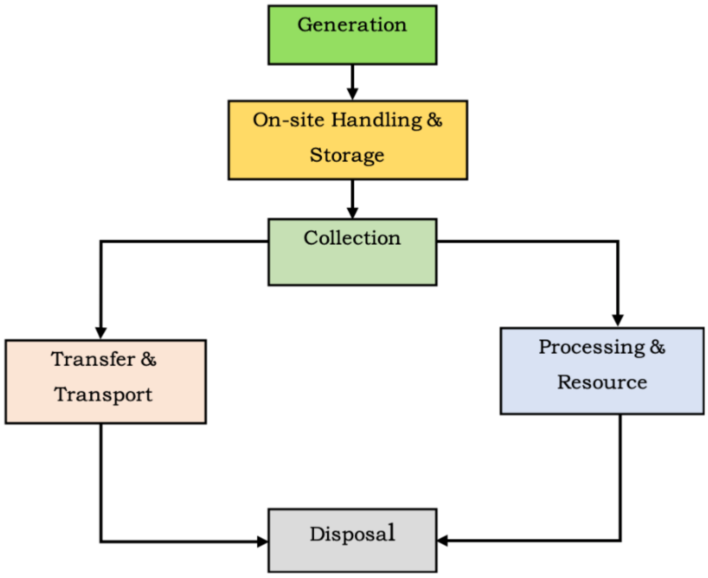

Figure 2: Elements of SWM.

1.2.2 Environmentally sound solid waste management (ESSWM):

- In any waste or resource management system, we must pay attention to the interaction between human activities and the ecosystem.
- We have to recognise that human activities including consumption of goods/services, production of wastes, etc., have a serious impact on the carrying capacity of the ecosystem.
- This in turn affects human health, as the environment deteriorates. The fundamental principles of ESSWM, which take into account economic and social issues along with environmental impact consideration, include the following:
- To ensure sustainable development of the ecosystem and human environment. To minimise the impact of human activities on the environment.
- To minimise the impact on the environment and maximise the ecosystem's carrying capacity.
- To ensure the implementation of ESSWM through environmentally sound technologies.

1.2.3 Environmentally sound technologies (EST)

EST refers to cost effective and energy efficient technologies, which generally perform better on the environment, as they do not pollute the ecosystem's vital components such as air, land or water and consider the reuse, recycling or recovery of wastes. EST can be categorised broadly as follows:

- Hard EST: This includes equipment, machines and other infrastructure with their material accessories to handle waste products and monitor/measure the quality of air, water and soil.
- Soft EST: This supports and complements hard technologies and include nature-based technologies and management tools. Nature-based technologies include processes and mechanisms nature uses within a specific ecosystem (such as vermin composting) and its carrying capacity, while management tools include system and procedures, policy and regulatory frameworks, and environmental performance standards and guidelines.

EST is selected based on the following generic criteria, the indicators of which may vary depending on the regions in which they are implemented:

- Affordability: This means low investment, reasonableness, maintenance free and durability.
- Validity: This refers to effectiveness, easy operation and maintenance.
- Sustainability: This means low impact, energy saving and cultural acceptability.

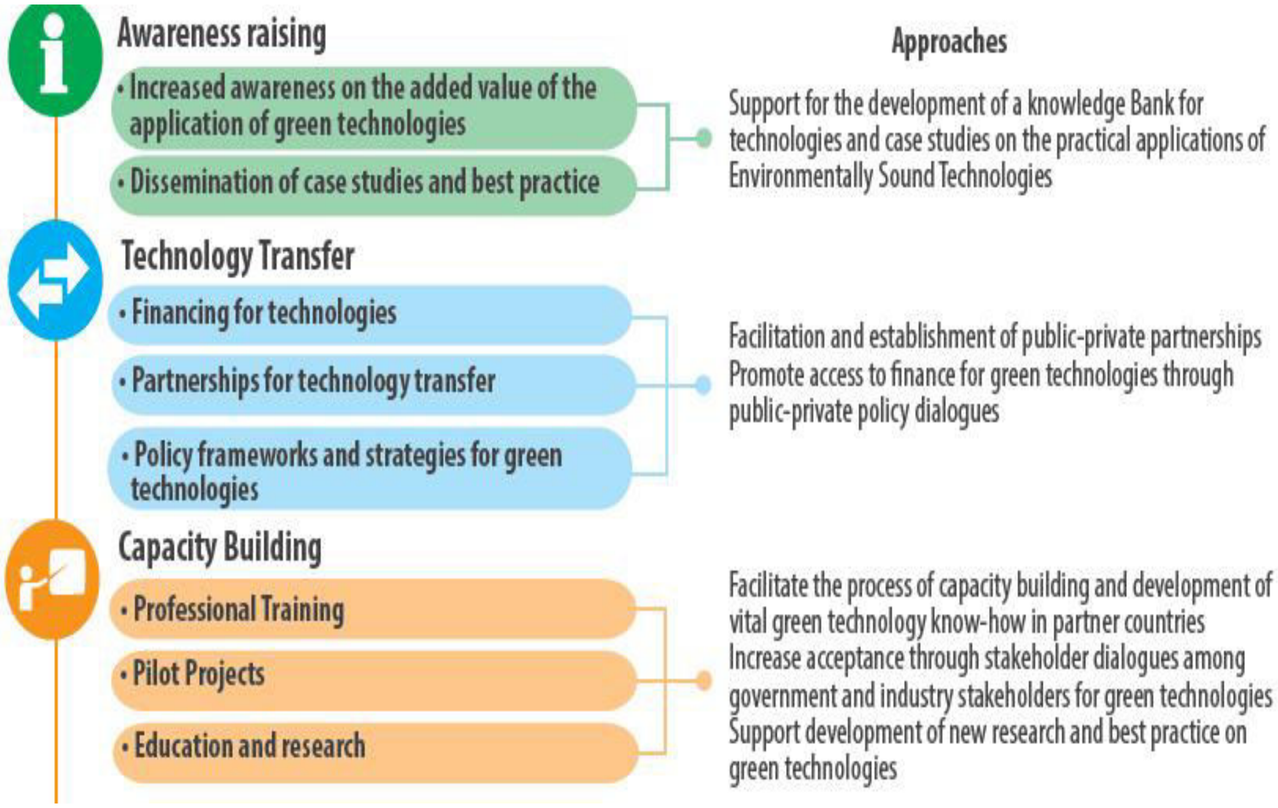

Figure 3: EST.

1.2.4 Factors affecting SWM system

Many factors influence the decision-making process in the implementation of a SWM system. Some of the factors that need to be considered in developing a SWM system are Quantities and characteristics of wastes, Climate and seasonal variations, Physical characteristics of an urban area, Financial and foreign exchange constraints, Cultural constraints, and Management and technical resources,

Quantities and characteristics of wastes:

- The quantities of wastes generated generally depend on the income level of a family, as higher income category tends to generate larger quantity of wastes, compared to low-income category.
- The quantity ranges from about 0.25 to about 2.3 kg per person per day, indicating a strong correlation between waste production and per capita income.
- One of the measures of waste composition (and characteristics) is density, which ranges from 150 kg/m^3 to 600 kg/m^3.
- Proportion of paper and packaging materials in the waste largely account for the differences.
- When this proportion is high, the density is low and vice versa.
- The wastes of high density reflect a relatively high proportion of organic matter and moisture and lower levels of recycling.

Climate and seasonal variations:

- There are regions in extreme north (>70 N Latitude) and south (> 60 S Latitude), where temperatures are very low for much of the year. In cold climates, drifting snow and frozen ground interfere with landfill operations, and therefore, trenches must be dug in summer and cover material stockpiled for winter use.
- Tropical climates, on the other hand, are subject to sharp seasonal variations from wet to dry season, which cause significant changes in the moisture content of solid waste, varying from less than 50% in dry season to greater than 65% in wet months.
- Collection and disposal of wastes in the wet months are often problematic.
- High temperatures and humidity cause solid wastes to decompose far more rapidly than they do in colder climates.
- The frequency of waste collection in high temperature and humid climates should, therefore, be higher than that in cold climates. In sub-tropical or desert climate, there is no significant variation in moisture content of wastes (due to low rainfall) and low production of leachate from sanitary landfill.

- High winds and windblown sand and dust, however, cause special problems at landfill sites.
- While temperature inversions can cause airborne pollutants to be trapped near ground level, landfill sites can affect groundwater by altering the thermal properties of the soil.

Physical characteristics of an urban area:

- In urban areas (i.e., towns and cities), where the layout of streets and houses is such that access by vehicles is possible and door-to-door collection of solid wastes is the accepted norm either by large compaction vehicle or smaller vehicle.
- The picture is, however, quite different in the inner and older city areas where narrow lanes make service by vehicles difficult and often impossible.
- Added to this is the problem of urban sprawl in the outskirts (of the cities) where population is growing at an alarming rate.
- Access ways are narrow, unpaved and tortuous, and therefore, not accessible to collection vehicles.
- Problems of solid waste storage and collection are most acute in such areas.

Financial and foreign exchange constraints:

- Solid waste management accounts for sizeable proportions of the budgets of municipal corporations.
- This is allocated for capital resources, which go towards the purchase of equipments, vehicles, and fuel and labour costs.
- Typically, 10% to 40% of the revenues of municipalities are allocated to solid waste management. In regions where wage rates are low, the aim is to optimise vehicle productivity.
- The unfavourable financial situation of some countries hinders purchase of equipment and vehicles, and this situation is further worsened by the acute shortage of foreign exchange.
- This means that the balance between the degree of mechanisation and the size of the labour force becomes a critical issue in arriving at the most cost-effective solution.

Cultural constraints:

- In some regions, long-standing traditions preclude the intrusion of waste collection on the precincts of households, and therefore, influence the collection system.
- In others, where the tradition of caste persists, recruits to the labour force for street cleaning and handling of waste must be drawn from certain sections of the population, while others will not consent to placing storage bins in their immediate vicinity.
- Social norms of a community more often than not over-ride what many may consider rational solutions.

- Waste management should, therefore, be sensitive to such local patterns of living and consider these factors in planning, design and operation.

  Management and technical resources:

- Solid waste management, to be successful, requires a wide spectrum of workforce in keeping with the demands of the system.
- The best system for a region is one which makes full use of indigenous crafts and professional skills and/or ensures that training programmes are in place to provide a self-sustaining supply of trained workforce.

1.3 SWM: THE INDIAN SCENARIO

- The problem of municipal solid waste management has acquired alarming dimensions in India especially over the last decade, before which waste management was hardly considered an issue of concern as the waste could be easily disposed of in an environmentally safe manner.
- However, with time, due to changing lifestyles of people coupled with unplanned developmental activities, urbanisation and industrialisation, the waste quantity and characteristics have changed, and as a result, managing solid wastes has become torturous.
- The physical and chemical characteristics of Indian city refuse, nonetheless, show that about 80% of it is compostable and ideal for biogas generation due to adequate nutrients (NPK), moisture content of 50-55% and a carbon-to-nitrogen ratio of 25-40:1. Therefore, the development of appropriate technologies for utilisation of wastes is essential to minimise adverse health and environmental consequences

Waste Generation Statistics

Year	Per capita waste generated (g/day)	Total urban municipal waste generated (Mt/year)
1971	375	14.9
1981	430	25.1
1991	460	43.5
2000	500	48.8
2010	600	~70.2

Table 1 : Waste generation statistics

- **Waste quantum:** The per capita waste generation rate is about 500 g/day. This along with increased population has contributed to higher total waste generation quantum .During the last decade, garbage was generated in India at nearly twice the rate of the population growth. Estimates of the solid wastes generated in Indian towns and cities range from 52,000 tonnes to 85,000 tonnes of city garbage every day.

- **Waste composition**: Studies reveal that the percentage of the organic matter has remained almost static at 41% in the past 3 decades, but the recyclables have increased from 9.56% to 17.18%. Garbage in Indian cities is estimated to contain about 45-75% biodegradable waste with 50-55% moisture; 35-45% being fruits, vegetable and food biomass; and 8-15% non-organic materials like plastic, metal, glass, stones, etc.
- **Waste disposal methods:** Waste disposal is the final stage of the waste management cycle. About 90% of the municipal waste collected by the civic authorities in India is dumped in low-lying areas outside the city/town limits, which have no provision of leachate collection and treatment, and landfill gas collection and use.
- **Recycling:** This involves collection of recyclables from various sources, which ultimately reach recycling units. It is estimated that about 40-80% of plastic waste gets recycled in India, as compared to 10-15% in the developed nations of the world. However, due to lack of suitable government policies, incentives, subsidies, regulations, standards, etc., related to recycling, this industry is still far behind its western counterparts in terms of technology and quality of manufactured goods. Nevertheless, recycling in India is a highly organised and profit-making venture, though informal in nature.
- **Health impacts:** Due to the absence of standards and norms for handling municipal wastes, municipal workers suffer occupational health hazards of waste handling. At the dumpsites in the city of Mumbai, for example, 95 workers were examined and it was found that about 80% of them had eye problems, 73% respiratory ailments, 51% gastrointestinal ailments and 27% skin lesions. Also, municipal workers and rag pickers who operate informally for long hours rummaging through waste also suffer from similar occupational health diseases ranging from respiratory illnesses (from ingesting particulates and bio-aerosols), infections (direct contact with contaminated material), puncture wounds (leading to tetanus, hepatitis and HIV infection) to headaches and nausea, etc. Studies among the 180 rag pickers at open dumps of Kolkata city reveal that average quarterly incidence of diarrhoea was 85%, fever 72% and cough and cold 63%
- **Environmental impacts:** In addition to occupational health, injury issues and environmental health also need to be mentioned in the context of waste management. Contaminated leachate and surface run-off from land disposal facilities affects ground and surface water quality. Volatile organic compounds and dioxins in air-emissions are attributed to increasing cancer incidence and psychological stress for those living near incinerators or land disposal facilities. Drain clogging

due to uncollected wastes leading to stagnant waters and subsequent mosquito vector breeding are a few of the environmental health issues, which affect the waste workers as well as the public. The pneumonic plague that broke out in November 1994 in India (Surat, Gujarat) is a typical example of solid waste mismanagement.

