جامعة حلوان

كلية الهندسة بالمطرية

WM

WASTE MANAGEMENT

إدارة المخلفات

ASSOC. PROF. DR. KARIM EMARA

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Assoc. Prof. Dr. Karim Emara

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CHAPTER 1

PRINCIPLES OF MUNICIPAL SOLID WASTE MANAGEMENT

1.1. Introduction

Solid waste management is as old as human civilization, although only considered an engineering discipline for about one century. The change from the previous focus on public cleansing of the cities to modern waste management was primarily driven by industrialization, which introduced new materials and chemicals, dramatically changing the types and composition of waste, and by urbanization making waste management in urban areas a complicated and costly logistic operation. Management of municipal solid waste involves (a) development of an insight into the impact of waste generation, collection, transportation and disposal methods adopted by a society on the environment and (b) adoption of new methods to reduce this impact.

This book focuses on waste that commonly appears in the municipal waste management system. This chapter introduces modern waste management, including issues as waste definition, problems associated with waste, waste management criteria and approaches to waste management.

1.2. Defining Solid Waste

"*Waste is a left-over, a redundant product or material of no or marginal value for the owner and which the owner wants to discard.*"

An important characteristic is that being 'waste' is not an intrinsic property of an item but depends on the situation in which the item appears as defined by its owner or in other words how the owner values the item. The owner sees little value in an item if the effort required converting the excessive item to cash value or preserving the item for future use or consumption exceeds the effort it takes to obtain the same cash value or function of the item by other means. Then the item becomes waste. This means that becoming 'waste' may depend on many factors, for example:

- Time: If supplies are scarce, for example during war time and embargos, the owner will spend more time and effort repairing an item since the alternative may be costly and hard to find.
- Location: Farming communities may easily make use of food waste for animal feeding, while this is less feasible in a high-rise in an urban area.
- State: The item may be repairable depending on its state (price, age, type of damage) and thereby avoid being discarded.
- Income level: The higher your income the more food you may discard or the more items you may discard because they no longer are in fashion or up to date.

- Personal preferences: Certain types of items may be collector's items or possess veneration for some individuals.

This also suggests that what is waste to one person may not be waste to another person and there may be a potential for trading if the cost for transferring the item does not exceed the value of the item as perceived by the new owner. Hence quantity and purity of the item is a key issue; the metallic paper clip in a private household may be discarded as waste, while tons of iron cuttings in a manufacturing industry may not be a waste but a secondary product that can be traded. In addition to the abovementioned factors, what becomes waste depends on which items are being purchased and consumed. Or in other words culture, climate, religious and ethnic background as well as economical abilities affect what becomes waste. Hence, waste quantities and composition vary widely, both geographically (regionally, locally) and over time.

1.2.1.Solid Waste

The definition of 'solid waste' would be anticipated to be 'a waste in a solid state'. However, solid waste may be solid, or liquid as a sludge or as a free chemical phase. This originates from defining solid waste as waste that is not water (wastewater) or air borne (flue gases). This also suggests that solid waste has no transporting media like water and air that must be cleaned. While obtaining clean water and clean air are the main purposes of treating wastewater and cleaning flue gases, the purpose of waste management is not to clean the waste bins, but to handle the waste in the bins, as discussed later.

1.2.2.Solid Waste Generation and Material Flow

Solid waste is generated, in the beginning, with the recovery of raw materials and thereafter at every step in the technological process as the raw material is converted to a product for consumption. A society receives energy and raw material as inputs from the environment and gives solid waste as output to the environment. In the long-term perspective, such an input-output imbalance degrades the environment.

Waste generation is linked to economical activities and the flow of materials in society. The schematic diagram in **Figure 1** (Christensen, 2011) illustrates the flow of materials from the environment through society and back to the environment. The diagram pictures the fact that resources are not consumed but merely transformed in the process of extraction from the environment, production and use before ending up as waste. This waste may be returned into the production-use cycle in society or disposed of into the environment. The material flow is driven by a significant use of energy, and emissions to air, water and soil are associated with all activities within the flow system.