1.3.1 Progress of MSW management in India

- Over the years, the problems faced due to MSW were highlighted by civic and environmental activists.
- This resulted in framing rules for MSW in the year 2000which are directed by the Supreme Court and MoEF. In October 2004, specific directions to the larger cities to meet the requirements of these rules were issued by Supreme Court.
- In 2005 Ministry of Urban Development giving priority to MSWM has allocated grants to the tunes of Rs 25000 million covering 423 classes I towns as part of 12th finance committee.

1.5 Indian and global scenario of e-waste

- Global demand for electronic devices is on the rise and so is the number of used and discarded gadgets.
- Around 50 million tonnes of e-waste is generated every year, which is more than the weight of all of the commercial airplanes ever made.
- If nothing changes, it is estimated that the annual amount of e-waste could more than double by 2050.
- Out of all discarded electronics, only about 20% is recycled through organised and regulated channels, while most e-waste ends up in landfills or is managed in informal settings in a number of developing countries.
- Even in the EU, which is considered to be a global leader in e-waste recycling, only 35 percent of e-waste is reported as properly managed and recycled.
- E-waste in landfills pollutes soil and groundwater.
- The informal and unregulated management of e-waste poses a serious risk to the health and well-being of both workers and communities as a whole, due to the substantial amount of harmful components such as mercury, lead, bromine, and arsenic that our devices contain.
- For instance, long-term exposure to arsenic, which is found in the microchips of many devices such as mobile phones, may cause lung cancer, nerve damage, and a variety of skin diseases.
- Lead exposure can cause brain damage, kidney damage, blood disorders, and is particularly harmful to children.

- The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, effective since 1992, outlaws the export of e-waste from developed to developing countries. Moreover, the parties to the Basel Convention adopted the Ban on Exporting Hazardous Waste to Developing Countries in 1995, which prohibits the export of hazardous wastes from the members of the EU, Organisation for Economic Co-operation and Development (OECD), and Liechtenstein to all other countries. The Ban entered into force on 5 December 2019 and 98 countries that have ratified it.
- Nonetheless, a substantial amount of obsolete electronics from the developed countries end up in developing countries.
- It is estimated that 352,474 metric tonnes of electronic waste is illegally shipped from the EU to developing countries each year, most of which is exported to the African region (Nigeria, Ghana, and Tanzania, in particular).
- Large economies such as the US, Canada, South Korea, and Japan, to name a few, still have not ratified the ban.
- Even the countries that have ratified the ban have failed to comply with its provisions. For instance, the UK, which has been a party to the Ban since 1997, is considered to be Europe’s worst offender for the illegal export of e-waste, according to a two-year study that tracked shipments from 10 European countries.
- National e-waste legislation/policy or regulation in place
- The UN has also addressed the growing problem of e-waste, often warning of a ‘tsunami of e-waste rolling out over the world.’ A number of global agencies have emphasised the importance of confronting the global e-waste challenge effectively and in a timely manner, including the International Telecommunications Union (ITU), International Labour Organisation (ILO), UN Environment Programme (UNEP), and others.
- In March 2018, a number of organisations, including the aforementioned UN agencies, signed a ‘Letter of Intent’ aimed at creating a mechanism for co-ordination and collaboration among stakeholders in tackling e-waste.
- Apart from being the basis of the problem, electronics could also be part of the solution. An enormous amount of raw materials that are actually reusable are being thrown away on a daily basis, including copper, tin, iron, aluminum, fossil fuels, titanium, gold, and silver. For example, around 32kg of gold, 3,500kg of silver, and 2,200kg of bronze was recovered from about 78,985 tonnes of electronics and used to make the medals for the 2020 Olympic and Paralympic Games in Tokyo.

Current Challenges for e-Waste Elimination:

Cost of recycling e-Waste exceeds the revenue recovered:

- In many cases, the cost of recycling e-Waste exceeds the revenue recovered from materials especially in countries with strict environment regulations.

e-Waste Dumped in poor countries:

- E-Waste mostly ends up dumped in countries where environmental standards are low or nonexistent and working conditions are poor.

Lack of Waste Removal Infrastructure:

- Most developing countries lack the waste removal infrastructure and technical capacities necessary to ensure the safe disposal of hazardous waste.

Variety of Health Problems:

- E-Waste has been linked to a variety of health problems, including cancer, neurological and respiratory disorders, and birth defects.

Indian Enforcement Agencies involved in E-waste:

- Ministry of Environment Forest and Climate Change, Government of India is responsible for identification of hazardous wastes and provides permission to exporters and importers under the Environment (protection) Act, 1986.
- Central Pollution Control Board (CPCB) was constituted under the Water (Prevention and Control of Pollution) Act, 1974.
- CPCB coordinates activities with the State Pollution Control Boards and ensures implementations of the conditions of imports.
- It also monitors the compliance of the conditions of authorization, import and export and conduct training courses for authorities dealing with management of hazardous wastes.

Module 2

WASTE GENERATION ASPECTS

WASTE GENERATION ASPECTS:
2.1 Waste stream assessment (WSA),
2.2 Waste generation and composition,
2.3 Waste characteristics (physical and chemical),
2.3 Health and environmental effects (public health and environmental),
2.4 comparative assessment of waste generation and composition of developing and developed nations, a case study results from an Indian city,
2.5 Handouts on solid waste compositions.
2.6 E-waste generation.

2.1 Waste stream assessment (WSA)

- Waste stream assessment (WSA) is a means to determine the basic aspects of quantity (i.e., the amount of waste generated in the community, both in terms of weight and volume), composition (i.e., the different components of waste stream) and sources of wastes.
- The information relating to these basic aspects of wastes is vital for making decisions about the SWM system, finance and regulations.
- Put differently, an assessment of waste stream is essential in the analyses of short and long-term problems within the local waste management system.
- It also helps in targeting waste management activities and setting goals for different elements of a waste management plan.
- Waste stream assessment, however, is not a one-time activity. It is a continuous and dynamic process, because the characteristics of wastes differ depending on the regions, communities, seasons, etc.

The reasons for the analysis of waste composition, characteristics and quantity include the following

- It provides the basic data for the planning, designing and operation of the management systems.
- An ongoing analysis of the data helps detect changes in composition, characteristics and quantities of wastes, and the rates at which these changes take place, which facilitates effective implementation of management systems.
- It quantifies the amount and type of materials suitable for processing, recovery and recycling.

- It provides information that helps in deciding appropriate technologies and equipment.
- The forecast trends assist designers and manufacturers in the production of collection vehicles and equipment suitable for future needs.

2.2 WASTE GENERATION AND COMPOSITION

- Information on waste quantity and composition is important in evaluating alternatives in terms of equipment, systems, plans and management programmes.
- For example, if wastes generated at a commercial facility consist of only paper products, the appropriate equipment are shredders and balers.
- Similarly, on the basis of quantity generated, we can plan appropriate means for separation, collection and recycling programmes.
- That is to say, the success of SWM depends on the appropriate assessment of quantity of wastes generated.

Waste generation

- Waste generation encompasses those activities in which waste, be it solid or semi-solid material, no longer has sufficient economic value for its possessor to retain it.
- The processing of raw materials is the first stage when wastes are generated, and waste generation continues thereafter at every step in the process as raw materials are converted into final products for consumption.

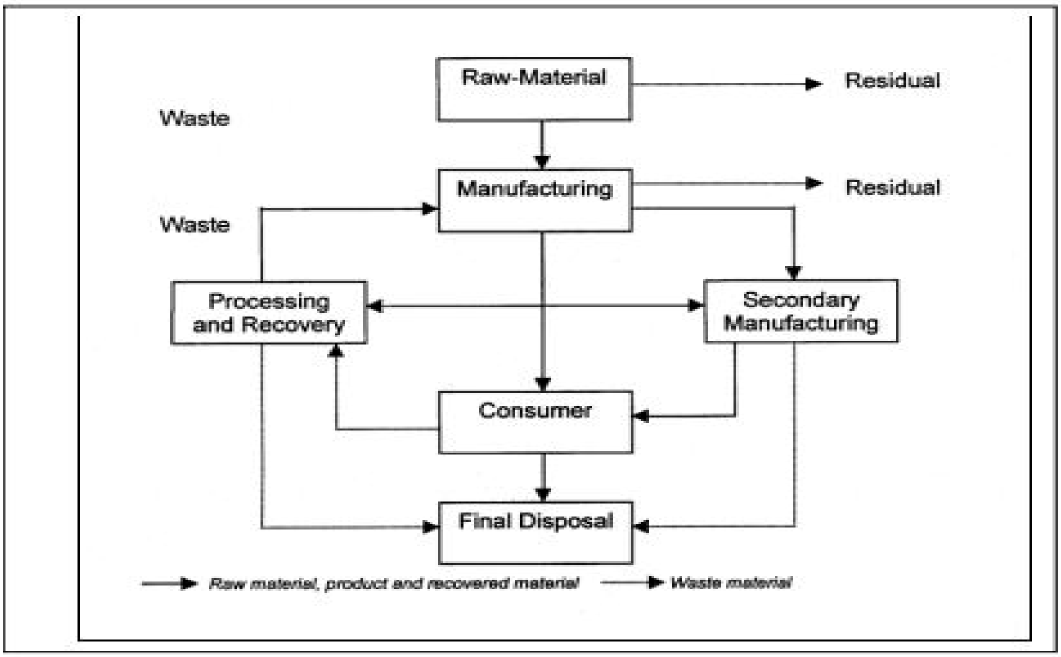

Figure 4: Simplified material-flow diagram indicating the path of generation of solid wastes

Waste composition:

Some of the general observations associated with the composition of wastes include the following:

- The major constituents are paper and decomposable organic materials.
- More often than not, metal, glass, ceramics, textile, dirt and wood form part of the composition, and their relative proportion depends on local factors.
- Average proportions of the constituents reaching the disposal sites are consistent and urban wastes are fairly constant although subject to long-term changes such as seasonal variations.
- Waste composition varies with the socio-economic status within a particular community, since income, for example, determines life style, composition pattern and cultural behaviour.
- Note that the density of waste changes as it moves from the source of generation to the point of ultimate disposal, and such factors as storage methods, salvaging activities, exposure to weather, handling methods and decomposition influence the density.
- In short, predicting changes of waste composition is as difficult as forecasting waste quantities.

2.3 WASTE CHARACTERISTICS

In order to identify the exact characteristics of municipal wastes, it is necessary that we analyse them using physical and chemical parameters.

2.3.1Physical characteristics

- 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.

The required information and data include the following:

- **Density:** Density of waste, i.e., its mass per unit volume (kg/m^3), is a critical factor in the design of a SWM system, e.g., the design of sanitary landfills, storage, types of collection and transport vehicles, etc. To explain, an efficient operation of a landfill demands compaction of wastes to optimum density. Any normal compaction equipment can achieve reduction in volume of wastes by 75%, which increases an initial density of 100 kg/m3 to 400 kg/m^3.
- **Moisture content:** Moisture content is defined as the ratio of the weight of water (wet weight - dry weight) to the total weight of the wet waste. Moisture increases the weight of solid wastes, and thereby, the cost of collection and transport. In addition, moisture content is a critical determinant in the economic feasibility of waste treatment by incineration, because wet waste consumes energy for evaporation of water and in raising the temperature of water vapour. In the main, wastes should be insulated from rainfall or other extraneous water.

- **Size:** Measurement of size distribution of particles in waste stream is important because of its significance in the design of mechanical separators and shredders. Generally, the results of size distribution analysis are expressed in the manner used for soil particle analysis. That is to say, they are expressed as a plot of particle size (mm) against percentage, less than a given value.
- The physical properties that are essential to analyse wastes disposed at landfills are: Field capacity, Permeability of compacted wastes,
- Compressibility of MSW

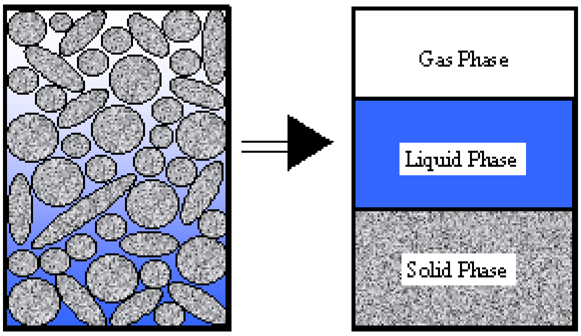

Figure 5: Geotechnical properties

2.3.2Chemical characteristics

- Knowledge of the classification of chemical compounds and their characteristics is essential for the proper understanding of the behaviour of waste, as it moves through the waste management system.
- The products of decomposition and heating values are two examples of chemical characteristics.

If solid wastes are to be used as fuel, or are used for any other purpose, we must know their chemical characteristics, including the following:

- **Lipids:** This class of compounds includes fats, oils and grease, and the principal sources of lipids are garbage, cooking oils and fats. Lipids have high heating values, about 38,000 kJ/kg (kilojoules per kilogram), which makes waste with high lipid content suitable for energy recovery. Since lipids become liquid at temperatures slightly above ambient, they add to the liquid content during waste decomposition. Though they are biodegradable, the rate of biodegradation is relatively slow because lipids have a low solubility in water.
- **Carbohydrates:** These are found primarily in food and yard wastes, which encompass sugar and polymer of sugars (e.g., starch, cellulose, etc.) with general formula $(CH2O)x$. Carbohydrates are readily biodegraded to products such as carbon dioxide, water and methane. Decomposing carbohydrates attract flies and rats, and therefore, should not be left exposed for long duration.

- **Proteins:** These are compounds containing carbon, hydrogen, oxygen and nitrogen, and consist of an organic acid with a substituted amine group (NH_2). They are mainly found in food and garden wastes. The partial decomposition of these compounds can result in the production of amines that have unpleasant odours.
- **Natural fibres:** These are found in paper products, food and yard wastes and include the natural compounds, cellulose and lignin, that are resistant to biodegradation. (Note that paper is almost 100% cellulose, cotton over 95% and wood products over 40 %.) Because they are a highly combustible solid waste, having a high proportion of paper and wood products, they are suitable for incineration. Calorific values of oven-dried paper products are in the range of 12,000 -18,000 kJ/kg and of wood about 20,000 kJ/kg, i.e., about half that for fuel oil, which is 44,200 kJ/kg.
- **Synthetic organic material (Plastics):** Accounting for 1 – 10%, plastics have become a significant component of solid waste in recent years. They are highly resistant to biodegradation and, therefore, are objectionable and of special concern in SWM. Hence the increasing attention being paid to the recycling of plastics to reduce the proportion of this waste component at disposal sites. Plastics have a high heating value, about 32,000 kJ/kg, which makes them very suitable for incineration. But, you must note that polyvinyl chloride (PVC), when burnt, produces dioxin and acid gas. The latter increases corrosion in the combustion system and is responsible for acid rain.
- **Non-combustibles:** This class includes glass, ceramics, metals, dust and ashes, and accounts for 12 – 25% of dry solids.
- **Heating value:** An evaluation of the potential of waste material for use as fuel for incineration requires a determination of its heating value, expressed as kilojoules per kilogram (kJ/kg). The heating value is determined experimentally using the Bomb calorimeter test, in which the heat generated, at a constant temperature of 25 C from the combustion of a dry sample is measured. Since the test temperature is below the boiling point of water (100 C), the combustion water remains in the liquid state. However, during combustion, the temperature of the combustion gases reaches above 100 C, and the resultant water is in the vapour form. Table 2.3 shows the typical inert residue and heating values for the components of municipal solid waste
- **Ultimate analysis:** This refers to an analysis of waste to determine the proportion of carbon, hydrogen, oxygen, nitrogen and sulphur, and the analysis is done to make mass balance calculation for a chemical or thermal process. Besides, it is necessary to determine ash fraction because of its potentially harmful environmental effects, brought about by the presence of toxic metals such as cadmium, chromium, mercury, nickel, lead, tin and zinc. Note that other metals (e.g., iron, magnesium, etc.) may also be present but they are non-toxic

- **Proximate analysis:** This is important in evaluating the combustion properties of wastes or a waste or refuse derived fuel.

The fractions of interest are:

- **Moisture content**, which adds weight to the waste without increasing its heating value, and the evaporation of water reduces the heat released from the fuel;
- **Ash,** which adds weight without generating any heat during combustion;
- **Volatile matter**, i.e., that portion of the waste that is converted to gases before and during combustion;
- **Fixed carbon**, which represents the carbon remaining on the surface grates as charcoal. A waste or fuel with a high proportion of fixed carbon requires a longer retention time on the furnace grates to achieve complete combustion than a waste or fuel with a low proportion of fixed carbon.

2.4 Health and environmental effects

An effective solid waste management system is necessary to avoid public health disasters, spread of disease by insects and vectors and adverse effect on water and air Solid waste workers are the most exposed to the risks of parasitic infections and accidents, and therefore, a SWM system must include proper mechanisms to avoid these incidences.

2.4.1 Public health effect

- The volume of waste is increasing rapidly as a result of increasing population and improving economic conditions in various localities.
- This increased volume of wastes is posing serious problems due to insufficient workforce and other constraints in disposing of it properly.

The consequences of improper management and handling of waste include:

- **Disease vectors and pathways:** Wastes dumped indiscriminately provide the food and environment for thriving populations of vermin, which are the agents of various diseases. The pathways of pathogen transmission from wastes to humans are mostly indirect through insects – flies, mosquitoes and roaches and animals – rodents and pigs. Diseases become a public health problem when they are present in the human and animal population of surrounding communities, or if a carrier transmits the etiological agent from host to receptor.
- **Flies:** Most common in this category is the housefly, which transmits typhoid, salmonellosis, gastro-enteritis and dysentery. Flies have a flight range of about 10 km, and therefore, they are able to spread their influence over a relatively wide area. The four stages in their life-cycle are egg, larva, pupa and adult. Eggs are deposited in the warm, moist environment of decomposing food

wastes. When they hatch, the larvae feed on the organic material, until certain maturity is reached, at which time they migrate from the waste to the soil of other dry loose material before being transformed into pupae. The pupae are inactive until the adult-fly emerges. The migration of larvae within 4 to 10 days provides the clue to an effective control measure, necessitating the removal of waste before migration of larvae. Consequently, in warm weather, municipal waste should be collected twice weekly for effective control. In addition, the quality of household and commercial storage containers is very significant. The guiding principle here is to restrict access to flies. Clearly, the use of suitable storage containers and general cleanliness at their location, as well as frequent collection of wastes, greatly reduces the population of flies. Control is also necessary at transfer stations, composting facilities and disposal sites to prevent them from becoming breeding grounds for flies. Covering solid wastes with a layer of earth at landfill sites at the end of every day arrests the problem of fly breeding at the final stage.

- **Mosquitoes:** They transmit diseases such as malaria, filaria and dengue fever. Since they breed in stagnant water, control measures should centre on the elimination of breeding places such as tins, cans, tyres, etc. Proper sanitary practices and general cleanliness in the community help eliminate the mosquito problems caused by the mismanagement of solid waste.
- **Rodents:** Rodents (rats) proliferate in uncontrolled deposits of solid wastes, which provide a source of food as well as shelter. They are responsible for the spread of diseases such as plague, murine typhus, leptospirosis, histoplasmosis, rat bite fever, dalmonelosis, trichinosis, etc. The fleas, which rats carry, also cause many diseases. This problem is associated not only with open dumping but also poor sanitation
- **Occupational hazards:** Workers handling wastes are at risk of accidents related to the nature of material and lack of safety precautions. The sharp edges of glass and metal and poorly constructed storage containers may inflict injuries to workers. It is, therefore, necessary for waste handlers to wear gloves, masks and be vaccinated.

The infections associated with waste handling, include:

- Skin and blood infections resulting from direct contact with waste and from infected wounds;
- Eye and respiratory infections resulting from exposure to infected dust, especially during landfill operations;
- Diseases that result from the bites of animals feeding on the waste;
- Intestinal infections that are transmitted by flies feeding on the waste;
- Chronic respiratory diseases, including cancers resulting from exposure to dust and hazardous compounds.

2.4.2 Environmental effect

Inadequate and improper waste management causes adverse environmental effects such as the following:

- **Air pollution:** Burning of solid wastes in open dumps or in improperly designed incinerators emit pollutants (gaseous and particulate matters) to the atmosphere. Studies show that the environmental consequences of open burning are greater than incinerators, especially with respect to aldehydes and particulates. Emissions from an uncontrolled incinerator system include particulate matter, sulphur oxides, nitrogen oxides, hydrogen chloride, carbon monoxide, lead and mercury
- **Water and land pollution:** Water pollution results from dumping in open areas and storm water drains, and improper design, construction and/or operation of a sanitary landfill. Control of infiltration from rainfall and surface runoff is essential in order to minimise the production of leachate.

  Pollution of groundwater can occur as a result of:
  - the flow of groundwater through deposits of solid waste at landfill sites;
  - percolation of rainfall or irrigation waters from solid wastes to the water table;
  - Diffusion and collection of gases generated by the decomposition of solid wastes.
- **Noise pollution:** Undesirable noise is a nuisance associated with operations at landfills, incinerators, transfer stations and sites used for recycling. This is due to the movement of vehicles, the operation of large machines and the diverse operations at an incinerator site. The impacts of noise pollution may be reduced by careful siting of SWM operations and by the use of noise barriers.
- **Odour pollution:** Obnoxious odours due to the presence of decaying organic matter are characteristic of open dumps. They arise from anaerobic decomposition processes and their major constituents are particularly offensive. Proper landfill covering eliminates this nuisance.
- **Explosion hazards:** Landfill gas, which is released during anaerobic decomposition processes, contains a high proportion of methane (35 – 73%). It can migrate through the soil over a considerable distance, leaving the buildings in the vicinity of sanitary landfill sites at risk, even after the closure of landfills. Several methods are available for control of landfill gas, such as venting, flaring and the use of impermeable barriers

2.5 Comparative assessment of waste generation and composition of developing and developed nations

CASE STUDY: STATUS OF WASTE GENERATION IN BANGALORE

- Bangalore, also known as the Garden City, is one of the fastest growing metropolitan cities in South India.
- It is the state capital of Karnataka and the sixth largest city in India.
- Topographically, Bangalore is located in the south Deccan and physically, has grown on watershed running through the middle of the Mysore Plateau from west to east which serves as the main water parting of the state at an average elevation of 900 meters above sea level.
- The city gets moderate rainfall of around 900 mm largely between June and October. On account of its elevation,
- Bangalore is bestowed with salubrious and equable climate comparable to those of temperate regions.

The waste generation and composition details of Bangalore are as follows:

- **Waste generation:** Bangalore produces over 2500 tonnes of solid waste per day and the Municipal Corporation has miserably inadequate infrastructure in managing the disposal of solid wastes generated. It is estimated that the per capita generation of solid waste works out to 0.59 kg/day. The sources of waste generation and the amount generated at each source are given in Table

Sl No.	Source	Quantity (in MT/day)
1	Households	1000
2	Shops, Establishments, Institutions, etc.	600
3	Markets	600
4	Others	300
5	TOTAL	2500

Table 2. Different sources of solid waste generation in Bengaluru

- **Waste composition:** The composition of wastes in Bangalore has wide variations in the proportion of contents. It varies from area to area, depending upon the socio-economic conditions and the population density. The composition of the total wastes generated in Bangalore city is given in Table

Sl No.	Type of Waste	Composition (in percentage)
1	Putrescible waste	75.2
2	Dust and ash	12
3	Textiles	3.1
4	Paper	1.5
5	Plastic, leather and rubber	0.9
6	Glass	0.2
7	Metals	0.1
8	Earth and building debris and others	0.7

Table 3. Composition of solid waste in Bengaluru

2.3 E-waste generation

- The major problem associated with e-waste management is its ever increasing quantum.
- However, the e-waste quantities represent a small percentage of the overall municipal solid waste (MSW).
- Data on e-waste generation may vary between areas of a country because of the definitions of waste arising, technological equipment used, the consumption patterns of the consumers, and changes in the living standards across the globe.
- Global e-waste generated per year amounts to approximately 20-25 million tons, most of which is being produced in rich nations such as the United States (US) or European Union member countries.
- The US, is the largest generator of e-waste, with a total accumulation of 3 million tons per year; and China is the second largest, producing 2.3 million tons each year.
- Brazil generates the second greatest quantity of e-waste among emerging countries.
- In Malaysia, the volume of e-waste generated is estimated at roughly 0.8-1.3 kg of waste per capita per day, with an increasing trend of e-waste generation, which rose to 134,000 tons in 2009. Furthermore, the volume of e-waste in Malaysia is expected to rise to 1.1 million metric tons in 2020, at an annual rate of 14%.
- In South Africa and China, e-waste production from old computers will increase by 200-400% from 2007 to 2020, and by 500% in India.
- In this same period e-waste from televisions will be 1.5-2 times higher in China and India; whereas in India, e-waste from discarded refrigerators will double or triple by 2020.
- For India, the volume of e-waste generated is 146,000 tonnes per year. The rate at which the e-waste volume is increasing globally is 5 to 10% yearly.