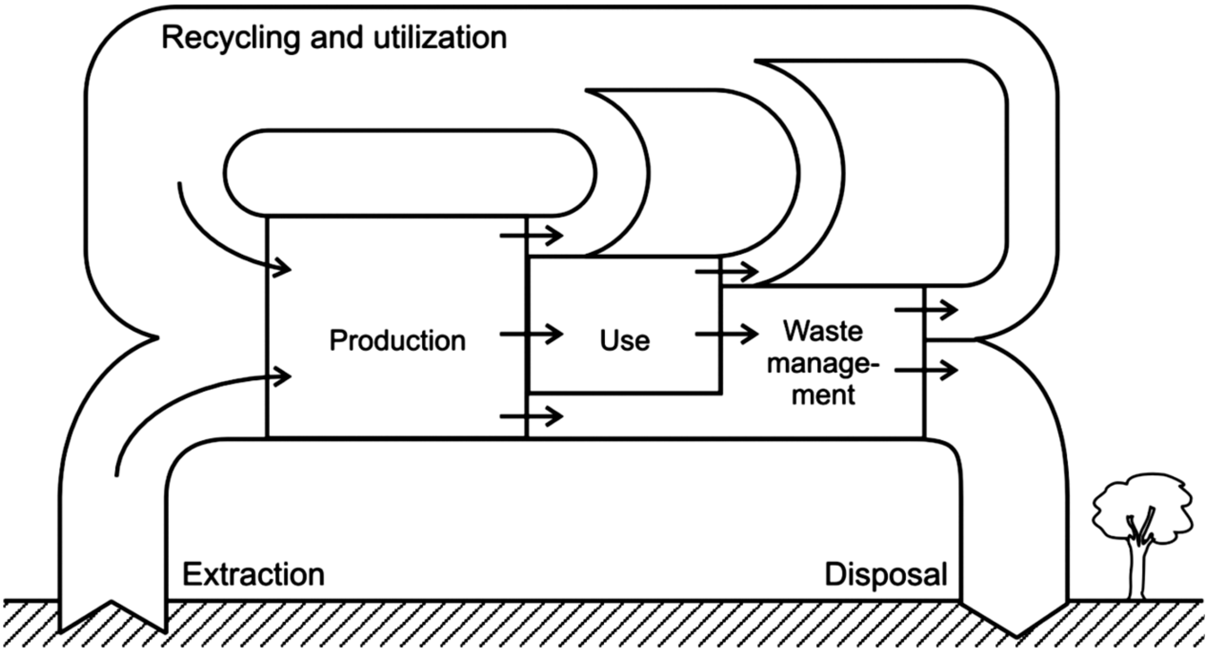


Figure 1: Schematic material flow in society showing extraction of resources, production, use, waste management and disposal into the environment

1.2.3. Environmental Impact of Solid Waste Disposal on Land

When solid waste is disposed of on land in open dumps or in improperly designed landfills (e.g., in low lying areas), it causes the following impact on the environment.

- Ground water contamination by the leachate generated by the waste dump.
- Surface water contamination by the run-off from the waste dump

- Bad odor, pests, rodents and wind-blown litter in and around the waste dump
- Generation of inflammable gas (e.g., methane) within the waste dump
- Bird threat above the waste dump which affects flight of aircraft.
- Fires within the waste dump
- Erosion and stability problems relating to slopes of the waste dump.
- Acidity to surrounding soil and
- Release of greenhouse

1.3. Waste Management Systems

Municipal Solid Waste Management involves the application of principle of Integrated Solid Waste Management (ISWM) to municipal waste. ISWM is the application of suitable techniques, technologies and management programs covering all types of solid wastes from all sources to achieve the twin objectives of (a) waste reduction and (b) effective management of waste still produced after waste reduction. A waste management system is the strategy an organization uses to dispose, reduce, reuse, and prevent waste. Possible waste disposal methods are recycling, composting, incineration, landfills, bioremediation, waste to energy, and waste minimization.