Module 3

COLLECTION, STORAGE, TRANSPORT AND DISPOSAL OF WASTES:

3.1 WASTE COLLECTION, STORAGE AND TRANSPORT:

3.1.1 COLLECTION COMPONENTS

- Waste collection does not mean merely the gathering of wastes, and the process includes, as well, the transporting of wastes to transfer stations and/or disposal sites.

To elaborate, the factors that influence the waste collection system include the following

- **Collection points:** These affect such collection system components as crew size and storage, which ultimately control the cost of collection. Note that the collection points depend on locality and may be residential, commercial or industrial.
- **Collection frequency:** Climatic conditions and requirements of a locality as well as containers and costs determine the collection frequency. In hot and humid climates, for example, solid wastes

must be collected at least twice aweek, as the decomposing solid wastes produce bad odour and leachate.

. While deciding collection frequency, therefore, you must consider the following:

- Cost, e.g., optimal collection frequency reduces the cost as it involves fewer trucks, employees and reduction in total route distance;
- Storage space, e.g., less frequent collection may require more storagespace in the locality;
- Sanitation, e.g., frequent collection reduces concerns about health, safety and nuisance associated with stored refuse.

- **Storage containers:** Proper container selection can save collection energy, increase the speed of collection and reduce crew size. Most importantly, containers should be functional for the amount and type of materials and collection vehicles used.
- **Collection crew** the optimum crew size for a community depends on labour and equipment costs, collection methods and route characteristics. The size of the collection crew also depends on the size and type of collection vehicle used, space between the houses, waste generation rate and collection frequency. For example, increase in waste generation rate and quantity of wastes collected per stop due to less frequent collection result in a bigger crew size.

  However, with increase in collection costs, the trend in recent years is towards:
  - Decrease in the frequency of collection;
  - Increase in the dependence on residents to sort waste materials;
  - Increase in the degree of automation used in collection.
  - This trend has, in fact, contributed to smaller crews in municipalities.
- **Collection route: The** collection programmemust consider the route that is efficient for collection. An efficient routing of collection vehicles helps decrease costs by reducing the labour expended for collection. Proper planning of collection route also helps conserve energy and minimise working hours and vehicle fuel consumption. It is necessary therefore to develop detailed route configurations and collection schedules for the selected collection system. The size of each route, however, depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad, embankments, rivers and roads with heavy traffic, can be considered to divide route territories.

3.1.2 STORAGE: CONTAINERS/COLLECTION VEHICLES:

- Waste storage is an important component of a waste management system.
- Waste storage encompasses proper containers to store wastes and efficient transport of wastes

without any spillage to transfer stations/disposal sites.

Containers/storage bins

- The design of an efficient waste collection system requires careful consideration of the type, size and location of containers at the point of generation for storage of wastes until they are collected. While single-family households generally use small containers, residential units, commercial units, institutions and industries require large containers. Smaller containers are usually handled manually whereas the larger, heavier ones require mechanical handling. The containers may fall under either of the following two categories:
- Stationary containers: These are used for contents to be transferred to collection vehicles at the site of storage.
- Hauled containers: These are used for contents to be directly transferred to a processing plant, transfer station or disposal site for emptying before being returned to the storage site.
- The desirable characteristics of a well-designed container are low cost, size, weight, shape, resistance to corrosion, water tightness, strength and durability. For example, a container for manual handling by one person should not weigh more than 20 kg, lest it may lead to occupational health hazards such as muscular strain, etc. Containers that weigh more than 20 kg, when full, require two or more crew members to manually load and unload the wastes, and which result in low collection efficiency.

Communal Containers

- Generally, the containers used for waste storage are communal/public containers.
- Figure below shows a typical communal container, which a compactor collection vehicle can lift and empty mechanically:

Fig 6. Typical Communal Container

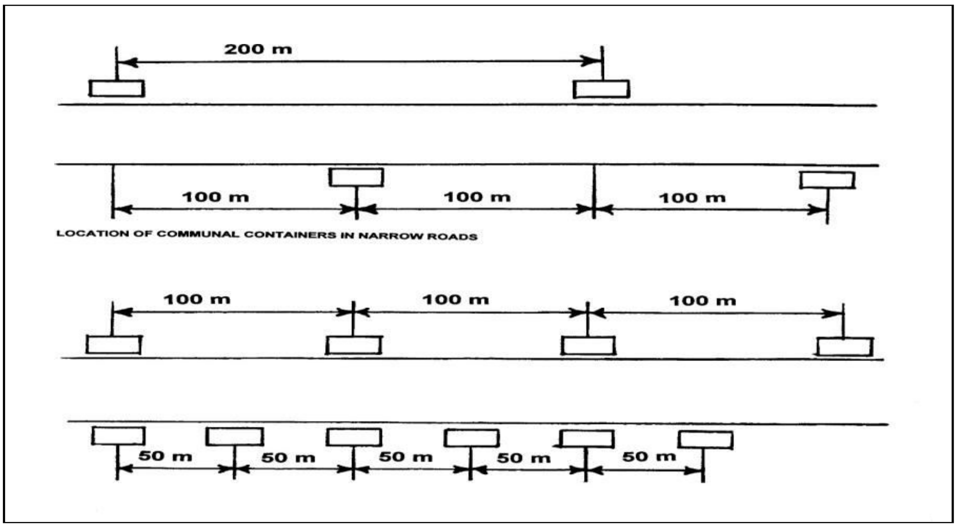

Fig 7 Location of Communal Container

- This means that the farthest distance the householder will have to walk is 50 meters.
- However, in narrow streets with low traffic, where the house owner can readily cross the street, a longer distance is advisable.
- If the collection vehicle has to stop frequently, say, at every 50 m or so, fuel consumption increases, and this must be avoided.

Collection vehicles

- Almost all collections are based on collector and collection crew, which move through the collection service area with a vehicle for collecting the waste material.
- The collection vehicle selected must be appropriate to the terrain, type and density of waste generation points, the way it travels and type and kind of material.
- It also depends upon strength, stature and capability of the crew that will work with it.
- The collection vehicle may be small and simple (e.g., two-wheeled cart pulled by an individual) or large, complex and energy intensive (e.g., rear loading compactor truck).
- The most commonly used collection vehicle is the dump truck fitted with a hydraulic lifting mechanism.
- A description of some vehicle types follows:
- **Small-scale collection and muscle-powered vehicles:** These are common vehicles used for waste collection in many countries and are generally used in rural hilly areas. As Figure 3.3 illustrates, these can be small rickshaws, carts or wagons pulled by people or animals, and are less expensive, easier to build and maintain compared to other vehicles:

- They are suitable for densely populated areas with narrow lanes, and squatter settlements, where there is relatively low volume of waste generated.
- Some drawbacks of these collection vehicles include limited travel range of the vehicles and weather exposure that affect humans and animals.
- **Non-compactor trucks:** Non-compactor trucks are efficient and cost effective in small cities and in areas where wastes tend to be very dense and have little potential for compaction. Figure 3.4 illustrates a non- compactor truck:
- When these trucks are used for waste collection, they need a dumping system to easily discharge the waste.
- It is generally required to cover the trucks in order to prevent residue flying off or rain soaking the wastes.
- Trucks with capacities of 10 – 12 m^3 are effective, if the distance between the disposal site and the collection area is less than 15 km.
- If the distanceis longer, a potential transfer station closer than 10 km from the collection area is required.
- Non-compactor trucks are generally used, when labour cost is high. Controlling and operating cost is a deciding factor, when collection routes are long and relatively sparsely populated.
- **Compactor truck:** Compaction vehicles are more common these days, generally having capacities of 12 – 15 m^3 due to limitations imposed by narrow roads.
- Although the capacity of a compaction vehicle, illustrated in Figure 3.4, is similar to that of a dump truck, the weight of solid wastes collected per trip is 2 to 2.5 times larger since the wastes are hydraulically compacted.
- Success of waste management depends on the level of segregation at source. One of the examples for best collection method is illustrated in the figure below

3.1.3 COLLECTION OPERATION

Movement of Collection Crew

- In cultures such as India, Bangladesh, etc., solid waste collection is assigned to the lowest social group.
- More often, the collection crew member accepts the job as a temporary position or stopgap arrangement, while looking for other jobs that are considered more respectable.
- Apart from this cultural problem, the attitude of some SWM authorities affects collection operation. For example, some authorities still think that the collection ofsolid waste is mechanical,

and therefore, the collection crew does not need any training to acquire special skills.

- As a result, when a new waste collector starts working, he or she is sent to the field without firm instruction concerning his or her duties, responsibilities and required skills.
- For an effective collection operation, the collection team must properly be trained.
- The collection crew and the driver of the collection vehicle must, for example, work as a team, and this is important to maintain the team morale and a sense of social responsibility amongthese workers.

Collection Vehicle Routing

- Efficient routing and re-routing of solid waste collection vehicles can help decrease costs by reducing the labour expended for collection. Routing procedures usually consist of the following two separate components:
- **Macro-routing:** Macro-routing, also referred to as route-balancing, consists of dividing the total collection area into routes, sized in such a way as to represent a day’s collection for each crew. The size of each route depends on the amount of waste collected per stop, distance between stops, loading time and traffic conditions. Barriers, such as railroad embankments, rivers and roads with heavy competing traffic, can be used to divide route territories. As much as possible, the size and shape of route areas should be balanced within the limits imposed by such barriers.
- **Micro-routing:** Using the results of the macro-routing analysis, micro- routing can define the specific path that each crew and collection vehicle will take each collection day. Results of micro-routing analyses can then be used to readjust macro-routing decisions. Micro-routing analyses should also include input and review from experienced collection drivers.
- Districting is the other method for collection route design.
- For larger areas it is not possible for one institution to handle it then the best way is to sub divide the area and MSW collection districting plan can be made.
- This routing will be successful only when road network integrity is good and the regional proximity has been generated.
- The heuristic (i.e., trial and error) route development process is a relatively simple manual approach that applies specific routing patterns to block configurations.
- The map should show collection, service garage locations, disposal or transfer sites, one-way streets, natural barriers and areas of heavy traffic flow.
- Routes should then be traced onto the tracing paper using the following rules:
- Routes should not be fragmented or overlapping. Each route should be compact, consisting of street segments clustered in the same geographical area.

- Total collection plus hauling time should be reasonably constant for each route in the community.
- The collection route should be started as close to the garage or motor pool as possible, taking into account heavily travelled and one-way streets.
- Heavily travelled streets should not be visited during rush hours.
- In the case of one-way streets, it is best to start the route near the upper end of the street, working down it through the looping process.
- Services on dead-end streets can be considered as services on the street segment that they intersect, since they can only be collected by passing down that street segment.
- To keep right turns at a minimum, (in countries where driving is left-oriented) collection from the dead-end streets is done when they are to the left of the truck.
- They must be collected by walking down, reversing the vehicle or taking a U-turn.
- Waste on a steep hill should be collected, when practical, on both sides of the street while vehicle is moving downhill. This facilitates safe, easy and fast collection. It also lessens wear of vehicle and conserves gas and oil.
- Higher elevations should be at the start of the route.
- For collection from one side of the street at a time, it is generally best to route with many anti-clockwise turns around blocks.
- For collection from both sides of the street at the same time, it is generally best to route with long, straight paths across the grid before looping anti- clockwise.
- For certain block configurations within the route, specific routing patterns should be applied. (Adapted from American Public Works Association, 1975.)

3.1.4 TRANSFER STATIONS

- A transfer station is a building or processing site for the temporary deposition of waste. Transfer stations are often used as places where local waste collection vehicles will deposit their waste cargo prior to loading into larger vehicles.
- Typical activities at the waste transfer station involved the unloading of garbage trucks, pre-screening and removal of inappropriate items such as automobile batteries, compacting and then reloading onto larger vehicles, including trucks, trains and barges to their final destination.
- The transfer station is a key component of cost-effective solid waste transportation. By transferring waste from local collection vehicles onto larger trailers or other transport modes such as barge and rail, the cost of transportation to distant disposal sites can be significantly reduced, freeing collection-specific vehicles and crews to devote their time to actual collection activities. Here are some of the main benefits:

- Provides fuel savings, reduction in road wear and less air pollution due to fewer vehicles being on the road
- Provides a trash and recyclable material drop-off location for citizens
- Reduces total traffic congestion in the community by transferring it onto larger vehicles
- Reduces total truck traffic and improves safety at the landfill or waste-to-energy facility
- Provides the opportunity to screen incoming trash for such purposes as removing hazardous waste or recovering recyclables

3.1.5 WASTE COLLECTION SYSTEM DESIGN

- After we identify appropriate options for collection, equipment and transfer, we must examine the various combinations of these elements to define system -wide alternatives for further analysis.
- Each should be evaluated for its ability to achieve the identified goals of the collection programme.
- Economic analysis will usually be a central focus of the system evaluation.
- This initial evaluation will lead to several iterations, with the differences between the alternatives under consideration becoming more narrowly focused with each round of evaluations.
- After comparing the alternative strategies, the various elements like crew and truck requirement, time requirement and cost involved are calculated.
- The various formulae used to calculate are:

  Number of services/vehicle load (N):

  $$N = (C \times D)/W$$

  where, C = Vehicle capacity (m^3); D = Waste density (kg/m^3)and W = Waste generation/residence (kg/service)

  Time required collecting one load (E):

  $$E = N \times L$$

  where, L = Loading time/residence, including on-route travel

  Number of loads/crew/day (n):

  The number of loads (n) that each crew can collect in a day can be estimated based on the workday length (t), and the time spent on administration and breaks (t_1), time for hauling and other travel (t_2) and collection route time (t)

Administrative and break time (t_1):

$t_1 = A + B$

where, A = Administrative time (i.e., for meetings, paperwork,unspecified slack time) and B = Time for breaks and lunch

Hauling and other travel time (t_2):

$t_2 = (n \times H) - f + G + J$

where, n = Number of loads/crew/day; H = Time to travelto disposal site, empty truck, and return to route; f = Timeto return from site to route; G = Time to travel from staging garage to route and J = Time to return from disposal site to garage.

Time spent on collection route (t_3):

$t_3 = n \times E$

where variables have been previously defined.

Length of workday (t):

$t = t_1 + t_2 + t_3$

where t is defined by work rules and equations A through D are solvedto find n.

Calculation of number of vehicles and crews (K):

$K = (S \times F)/(N \times n \times M)$

where, S = Total number of services in the collection area; F = Frequency of collection (numbers/week) and M =Number of workdays/week

Calculation of annual vehicle and labour costs:

Vehicle costs = Depreciation + Maintenance + Consumables + Overhead + License + Fees + Insurance

Labour costs = Drivers salary + Crew salaries + Fringe benefits + Indirect labour + Supplies + Overhead.

3.1.6 RECORD KEEPING, CONTROL, INVENTORYAND MONITORING

- For effective waste collection and, indeed, SWM, we must maintain records on the quantities of wastes collected and their variation within a week, month and year, as well as on established long-term trends in solid waste generation rates and composition, sources of wastes and the personnel collecting them.
- Long- term trends in solid waste generation rates and composition form the basis for planning, especially in budgeting for future vehicle requirements, allocating the collection vehicles and crew, building transfer stations, acquiring strategic lands and determining disposal options. Table below contains an illustration of a checklist of factors that affect the waste collection system:

Checklist of Variables Affecting Collection System

Components	Factors to Consider
Crew size	• Labour cost • Distance between containerssize and types of containers • Loading accessories available in thetruck • Collection vehicle used
Container type	• Solid wastes generation rate density of waste generation street width • Traffic volume • Collection crew configurationstandard of living
Collection accessory	• Labour cost • Protection of worker's health
Vehicle size/type	• Street width, traffic volume solid waste generation ratescrew size • Viability of a transfer station
Collection route	• Street width, traffic volumedirection of traffic flow • Solid waste generation ratesspatial distribution of wastes • Local topography
Transfer station	• Distance between disposal site andcollection area • Hauling cost for small and large trucks • Cost of transferring the solid wastesfrom small to large trucks

Table 4: Checklist of factors that affect the waste collection system

3.1.7 IMPLEMENTING COLLECTION AND TRANSFER SYSTEM

- Implementing of collection and transfer system involves the following activities,which are important for success of the plan:

Finalising and implementing the system management plan:

- For proper implementation of collection and transfer system, it is necessary to have clear organisational structures and management plans.
- The organisational structure should be simple, with a minimum of administrative and management layers between collection crews and top management. All workers in the department should clearly understand the department's mission and their roles.

Purchasing and managing equipment:

- For purchasing equipment, most municipalities issue bid specifications.
- Detailed specifications include exact requirements for equipment sizes and capacities, power ratings, etc.
- Performance specifications often request that equipment be equivalent to certain available models and meet standards for capacity, speed, etc.

- In addition, each vehicle should have an individual maintenance record that includes the following items:
  - Preventive maintenance schedule;
  - Current list of specific engine;
  - Description of repairs and
  - List containing information on the repair date, mechanic, cost, type and manufacturer of repair parts and the length of time the truck was out of service, for each maintenance event.

Hiring and training personnel:

- As in all organisations, good personnel management is essential to an efficient, high-quality waste collection system.
- Authorities responsible for SWM should, therefore, strive to hire and keep well-qualified personnel.
- The recruitment programme should assess applicants' abilities to perform the types of physical labour required for the collection, equipment and methods used.
- To retain employees, management should provide a safe working environment that emphasises career advancement, participatory problem solving and worker incentives.
- Worker incentives should be developed to recognise and reward outstanding performance by employees.
- Ways to accomplish motivation include merit-based compensation, awards programme and a work structure. Feedback on employee performance should be regular and frequent.

Providing public information:

- Maintaining good communication with the public is important to a well-run collection system.
- Residents can greatly influence the performance of the collection system by co-operating in separation requirements, and by keeping undesirable materials from entering the collected waste stream.
- Commonly used methods of communicating information include brochures, articles in community newsletters, newspaper articles, announcements, and advertisements on radio and television, information attachments to utility bills (either printed or given separately) and school handouts.

Monitoring system cost and performance:

- Collection and transfer facilities should develop and maintain an effective system for cost and performance reporting. Each collection crew should complete a daily report containing the following information:
  - Total quantity hauled.

- Total distance and travel times to and from the disposal site.
- Amounts delivered to each disposal, transfer, or processing facility.
- Number of loads hauled.
- Vehicle or operational problems needing attention.

CASE STUDY:

- In the Bangalore city in India the waste collected through street sweeping is the main system of primary collection of wastes.
- However, recently efforts are being made for doorstep collection of waste through NGOs (Non-Governmental Organizations) and private contractors, but only about 5% of the population is covered under this system.
- The waste generated by the rest is collected from either the street or the dustbins.
- Other details regarding the collection process in Bangalore are given below:
- **Waste storage:** There are about 14,000 bottomless cement bins having
- 0.9 meters diameter and 0.6 cubic meter storage capacity and large masonry bins for depositing wastes at a distance of about 100 to 200 meters. Besides these, there are 1500 places, where the waste is deposited but no bins are kept on these sites. Recently, metal containers have been placed and at present 55 metal containers are in the city for the storage of waste in a more hygienic manner.

3.2 WASTE DISPOSAL

3.2.1 KEY ISSUES IN WASTE DISPOSAL

- Let us first get one thing very clear: there is no option but to dispose of wastes.
- Disposal is the final element in the SWM system.
- It is the ultimate fate of all solid wastes, be they residential wastes collected and transported directly to a landfill site, semisolid waste (sludge) from municipal and industrial treatment plants, incinerator residue, compost or other substances from various solid waste processing plants that are of no further use to society.
- It is, therefore, imperative to have a proper plan in place for safe disposal of solid wastes, which involves appropriate handling of residual matter after solid wastes have been processed and the recovery of conversion products/energy has been achieved.

  Issues to be overcome

  - To achieve effective waste disposal, we must overcome the following the constraints:
  - Municipal capacities:

- Political commitment:
- Finance and cost recovery:
- Technical guidelines:
- Location:

3.2.2 DISPOSAL OPTIONS AND SELECTION CRITERIA

Uncontrolled dumping or non-engineered disposal:

- As mentioned, this is the most common method being practiced in many parts of the world, and India is no exception.
- In this method, wastes are dumped at a designated site without any environmental control.
- They tend to remain there for a long period of time, pose health risks and cause environmental degradation.
- Due to the **Refuse-derived fuel (RDF):** adverse health and environmental impact associated with it, the non-engineered disposal is not considered a viable and safe option.

Sanitary landfill:

- Unlike the non-engineered disposal, sanitary landfill is a fully engineered disposal option in that the selected location or wasteland is carefully engineered in advance before it is pressed into service.
- Operators of sanitary landfills can minimize the effects of leachate (i.e., polluted water which flows from a landfill) and gas production through proper site selection, preparation and management.

Composting: This is a biological process of decomposition in which organisms, under controlled conditions of ventilation, temperature and moisture, convert the organic portion of solid waste into humus-like material.

- If this process is carried out effectively, what we get as the final product is a stable, odour-free soil conditioner.

Incineration: This refers to the controlled burning of wastes, at a high temperature (roughly 1200 – 1500 C), which sterilises and stabilises the waste in addition to reducing its volume.

- This is the combustible part of raw waste, separated for burning as fuel.
- Various physical processes such as screening, size reduction, magnetic separation, etc., are used to separate the combustibles.

Pyrolysis:

- This is the thermal degradation of carbonaceous material to gaseous, liquid and solid fraction in the absence of oxygen. This occurs at a temperature between 200 and 900 C.

3.2.3 SANITARY LANDFILL

- The term landfill generally refers to an engineered deposit of wastes either in pits/trenches or on the surface.
- And, a sanitary landfill is essentially a landfill, where proper mechanisms are available to control the environmental risks associated with the disposal of wastes and to make available the land, subsequent to disposal, for other purposes.
- However, you must note that a landfill need not necessarily be an engineered site, when the waste is largely inert at final disposal, as in rural areas, where wastes contain a large proportion of soil and dirt.
- This practice is generally designated as non-engineered disposal method.
- When compared to uncontrolled dumping, engineered landfills are more likely to have pre-planned installations, environmental monitoring, and organised and trained workforce.
- Sanitary landfill implementation, therefore, requires careful site selection, preparation and management.

3.2.4 LANDFILL GAS AND LEACHATE

- Leachate and landfill gas comprise the major hazards associated with a landfill. While leachate may contaminate the surrounding land and water, landfill gas can be toxic and lead to global warming and explosion leading to human catastrophe.
- The factors, which affect the production of leachate and landfill gas, are the following:

Nature of waste:

- The deposition of waste containing biodegradable matter invariably leads to the production of gas and leachate, and the amount depends on the content of biodegradable material in the waste.

Moisture content:

- Most micro-organisms require a minimum of approximately 12% (by weight) moisture for growth, and thus the moisture content of landfill waste is an important factor in determining the amount and extent of leachate and gas production.

pH:

- The methanogen bacteria within a landfill produce methane gas, which will grow only at low pH range around neutrality.

Particle size and density:

- The size of waste particle affects the density that can be achieved upon compaction and affects the surface area and hence volume.
- Both affect moisture absorption and therefore are potential for biological degradation.

Temperature:

- An increase in temperature tends to increase gas production. The temperature affects the microbial activity to the extent that it is possible to segregate bacteria, according to their optimum temperature operating conditions.

3.2.5 LANDFILL GAS EMISSION

- Landfill gas contains a high percentage of methane due to the anaerobic decomposition of organic matter, which can be utilised as a source of energy

Composition and properties

- **Methane:** This is a colourless, odourless and flammable gas with a density lighter than air, typically making up 50 – 60% of the landfill gas.
- **Carbon dioxide:** This is a colourless, odourless and non-inflammable gas that is denser than air, typically accounting for 30 – 40%.
- **Oxygen:** The flammability of methane depends on the percentage of oxygen. It is, therefore, important to control oxygen levels, where gas abstraction is undertaken.
- **Nitrogen:** This is essentially inert and will have little effect, except to modify the explosive range of methane.

Hazards of landfill gas emission

- **Explosion and fire:** Methane is flammable in air within the range of 5 – 15% by volume, while hydrogen is flammable within the range of 4.1 – 7.5% (in the presence of oxygen) and potentially explosive.
- Fire, occurring within the waste, can be difficult to extinguish and can lead to unpredictable and uncontrolled subsidence as well as production of smoke and toxic fumes.
- **Trace components:** These comprise mostly alkanes and alkenes, and their oxidation products such as aldehydes, alcohols and esters.
- Many of them are recognised as toxicants, when p present in air at concentrations above occupational exposure standards.
- **Global warming:** Known also as greenhouse effect, it is the warming of the earth's atmosphere by the accumulation of gases (methane, carbon dioxide and chlorofluorocarbons) that absorbs reflected solar radiation

3.2.6 LEACHATE FORMATION

- Leachate can pollute both groundwater and surface water supplies.
- The degree of pollution will depend on local geology and hydrogeology, nature of waste and the proximity of susceptible receptors. Once groundwater is contaminated, it is very costly to clean it up.

- Landfills, therefore, undergo siting, design and construction procedures that control leachate migration.

Composition and properties

- Leachate comprises soluble components of waste and its degradation products enter water, as it percolates through the landfill.
- The amount of leachate generated depends on: Water availability; landfill surface condition; refuse state; condition of surrounding strata.

Leachate migration

- It is generally difficult to predict the movement of escaped leachate accurately. The main controlling factors are the surrounding geology and hydrogeology.
- Escape to surface water may be relatively easy to control, but if it escapes to groundwater sources, it can be very difficult both to control and clean up.
- The degree of groundwater contamination is affected by physical, chemical and biological actions.
- The relative importance of each process may change, however, if the leachate moves from the landfill to the sub-surface region.

Control

- The best way to control leachate is through prevention, which should be integral to the site design.
- In most cases, it is necessary to control liquid access, collection and treatment, all of which can be done using the following landfill liners:
- **Natural liners:** These refer to compacted clay or shale, bitumen or soil sealants, etc., and are generally less permeable, resistant to chemical attack and have good sorption properties.
- They generally do not act as true containment barriers, because sometimes leachate migrates through them.
- **Synthetic (geo-membrane) liners**: These are typically made up of high or medium density polyethylene and are generally less permeable, easy to install, relatively strong and have good deformation characteristics.
- They sometimes expand or shrink according to temperature and age.