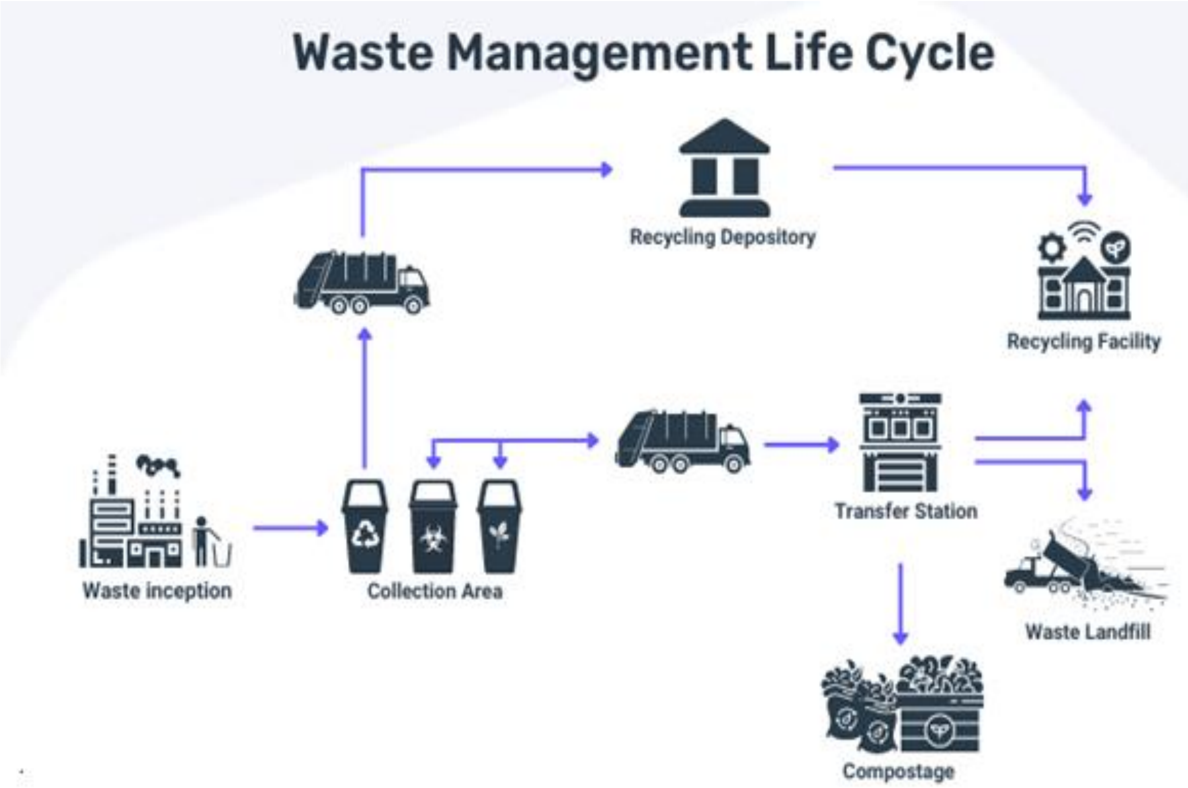


Figure 2: Waste Management Life Cycle

1.3.1.Objective of Solid Waste Management

The objective of solid waste management is to reduce the quantity of solid waste disposed of on land by recovery of materials and energy from solid waste. This in turn results in lesser requirement of raw material and energy as inputs for technological processes.

1.3.2.Waste Management Criteria

The ideal waste management system does probably not exist, but it may be useful to identify some of the main criteria that waste management as service and a public obligation should consider and try to balance.

The following criteria should be considered in all waste management planning:

- Provide a customized and robust handling of all waste with a minimum of effort for the customer and the citizen.
- Ensure the lowest possible load on the environment in terms of noise and contamination of air, water, and soil.
- Provide a maximum of resource recovery from the waste while minimizing use of resources in the waste handling.
- Be a safe and healthy occupation for the workers offering no uninteresting work and achievable challenges.
- Provide only little impact on the city with respect to traffic, vehicle exhaust, noise, traffic accidents and spill of waste.
- Include aesthetic and architectural considerations in establishing waste collection and treatment facilities.
- Respect as a minimum current laws, regulations, and code of practice.
- Be economically acceptable and fair.

1.3.3.Effective Management of Solid Waste

Effective solid management systems are needed to ensure better human health and safety. They must be safe for workers and safeguard public health by preventing the spread of disease. In addition to these prerequisites, an effective system of solid waste management must be both environmentally and economically sustainable.

- Environmentally sustainable: It must reduce, as much as possible, the environmental impacts of waste management.
- Economically sustainable: It must operate at a cost acceptable to community.