3.2.7 ENVIRONMENTAL EFFECTS OF LANDFILL,

- The environmental effects of a landfill include wind-blown litter and dust, noise, obnoxious odour, vermin and insects attracted by the waste, surface runoff and in aesthetic conditions.
- Gas and leachate problems also arise during the operation phase and require significant environmental controls.
- Some of the major environmental effects below:

- Wind-blown litter and dust are continuous problems of the ongoing landfill operation and a nuisance to the neighborhood.
- Covering the waste cells with soil and spraying water on dirt roads and waste in dry periods, in combination with fencing and movable screens, may minimize the problem of wind-blown litter and dust. However, note that the problem will remain at the tipping front of the landfill.
- Movement of waste collection vehicles, emptying of wastes from them, compactors, earthmoving equipment, etc., produce noise. Improving the technical capability of the equipment, surrounding the fill area with soil embankments and plantations, limiting the working hours and appropriately training the workforce will help minimize noise pollution.
- Birds (e.g., scavengers), vermin, insects and animals are attracted to the landfill for feeding and breeding. Since many of these may act as disease vectors, their presence is a potential health problem.
- Surface run-off, which has been in contact with the land filled waste, may be a problem in areas of intense rainfall. If not controlled, heavily polluted run-off may enter directly into creeks and streams. Careful design and maintenance of surface drains and ditches, together with a final soil cover on completed landfill sections, can help eliminate this problem.
- An operating landfill, where equipment and waste are exposed, appears in aesthetic. This problem may be reduced by careful design of screening soil embankments, plantings, rapid covering and re-vegetation of filled sections.
- Gas released, as a result of degradation or volatilisation of waste components, causes odour, flammability, health problems and damage of the vegetation (due to oxygen depletion in the root zone). The measures to control this include liners, soil covers, passive venting or active extraction of gas for treatment before discharge into the atmosphere.
- Polluted leachate appears shortly after disposal of the waste. This may cause groundwater pollution and pollution of streams through sub-surface migration. Liners, drainage collection, treatment of leachate, and groundwater and downstream water quality monitoring are necessary to control this problem.

3.2.9 CASE STUDY: WASTE DISPOSAL: A CASE STUDY OF BANGALORE

- One of the critical concerns of a municipal corporation is planning for a proper waste disposal in response to the increasing volume and hazardous nature of urban wastes.
- When wastes are disposed unhygienically, they do spoil the aesthetic value of the city as well as create problems such as breeding of pathogenic organisms, which serve as carriers of diseases.

- Some of the principal problems associated with disposal of solid wastes can be categorised as under:
- Diseases, i.e., rats, flies and other pests feed on the wastes and carry diseases.
- Air/noise pollution, e.g., increase in vehicular traffic, smoke, fly ash and odours.
- Ground and surface water pollution, e.g., runoff during the monsoon season causes surface water pollution, while percolation often causes groundwater contamination. Unaesthetic appearance because of litter.
- However, we can minimise or satisfactorily deal with these problems through competent engineering and planning, selecting appropriate waste disposal sites and methods of operation, and making SWM strategies essentially local.
- Against this backdrop, let us now assess the scenario in Bangalore.
- About two thirds of the waste (about 1600 tonnes/day) in the Bangalore city is getting dumped in the outskirts of the city.
- As there are no sanitary landfills in the city for proper dumping of waste, it is merely transported to the outskirts and disposed of in any abandoned open land, usually along public highways.
- The Bangalore Mahanagara Palike (BMP) along with the Karnataka State Pollution Control Board (KSPCB) has, however, identified 9 abandoned quarries around the city for sanitary landfills.

Module 4

WASTE PROCESSING TECHNIQUES & SOURCE REDUCTION, PRODUCT RECOVERY & RECYCLING:

4.1 PURPOSE OF WASTE PROCESSING

- The processing of wastes helps in achieving the best possible benefit from every functional element of the solid waste management (SWM) system and, therefore, requires proper selection of techniques and equipment for every element.
- Accordingly, the wastes that are considered suitable for further use need to be paid special attention in terms of processing, in order that we could derive maximum economical value from them.
- The purposes of processing, essentially, are

  Improving efficiency of SWM system:
- Various processing techniques are available to improve the efficiency of SWM system. For example, before waste papers are reused, they are usually baled to reduce transporting and storage volume requirements.

- In some cases, wastes are baled to reduce the haul costs at disposal site, where solid wastes are compacted to use the available land effectively.
- If solid wastes are to be transported hydraulically and pneumatically, some form of shredding is also required.
- Shredding is also used to improve the efficiency of the disposal site.
- **Recovering material for reuse:**
- Usually, materials having a market, when present in wastes in sufficient quantity to justify their separation, are most amenable to recovery and recycling.
- Materials that can be recovered from solid wastes include paper, cardboard, plastic, glass, ferrous metal, aluminium and other residual metals.
- **Recovering conversion products and energy:**
- Combustible organic materials can be converted to intermediate products and ultimately to usable energy.
- This can be done either through incineration, pyrolysis, composting or bio-digestion.
- Initially, the combustible organic matter is separated from the other solid waste components.
- Once separated, further processing like shredding and drying is necessary before the waste material can be used for power generation.

4.2 MECHANICAL VOLUME AND SIZE REDUCTION:

- Mechanical volume and size reduction is an important factor in the development and operation of any SWM system.
- The main purpose is to reduce the volume (amount) and size of waste, as compared to its original form, and produce waste of uniform size.

VOLUME REDUCTION OR COMPACTION:

- Volume reduction or compaction refers to densifying wastes in order to reduce their volume.
- Some of the benefits of compaction include: reduction in the quantity of materials to be handled at the disposal site; improved efficiency of collection and disposal of wastes; increased life of landfills; Economically viable waste management system.

  Equipment used for compaction:
- Based on their mobility, we can categorise the compaction equipment used in volume reduction under either of the following
- Stationary equipment: is represents the equipment in which wastes are brought to, and loaded into, either manually or mechanically.

- In fact, the compaction mechanism used to compress waste in a collection vehicle, is a stationary compactor.
- **Movable equipment:**
- This represents the wheeled and tracked equipment used to place and compact solid wastes, as in a sanitary landfill.

Location or Operation	Type of Compactor Stationary/residential	Remark
Solid waste generation points	Vertical	Vertical compaction ram may be used; may be mechanically or hydraulically operated, usually hand-fed; wastes compacted into corrugated box containers, or paper or plastic bags; used in medium and high-rise apartments
	Rotary	Ram mechanism used to compact waste into paper or plastic bags on rotating platform, platform rotates as containers are filled; used in medium and high-rise apartments.
	Bag or extrude	Compactor can be chute fed; either vertical or horizontal rams; single or continuous multi-bags; single bag must be replaced and continuous bags must be tied off and replaced; used in medium and high-rise apartments.
	Under counter	Small compactors used in individual residences and apartment units; wastes compacted into special paper bags; after wastes are dropped through a panel door into a bag and door is closed, they are sprayed for odour control; button is pushed to activate compaction mechanism.
	Stationary/commercial	Compactor with vertical and horizontal ram; wastes compressed into steel containers; compressed wastes are manually tied and removed; used in low, medium and high-rise apartments, commercial and industrial facilities.

Table 6. Types of Compaction Equipment

SIZE REDUCTION OR SHREDDING:

- This is required to convert large sized wastes (as they are collected) into smaller pieces.
- Size reduction helps in obtaining the final product in a reasonably uniform and considerably reduced size in comparison to the original form

Type	Mode of action	Application
Small grinders	Grinding, mashing	Organic residential solid wastes
Chippers	Cutting, slicing	Paper, cardboard, tree trimmings, yard waste, wood, plastics
Large grinders	Grinding, mashing	Brittle and friable materials, used mostly in industrial operation
Jaw crushers	Crushing, breaking	Large solids
Rasp mills	Shredding, tearing	Moistened solid wastes
Shredders	Shearing, tearing	All types of municipal wastes
Cutters, Clippers	Shearing, tearing	All types of municipal wastes
Hammer mills	Breaking, tearing, cutting, crushing	All types of municipal wastes, most commonly used equipment for reducing size and homogenizing composition of wastes
Hydropulper	Shearing, tearing	Ideally suited for use with pulpable wastes, including paper, wood chips. Used primarily in the papermaking industry. Also used to destroy paper records

Table 7. Types of Size reduction Equipment

4.2.1 COMPONENT SEPARATION

- Component separation is a necessary operation in which the waste components are identified and sorted either manually or mechanically to aid further processing.
- This is required for the: recovery of valuable materials for recycling; Preparation of solid wastes by removing certain components prior to incineration, energy recovery, composting and biogas production.
- The most effective way of separation is manual sorting in households prior to collection. In many cities (e.g., Bangalore, Chennai, etc., in India), such systems are now routinely used.
- The municipality generally provides separate, easily identifiable containers into which the householder deposits segregated recyclable materials such as paper, glass, metals, etc.
- Usually, separate collections are carried out for the recyclable material.
- At curbside, separate areas are set aside for each of the recyclable materials for householders to deliver material – when there is no municipal collection system.
- In case the separation is not done prior to collection, it could be sorted out through mechanical techniques such as air separation, magnetic separation, etc., to recover the wastes.

4.2.2 DRYING AND DEWATERING

- Drying and dewatering operations are used primarily for incineration systems, with or without energy recovery systems.
- These are also used for drying of sludges in wastewater treatment plants, prior to their incineration or transport to land disposal.
- The purpose of drying and dewatering operation is to remove moisture from wastes and thereby make it a better fuel.
- Sometimes, the light fraction is pelletised after drying to make the fuel easier to transport and store, prior to use in an incinerator or energy recovery facility.

4.3 SOURCE REDUCTION, PRODUCT RECOVERY AND RECYCLING

4.3.1 BASICS OF SOURCE REDUCTION

- Source reduction, also known as waste prevention, is an approach that precedes waste management and addresses how products are manufactured and, purchased.
- Put differently, this refers to the activities that reduce the amount of waste generated at source as well as activities that involve any change in the design, manufacture, purchase or usage of

materials/products to reduce their volume and/or toxicity, before they become part of the solid waste stream.

4.3.2 PURPOSE OF SOURCE REDUCTION:

Product reuse:

- Using reusable products, instead of their disposal equivalents, reduce the amount of materials that are to be managed as wastes. An example of product reuse is the reusable shopping bag.

Material volume reduction:

- Reducing the volume of material used changes the amount of waste entering the waste stream.
- This helps in controlling the waste generated and its disposal. For example, buying in bulk or using large food containers reduces the amount of packaging waste generated.

Toxicity reduction:

- Source reduction reduces the amount of toxic constituents in products entering the waste stream and reduces the adverse environmental impacts of recycling or other waste management activities.

Increased product lifetime:

- Source reduction facilitates the use of products with longer lifetime over short-lived alternatives that are designed to be discarded at the end of their useful lives.

Decreased consumption:

- This refers to the reduced consumption of materials that are not reusable.
- In brief four main advantages of source reduction are
  - Reduction in extent of environmental impacts.
  - Reduction in resource consumption and generation of pollution.
  - It includes producer, consumer, prudent and efficient activities.

4.3.3 IMPLEMENTATION OF SOURCE REDUCTION:

- **Education and research:** Consumers, businesses, industries, schools, etc., can implement education and research activities to address the need for source reduction, its consequences, available choices, benefits and costs.
- **Financial incentives and disincentives:** Linking an economic benefit to the implementation of source reduction activities encourages source reduction.
- **Regulation:** Although most regulation occurs at the national and state level, local authorities can participate in legislative activities in developing regulations that affect municipal SWM. It is possible, for example, to establish a programme to inform the consumers about environmental impacts, durability, reusability and recyclability of products as well as to declare source reduction as a top priority in SWM

4.3.4 MONITORING AND EVALUATION OF SOURCE REDUCTION

- **Monitoring**
- Monitoring facilitates the evaluation (i.e., efficacy and efficiency) of source reduction, the identification of possible source reduction measures and programme revisions and the obtaining of funds and resources for source reduction initiatives/programmes. Monitoring should, therefore, be an integral part of a source reduction programme.

  Evaluation
- Before adopting source reduction policies, it is important that we develop a framework for evaluating various options. Some of the criteria to be considered in this regard are:
- Social and economic equity.
- Economic and administrative feasibility, efficiency and cost.
- Volume requirement and scarcity of materials and natural resources in product manufacture.
- Volume of product and its by-products that must be eventually disposed.
- Useful life, reusability and/or recyclability of a product.
- Priority of source reduction of more hazardous products to less hazardous ones

4.3.5 SIGNIFICANCE OF RECYCLING

- Recycling is perhaps the most widely recognised form of source reduction involving the process of separating, collecting, processing, marketing and ultimately using a material that would have otherwise been discarded.
- This form of source reduction, i.e., recycling, is similar to other forms, in that it: lessens reliance on landfills and incinerators; protects human health and the environment by removing harmful substances from the waste stream; Conserves natural resources by reducing the demand for raw materials.
- Recycling has a lot of direct and indirect significance for the society, and this can be grouped under the following three broad areas
  - Economic significance:
  - Cost reduction
  - Employment
  - Energy saving
  - Reduced health care costs
  - Saving costs for other public utilities
  - Environmental and health significance:

- Improved environment
- Natural resource conservation
- Social significance:

- A formal recycling arrangement will help promote the social esteem of waste workers and facilitate their upward social mobility due to increased earning.
- In addition, the improved recycling activity will increase the economic value of the waste and will reduce waste scavenging activity providing opportunity for scavengers to switch to a more socially acceptable occupation.
- In short, institutionalised recycling programmes will help remove the stigma associated with waste scavenging and transform it to an economic enterprise.