Clearly it is difficult to minimize the two variables, cost, and environmental impact, simultaneously. There will always be a tradeoff. The balance that needs to be struck is to reduce the overall environmental impact of the waste management system as far as possible, within an acceptable level of cost.

An economically and environmentally sustainable solid waste management system is effective if it follows an integrated approach i.e., it deals with all types of solid waste materials and all sources of solid waste. A multi-material, multi-source management approach is usually effective in environmental and economic terms than a material specific and source specific approach. Specific waste should be dealt with in such a system but in separate streams. An effective waste management system includes one or more of the following options:

- Waste collection and transportation.
- Resource recovery through sorting and recycling i.e., recovery of materials (such as paper, glass, metals) etc. through separation.

- Resource recovery through waste processing i.e. recovery of materials (such as compost) or recovery of energy through biological, thermal or other processes.
- Waste transformation (without recovery of resources) i.e. reduction of volume, toxicity, or other physical/chemical properties of waste to make it suitable for final disposal.
- Disposal on land i.e. environmentally safe and sustainable disposal in landfills.

1.3.4.Functional Elements of Municipal Solid Waste Management

The activities associated with the management of municipal solid wastes from the point of generation to final disposal can be grouped into the six functional elements: (a) waste generation; (b) waste handling and sorting, storage, and processing at the source; (c) collection; (d) sorting, processing and transformation; (e) transfer and transport; and (f) disposal. The inter-relationship between the elements is identified in Figure 3.