4.3.6 PLANNING OF A RECYCLING PROGRAMME

- Numerous recycling options are available, and recycling programme development requires strategic planning.
- Planning for recycling involves understanding markets, assessing local expertise, setting goals and fostering public participation.
- An efficient recycling programme requires a systematic approach to all programme components, which are interrelated, and therefore, decisions about one must be made taking into consideration other components.
- The factors involved in the planning process include the following:
  - Build local expertise:
  - Understand and develop a recycling market:
  - Foster public education and involvement:
  - Assess local waste stream:
  - Augment existing programme
  - Set goals and objectives:
  - Coordinate the programme:
  - Evaluate the programme:

4.3.7 RECYCLING PROGRAMME ELEMENTS

- Recycling programmes are designed according to the needs and priorities of the communities. Elements of a recycling programme include source separation, curbside (kerbside) collection, material resource facilities and full stream processing.

- Recycling, generally, has a positive impact on other municipal waste management programmes. This may include a mix of strategies, ranging from simple, single material drop-off centres to large scale, centralised processing facilities.
- Major elements include:

Source separation:

- Source separation refers to the segregation of the recyclable and reusable materials at the point of generation

Drop-off/buy-back:

- A drop-off programme requires residents to separate the recyclable materials and bring them to a specified drop-off or collection centre.

Curbside programm:

- In a curbside system, source separated recyclables are collected separately from regular refuse from the curbside, alley, or commercial facility.

Storage and collection of recyclables:

- Collection of source-separated materials is a necessary component of recycling programme. Establishing a collection system for source-separated materials will require more careful planning than regular trash collection.
  - Collection vehicles for recycling.
  - Processing equipment for recycling'
  - Material recovery facilities (MRF).

4.3.8 COMMONLY RECYCLED MATERIALS AND PROCESSES

- **Paper and cardboard:**
- Paper recycling is one of the most profitable activities and is practised extensively. It reduces the demand for wood and energy and helps solve littering problem in the city and around dumping site.
- It has an acceptable working condition and health risks are limited.
- Recovered paper and paper products are bought and sold through a well-established network of local processors and vendors who typically bale these materials for sale.
- Glass: Glass is one of the most commonly recycled materials, and the market for post-consumer glass has historically been steady`.
- Recycling of broken glass reduces the risk of diseases caused by cuts and wounds.
- Glass recycling is a labour intensive process and provides employment opportunity.
- **Metal:** Using recycled metals substantially reduces operating costs of industries.

- Metal scrap is cheap and the energy consumption is lower when products are manufactured from scrap.
- The long-standing track record makes ferrous and non-ferrous metal market among the most stable of all recyclable materials.
- **Plastic**
- **Batteries and tyres**

4.4 CASE STUDY: SOURCE REDUCTION AND RECYCLING IN BANGALORE

- Source reduction, including reuse and recycling, can help reduce waste disposal and handling costs, because it avoids the costs of municipal composting, landfilling and combustion.
- Source reduction also conserves resources and reduces pollution, including greenhouse gases that contribute to global warming.
- Waste reduction, reuse and recycling, thus, play an important role in SWM. In what follows, we present the statistics on waste recovery and recycling done in Bangalore, India.
- In Bangalore, 66% of the waste generated is collected for recovery, i.e., about 2,373 tonnes per day. While 722 tonnes per day is reused, the rest (i.e., 1,450 tonnes) goes for recycling.
- The agents involved in the collection and recovery of wastes in the city include waste pickers, IWB (i.e., itinerant waste buyer), middlemen (or intermediaries), the municipality and recycling units (both large and small).
- While the three agents in the informal sector and the municipality are directly involved in waste collection activities, the waste is processed by the recycling units, which receive recyclable waste from middlemen and municipality.
- Of the 1450 tonnes collected for recycling, 1077.8 tonnes come from intermediaries, 60.4 come from IWB and 312 tonnes come from waste pickers. This amounts to 40% of the total waste (i.e., 3613 tonnes per day) generated.

Module 5

HAZARDOUS WASTE MANAGEMENT AND TREATMENT:

5.1 IDENTIFICATION AND CLASSIFICATION OF HAZARDOUS WASTE:

- Hazardous wastes refer to wastes that may, or tend to, cause adverse health effects on the ecosystem and human beings.
- These wastes pose present or potential risks to human health or living organisms, due to the fact that they: are non-degradable or persistent in nature; can be biologically magnified; are highly toxic and even lethal at very low concentrations

5.1.1 IDENTIFICATION

- By using either or both of the following criteria, we can identify as to whether or not a waste is hazardous:
- The list provided by government agencies declaring that substance as hazardous.
- Characteristics such as ignitibility, corrosivity, reactivity and toxicity of the substance.
- Listed hazardous wastes (priority chemicals)

F-list:

- The F-list contains hazardous wastes from non-specific sources, that is, various industrial processes that may have generated the waste. The list consists of solvents commonly used in degreasing, metal treatment baths and sludges, wastewaters from metal plating operations and dioxin containing chemicals or their precursors. Examples of solvents that are F-listed hazardous wastes, along with their code numbers, include benzene (F005), carbon tetrachloride (F001), cresylic acid (F004), methyl ethyl ketone (F005), methylene chloride (F001), 1,1,1, trichloroethane (F001), toluene (F005) and trichloroethylene (F001). Solvent mixtures or blends, which contain greater than 10% of one or more of the solvents listed in F001, F002, F003, F004 and F005 are also considered F-listed wastes.

- **K-list:**
- The K-list contains hazardous wastes generated by specific industrial processes. Examples of industries, which generate K-listed wastes include wood preservation, pigment production, chemical production, petroleum refining, iron and steel production, explosive manufacturing and pesticide production.
- P and U lists: The P and U lists contain discarded commercial chemical products, off-specification chemicals, container residues and residues from the spillage of materials. These two lists include commercial pure grades of the chemical, any technical grades of the chemical that are produced or marketed, and all formulations in which the chemical is the sole active ingredient

5.1.2 CHARACTERISTICS OF HAZARDOUS WASTES

- **Ignitability:** A waste is an ignitable hazardous waste, if it has a flash point of less than 60 C; readily catches fire and burns so vigorously as to create a hazard; or is an ignitable compressed gas or an oxidiser. A simple method of determining the flash point of a waste is to review the material safety data sheet, which can be obtained from the manufacturer or distributor of the material. Naphtha, lacquer thinner, epoxy resins, adhesives and oil based paints are all examples of ignitable hazardous wastes.
- **Corrosivity**: A liquid waste which has a pH of less than or equal to 2 or greater than or equal to 12.5 is considered to be a corrosive hazardous waste. Sodium hydroxide, a caustic solution with a high pH, is often used by many industries to clean or degrease metal parts. Hydrochloric acid, a solution with a low pH, is used by many industries to clean metal parts prior to painting. When these caustic or acid solutions are disposed of, the waste is a corrosive hazardous waste.
- **Reactivity:** A material is considered a reactive hazardous waste, if it is unstable, reacts violently with water, generates toxic gases when exposed to water or corrosive materials, or if it is capable of detonation or explosion when exposed to heat or a flame. Examples of reactive wastes would be waste gunpowder, sodium metal or wastes containing cyanides or sulphides.
- **Toxicity:** To determine if a waste is a toxic hazardous waste, a representative sample of the material must be subjected to a test conducted in a certified laboratory. The toxic characteristic identifies wastes that are likely to leach dangerous concentrations of toxic chemicals into ground water.

5.1.3 CLASSIFICATION

- **Radioactive substance:** Substances that emit ionising radiation are radioactive. Such substances are hazardous because prolonged exposure to radiation often results in damage to living organisms.
- **Chemicals:** Most hazardous chemical wastes can be classified into four groups: synthetic organics, inorganic metals, salts, acids and bases, and flammables and explosives. Some of the chemicals are hazardous because they are highly toxic to most life forms.
- **Biomedical wastes:** he principal sources of hazardous biological wastes are hospitals and biological research facilities. The ability to infect other living organisms and the ability to produce toxins are the most significant characteristics of hazardous biological wastes.
- **Flammable wastes**: Most flammable wastes are also identified as hazardous chemical wastes. This dual grouping is necessary because of the high potential hazard in storing, collecting and disposing of flammable wastes. T
- **Explosives**: Explosive hazardous wastes are mainly ordnance (artillery) materials, i.e., the wastes resulting from ordnance manufacturing and some industrial gases. Similar to flammables, these wastes also have a high potential for hazard in storage, collection and disposal
- **Household hazardous wastes**: Household wastes such as cleaning chemicals, batteries, nail polish etc. in MSW constitute hazardous waste. Especially batteries contain mercury which are alkaline which is dangerous enough to kill people

5.2 HAZARDOUS WASTE TREATMENT

- Prior to disposal, hazardous wastes need appropriate treatment, depending on the type of waste. The various options for hazardous waste treatment can be categorised under physical, chemical, thermal and biological treatments.

PHYSICAL AND CHEMICAL TREATMENT

- Physical and chemical treatments are an essential part of most hazardous waste treatment operations, and the treatments include the following
- **Filtration and separation:** Filtration is a method for separating solid particles from a liquid using a porous medium. The driving force in filtration is a pressure gradient, caused by gravity, centrifugal force, vacuum, or pressure greater than atmospheric pressure
- **Che**mical precipitation: This is a process by which the soluble substance is converted to an insoluble form either by a chemical reaction or by change in the composition of the solvent to diminish the solubility of the substance in it. Settling and/or filtration can then remove the precipitated solids. In the treatment of hazardous waste, the process has a wide applicability in the removal of toxic metal from aqueous wastes by converting them to an insoluble form.

- **Chemical oxidation and reduction (redox):** In these reactions, the oxidation state of one reactant is raised, while that of the other reactant is lowered. When electrons are removed from an ion, atom, or molecule, the substance is oxidised and when electrons are added to a substance, it is reduced. Such reactions are used in treatment of metal-bearing wastes, sulphides, cyanides and chromium and in the treatment of many organic wastes such as phenols, pesticides and sulphur containing compounds.
- **Solidification and stabilisation**: In hazardous waste management, solidification and stabilisation (S/S) is a term normally used to designate a technology employing activities to reduce the mobility of pollutants, thereby making the waste acceptable under current land disposal requirements.
- **Evaporation:** Evaporation is defined as the conversion of a liquid from a solution or slurry into vapour. All evaporation systems require the transfer of sufficient heat from a heating medium to the process fluid to vaporise the volatile solvent. Evaporation is used in the treatment of hazardous waste and the process equipment is quite flexible and can handle waste in various forms – aqueous, slurries, sludges and tars.
- **Ozonation:** Ozone is a relatively unstable gas consisting of three oxygen atoms per molecule (O3) and is one of the strongest oxidising agents known. It can be substituted for conventional oxidants such as chlorine, hydrogen peroxide and potassium permanganate. Ozone and UV radiations have been used to detoxify industrial organic wastes, containing aromatic and aliphatic polychlorinated compounds, ketones and alcohols.

THERMAL TREATMENT

- **Incineration:** Incineration can be regarded as either a pre-treatment of hazardous waste, prior to final disposal or as a means of valorising waste by recovering energy. It includes both the burning of mixed solid waste or burning of selected parts of the waste stream as a fuel.
- **Pyrolysis:** This is defined as the chemical decomposition or change brought about by heating in the absence of oxygen. This is a thermal process for transformation of solid and liquid carbonaceous materials into gaseous components and the solid residue containing fixed carbon and ash.

BIOLOGICAL TREATMENT

- **Land treatment:** This is a waste treatment and disposal process, where a waste is mixed with or incorporated into the surface soil and is degraded, transformed or immobilised through proper management. The other terminologies used commonly include land cultivation, land farming, land application and sludge spreading.

- **Enzymatic systems**: Enzymes are complex proteins ubiquitous in nature. These proteins, composed of amino acids, are linked together via peptide bonds. Enzymes capable of transforming hazardous waste chemicals to non-toxic products can be harvested from microorganisms grown in mass culture. Such crude enzyme extracts derived from microorganisms have been shown to convert pesticides into less toxic and persistent products.
- **Composting:** The principle involved in composting organic hazardous wastes are the same as those in the composting of all organic materials though with moderate modifications. The microbiology of hazardous wastes differs from that of composting in the use of inoculums.
- Aerobic and anaerobic treatment: Hazardous materials are present in low to high concentration in wastewaters, leachate and soil. These wastes are characterised by high organic content (e.g., up to 40,000 mg/l total organic carbon), low and high pH (2 to 12), elevated salt levels (sometimes, over 5%), and presence of heavy metals and hazardous organics. Hazardous wastes can be treated using either aerobic or anaerobic treatment methods.