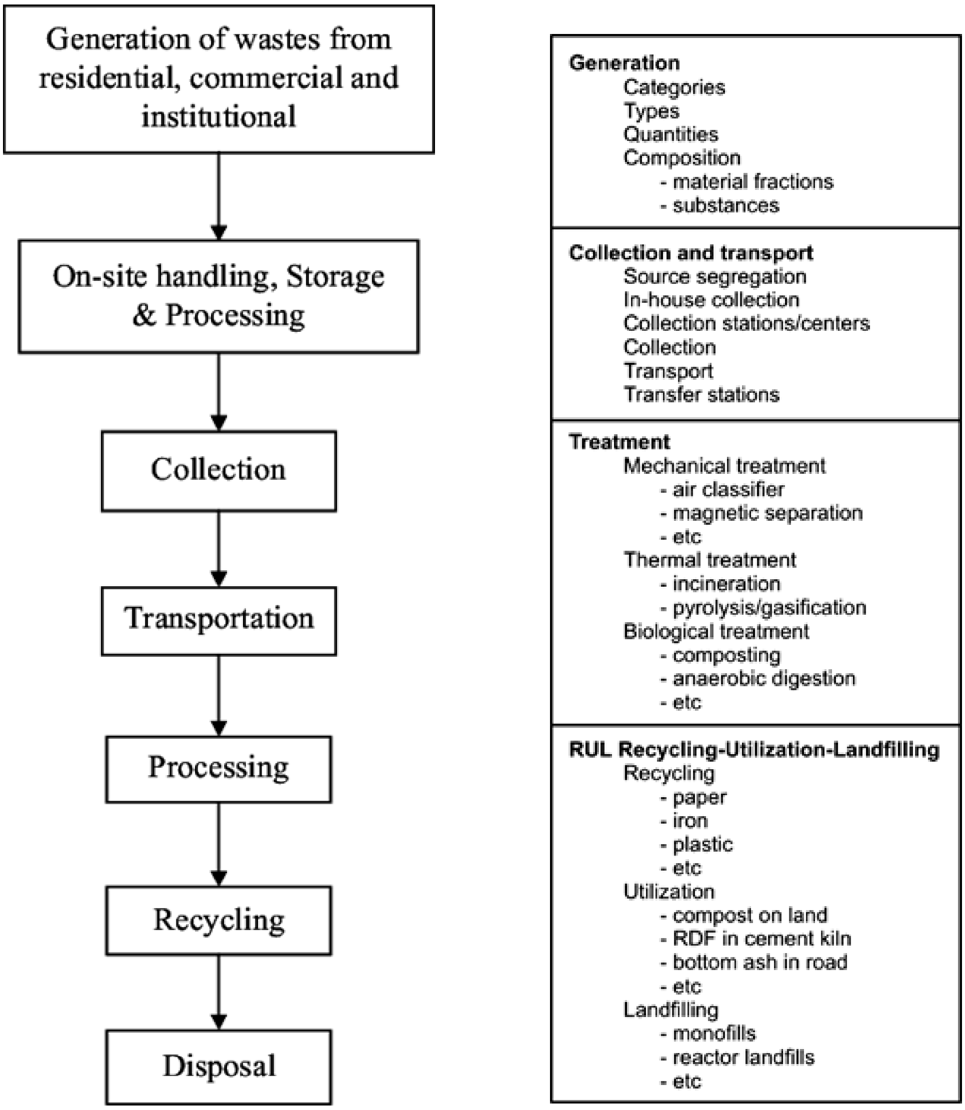


Figure 3: The inter-relationship between the elements of WM

Waste Generation:

Waste generation encompasses activities in which materials are identified as no longer being of value (in their present form) and are either thrown away or gathered for disposal. Waste generation is, at present, an activity that is not very controllable. In the future, however, more control is likely to be exercised over the generation of waste. Reduction of waste at source, although not controlled by solid waste managers, is now included in system evaluations as a method of limiting the quantity of waste generated.

Waste Handling, Sorting, Storage, and Processing at the Source:

Waste handling and sorting involves the activities associated with management of waste until they are placed in storage containers for collection. Handling also encompasses the movement of loaded containers to the point of collection. Sorting of waste components is an important step in the handling and storage of solid waste at the source. For example, the best place to separate waste materials for reuse and recycling is at the source of generation. Households are becoming more aware of the importance of separating newspaper and cardboard, bottles/glass, kitchen wastes and ferrous and non-ferrous materials.

Collection:

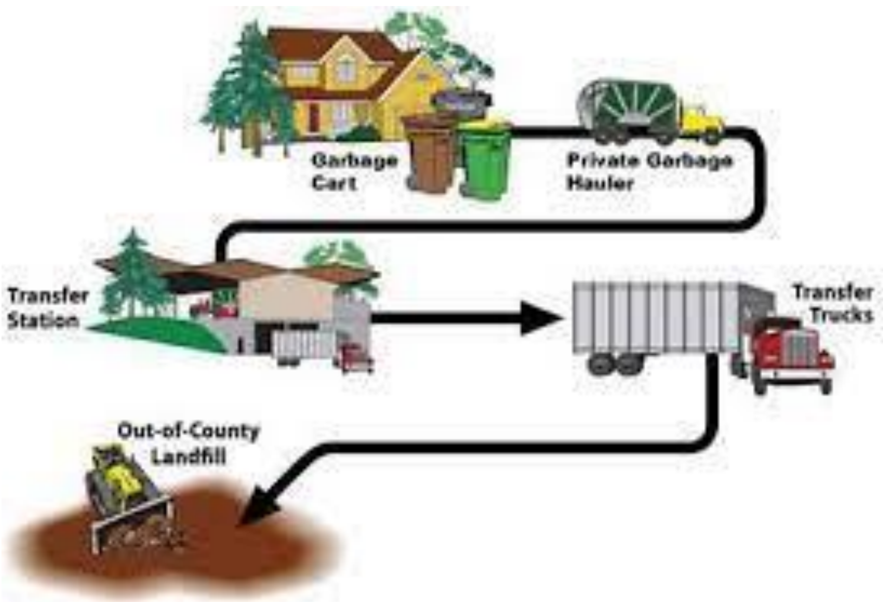
The functional element of collection, includes not only the gathering of solid wastes and recyclable materials, but also the transport of these materials, after collection, to the location where the collection vehicle is emptied. This location may be a materials processing facility, a transfer station, or a landfill disposal site.

Sorting, Processing, and Transformation of Solid Waste:

The sorting, processing and transformation of solid waste materials is the fourth of the functional elements. The recovery of sorted materials, processing of solid waste and transformation of solid waste that occurs primarily in locations away from the source of waste generation are encompassed by this functional element. Sorting of commingled (mixed) wastes usually occurs at a materials recovery facility, transfer stations, combustion facilities, and disposal sites. Sorting often includes the separation of bulky items, separation of waste components by size using screens, manual separation of waste components, and separation of ferrous and non-ferrous metals. Waste processing is undertaken to recover conversion products and energy. The organic fraction of Municipal Solid Waste (MSW) can be transformed by a variety of biological and thermal processes. The most used biological transformation process is aerobic composting. The most used thermal transformation process is incineration. Waste transformation is undertaken to reduce the volume, weight, size or toxicity of waste without resource recovery. Transformation may be done by a variety of mechanical (e.g. shredding), thermal (e.g. incineration without energy recovery) or chemical (e.g., encapsulation) techniques.