5.3 POLLUTION PREVENTION AND WASTE MINIMISATION

- Pollution prevention is the use of materials, processes, or practices that reduce or eliminate the generation of pollutants or wastes at the source.
- It includes practices that reduce the use of hazardous and non-hazardous materials, energy, water or other resources as well as those that protect natural resources through conservation or more efficient use.
- Pollution prevention is the maximum feasible reduction of all wastes generated at production sites.
- It involves the judicious use of resources through source reduction, energy efficiency, and reuse of input materials and reduces water consumption.

  Factors that can contribute to pollution prevention and waste minimisation.
- **Management support and employee participation:** A clear commitment by management (through policy, communications and resources) for waste minimisation and pollution prevention is essential to earn the dedication of all employees.
- For this to happen, a formal policy statement must be drafted and adopted.
- The purpose of this statement is to reflect commitment and attitude towards protecting the environment, minimising or eliminating waste and reusing or recycling materials by the laboratories, departments and industries.
- Creative, progressive and responsible leadership will serve to develop an environmental policy.
- However, the total employee workforce will need to be involved to realise the fruits of the planning.

- **Training:** As with any activity, it is important for management to train employees so that they will have an understanding of what is expected of them and why they are being asked to change the way things are done.
- Employees must be provided with formal and on-the-job training to increase awareness of operating practices that reduce both solid and hazardous waste generation.
- The training programme should include the industries' compliance requirements, which may be found in the waste management policies, occupational health and safety requirements.
- Additionally, training on waste minimisation and pollution prevention is necessary.
- **Waste audits:** A programme of waste audits at the departmental level will provide a systematic and periodic survey of the industries designed to identify areas of potential waste reduction.
- The audit programme includes the identification of hazardous wastes and their sources, prioritisation of various waste reduction actions to be undertaken, evaluation of some technically, economically and ecologically feasible approaches to waste minimisation and pollution prevention, development of an economic comparison of waste minimisation and pollution prevention options and evaluation of their results.
- **Good operating practices:** These practices involve the procedural or organisational aspects of industry, research or teaching activities and, in some areas, changes in operating practices, in order to reduce the amount of waste generated.
- These practices would include, at a minimum, material handling improvements, scheduling improvements, spill and leak prevention, preventive maintenance, corrective maintenance, material/waste tracking or inventory control and waste stream segregation, according to the toxicity, type of contaminant and physical state.
- **Material substitution practices:** The purpose of these practices is to find substitute materials, which are less hazardous than those currently utilised and which result in the generation of waste in smaller quantities and/or of less toxicity.
- **Technological modification practices:** These practices should be oriented towards process and equipment modifications to reduce waste generation. These can range from changes that can be implemented in a matter of days at low cost to the replacement of process equipment involving large capital expenditures.
- **Recycling options:** These options are characterised as use/reuse and resource recovery techniques. Use and reuse practices involve the return of a waste material either to the originating process or to another process as a substitute for an input material. Reclamation practices tender a waste to another company.

- **Surplus chemical waste exchange options:** Inter- and intra-department chemical exchange is to be implemented and encouraged by employers/employees. Material exchanges not only reduce wastes but also save money – both are important considerations, during times of fiscal crisis.

5.4 HAZARDOUS WASTES MANAGEMENT IN INDIA

- In the USA, more than 70% of the hazardous waste generated was produced from chemical and petrochemical industries.
- Of the remaining waste produced, 22% was generated by metal related industries. As industrialisation proceeds, the management of hazardous wastes is increasingly becoming a serious problem in India as well.
- The Indian chemical industry, which accounts for about 13% of the total industrial production and about 10% of the GNP valued at US $ 2.64 X 1011 (NNP is US $ 2.345 X 1011) per annum, employs about 6% of the nation's industrial workforce and is one of the major generators of toxic and hazardous wastes.
- There are 13,011 industrial units located in 340 districts, out of which 11,038 units have been granted authorization for multiple disposal practices encompassing incineration, storage land disposal and other disposal options.
- However, small and medium sized enterprises (SMEs) are the major sources of hazardous wastes. And, the States of Andhra Pradesh, Assam, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, Rajasthan and Tamil Nadu generate the majority of all hazardous wastes.
- The total estimate of hazardous waste generated in India is 4,434,257 tonnes per annum.
- India is the first country that has made provisions for the protection and improvement of environment in its Constitution.
- The Directive Principles of State Policy of the Constitution, Article 48-A of Chapter IV enjoins the State to make endeavour for protection and improvement of the environment and for safeguarding the forest and wild life of the country.
- In Article 51 A (g) of the Constitution, one of the Fundamental Duties of every citizen of India is to protect and improve the natural environment including forests, lakes, rivers and wild life and to have compassion for living creatures. India has enacted the following laws, regulations and standards governing the country's environmental protection:
- The Water (Prevention and Control of Pollution) Act, 1974 as amended in 1988.
- Water (Prevention and Control of Pollution) Rules, 1975.
- The Water (Prevention and Control of Pollution) Cess Act, 1977, as amended by Amendment Act, 1991.

- The Water (Prevention and Control of Pollution) Cess Rules, 1978.
- The Air (Prevention and Control of Pollution) Act, 1984, as amended by Amendment Act, 1987.
- The Air (Prevention and Control of Pollution) Rules 1982 and 1983. (vii) The Environment (Protection) Act, 1986
- Hazardous Waste (Management and Handling) Rules, 1989 as amended in 2000.
- Management, Storage and Import of Hazardous Chemical Rules, 1989.
- Manufacture, Use, Import, Export and Storage of Hazardous Microorganisms, Genetically Engineered Microorganisms or Cells Rules, 1989.
- The Public Liability Insurance Act, 1991. (xii) The Public Liability Insurance Rules, 1991.
- The Biomedical Wastes (Management and Handling) Rules, 1995.
- Municipal Wastes (Management and Handling) Draft Rules, 1999.
- Hazardous Waste (Management and Handling) Amendment Rules 2000

5.5 E-WASTE RECYCLING PROCESS

- The amount of e-waste generated around the world in recent years has exploded, driven by changes in technology, planned obsolescence, changes in media and storage types (tapes, CDs, HDs, SSDs etc.), and easier accessibility through decreasing costs.
- As the availability and use of electronics increases across the globe, e-waste has become the fastest-growing waste stream in the world.
- E-waste refers to any electronic devices that have reached the end of life. Unfortunately, many of the items that are labeled as "e-waste" are in fact not, since old devices that are no longer wanted but still working (or suitable for repair) can be donated, reused, or refurbished.

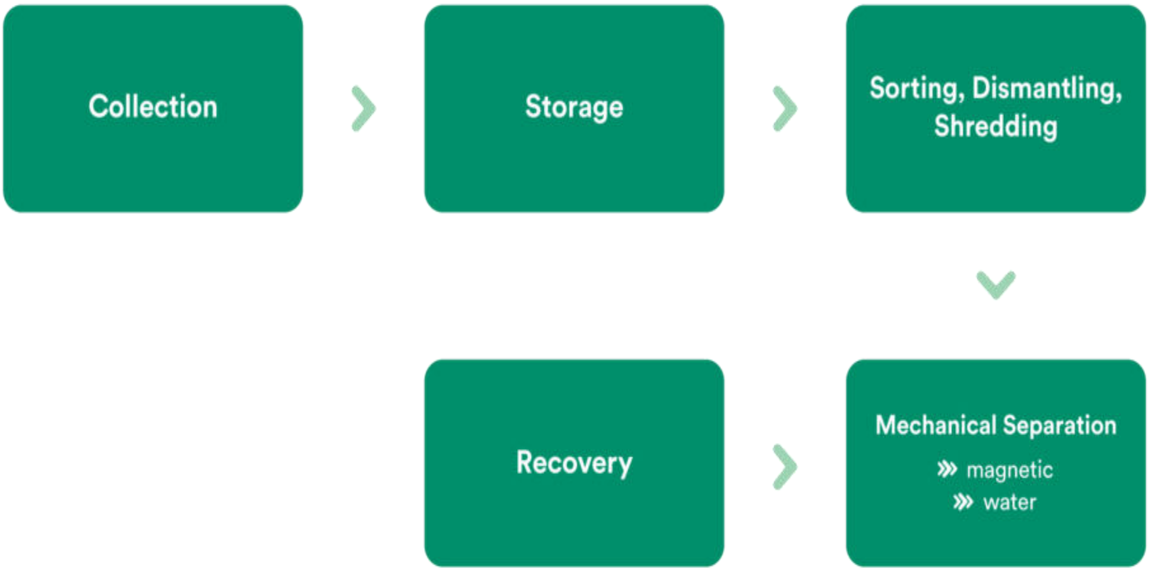

Fig 7 E-waste recycling process flowchart

- The e-waste recycling process

Step One — Collection

- The first stage in the recycling process for e-waste is the collection of electronic products through recycling bins, collection locations, take-back programs, or on-demand collection services. The mixed e-waste is then taken to specialized electronics recyclers.
- Best practice dictates that e-waste should be separated by type at this stage of the process, which is why many collection sites will have different bins or boxes for different items. This is especially important for e-waste containing batteries, which require special treatment and can be very damaging if mixed with other waste.

Step Two — Storage

- While safe storage may not appear critical, it can prove very important. For example, the glass screens of Cathode Ray Tubes (CRT) TVs and monitors are highly contaminated by lead. In the past, they were recycled into new computer monitors, but the growth of new technology and subsequent decline in demand for CRT products means much of this glass is now simply being stored indefinitely.

Step Three — Manual Sorting, Dismantling, Shredding

- E-waste then goes through the initial stage of manual sorting, where various items (such as batteries and bulbs) are removed for their own processing. This is the stage at which some items may also be manually dismantled for components, reuse, or the recovery of valuable materials.
- E-waste is then shredded into small pieces allowing for accurate sorting of materials, a key part of the process. Most electronics are a mix of materials, and breaking items down into pieces that measure just a few centimeters means they can be separated mechanically.

Step Four — Mechanical Separation

- The mechanical separation of the different materials actually consists of several processes one after the other. The two key steps are magnetic separation and water separation

Magnetic Separation

- The shredded e-waste is passed under a giant magnet, which is able to pull ferrous metals such as iron and steel from the mix of waste.
- In addition to this, an eddy current may also be used, separating the nonferrous metals.
- These materials can then be diverted to dedicated recycling plants for smelting.
- Other materials such as metal-embedded plastic and circuit boards are also separated at this stage.

Water Separation

- With a solid waste stream that now consists mainly of plastic and glass, water is used to separate the materials, further purifying for the separation of different plastics as well as hand-sorting obvious contaminants.

Step Five: Recovery

- The materials, now separated, are prepared for sale and reuse. For some materials, such as plastic or steel, this means joining another recycling stream. Others may be processed onsite and sold directly alongside usable components separated in the early stages.
- How the universal recycling process differs across common items
- While this represents the general e-waste management recycling process, many items have their own unique processes. For example:

The Recycling Process for Batteries

- Upon arrival at a site, batteries are sorted by chemistry—lead-acid, nickel-cadmium, nickel-metal-hydride, and lithium-ion. Combustible materials, such as plastic casings and insulation, are burned off, with a scrubber being used to capture polluting particles and gasses created during the incineration process.
- The emptied metal cells are then chopped into pieces and heated until the metal liquefies, and non-metal components burn and gather on the top as a substance known as slag, which is scraped from the surface.
- At this point, some centers send unprocessed metal to specialized recycling plants. Other plants collect the metals during the liquification process since they settle in layers according to density. Cadmium vaporizes during this process and is collected through a condensation process

The Recycling Process for Cathode Ray Tubes

- Cathode Ray Tubes are considered one of the most troublesome types of waste to recycle. While many of their components can be broken down, they can contain as much as four pounds of lead per monitor/TV.
- This represents a significant threat, and the glass is so contaminated by this lead that it can't be added to normal glass recycling streams. While this outdated technology might not seem like a problem going forward, there remains a huge issue regarding recycling old items.

The E-waste Recycling Process for Computers and Laptops

- The process for recycling laptops and computers is very similar to the general process outlined above. However, there is likely to be a greater focus on manual sorting and separation since computer components from broken machines can be combined into new computers with no extra resources.
- What's more, the e-waste recycling process is also likely to include some sort of data destruction. This will be carried out digitally by wiping those hard drives that are reusable, or physically, by

shredding them or using other data destruction methods. Businesses and individuals are increasingly concerned about data protection, and the shredding of confidential paper documents is already common practice. Destroying data on hard drives is simply the 21st-century equivalent.

- Finally, the Basel Convention identified e-waste as a problem back in 2002, and yet, we are only just at the beginning of a long journey towards an ideal zero e-waste world. Our digital world is here to stay, and if we continue to consume non-recyclable equipment at current rates without comprehensive reduction, reuse, and recycling programs in place, we will quickly deplete natural resources and create e-scrap on an unimaginable scale.
- However, there is hope that we can strive for a more circular economy with e-waste, and both businesses and individuals can make a difference through conscientious consumption, reduction, and reuse, eventually pushing manufacturers towards more easily recyclable devices through producer responsibility programs.

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