Transfer and Transport:

The functional element of transfer and transport involves two steps: (i) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (ii) the subsequent transport of the wastes, usually over long distances, to a processing or disposal site. The transfer usually takes place at a transfer station.



Disposal:

The final functional element in the solid waste management system is disposal. Today the disposal of wastes by landfilling or uncontrolled dumping is the ultimate fate of all solid wastes, whether they are residential wastes collected and transported directly to a landfill site, residual materials from Materials

Recovery Facilities (MRFs), residue from the combustion of solid waste, rejects of composting, or other substances from various solid waste-processing facilities. A municipal solid waste landfill plant is an engineered facility used for disposing of solid wastes on land or within the earth's mantle without creating nuisance or hazard to public health or safety, such as breeding of rodents and insects and contamination of groundwater.

CHAPTER 2

SOLID WASTE CLASSIFICATION, COMPOSITION AND QUANTITY

2.1. Introduction

The information on the nature of wastes, its composition, physical and chemical characteristics – and the quantities generated are basic needs for the planning of a Solid Waste Management system.

2.2. Terminology and Classification

In the literature, it is observed that various authors have used different terminology to describe the nature of waste. In this text, 'composition' refers to the limited list of components or constituents, such as paper, glass, metal, plastic, and garbage, into which an aggregate of municipal waste may conveniently be separated. 'Characteristics' on the other hand, refers to those physical and chemical properties, which are relevant to the storage, collection, treatment, and disposal of waste such as density, moisture content, calorific value, and chemical composition. In addition to these general terms, there are a number of more specific terms which, for greater clarity, must also be defined. A comprehensive list of definitions is therefore presented later in this chapter. Some terms, like 'domestic waste' and municipal waste refer to the sources of the wastes, while others, such as ‘garbage’, ‘street waste’ and ‘hazardous waste’, indicate the types of wastes.

2.3. Variations in Composition and Characteristics

An examination of the composition and characteristics of wastes in different parts of the country underscores the deep influences of national income, socio-economic conditions, social developments and cultural practices, and thereby focuses attention on the importance of obtaining the data locally. Since different kinds of solid waste management systems are designed for the future as well as the present, careful consideration should be given to changes that may occur during the design life of a system. Changes are inevitable, occur at an increasingly rapid rate in response to the increasing pace of social and technological development and the nature and extent of such changes cannot be predicted with accuracy. A built-in flexibility in the waste management system hence becomes essential. Nevertheless, it is possible to identify some of the factors that are likely to cause changes in waste composition and characteristics, which will enable planners to make reasonable judgements about the future.

2.4. Definitions And Classification of Solid Wastes

To plan, design and operate a solid waste management system, a thorough knowledge of the quantities generated, the composition of wastes and its characteristics are essential. As a first step, a proper definition of the terms is necessary to avoid the general confusion that is common in the usage of these terms.

2.4.1.Definitions

There are many terms, which relate to the types and sources of wastes and these too must be defined. Based on the source, origin and type of waste a comprehensive classification is described below:

- **Domestic/Residential Waste:**

This category of waste comprises the solid wastes that originate from single and multi-family household units. These wastes are generated as a consequence of household activities such as cooking, cleaning, repairs, hobbies, redecoration, empty containers, packaging, clothing, old books, writing/new paper, and old furnishings. Households also discard bulky wastes such as furniture and large appliances which cannot be repaired and used.

- **Municipal Waste:**

Municipal waste include wastes resulting from municipal activities and services such as street waste, dead animals, market waste and abandoned vehicles. However, the term is commonly applied in a wider sense to incorporate domestic wastes, institutional wastes, and commercial wastes.

- **Commercial Waste:**

Included in this category are solid wastes that originate in offices, wholesale and retail stores, restaurants, hotels, markets, warehouses and other commercial establishments. Some of these wastes are further classified as garbage and others as rubbish.

- **Institutional Waste:**

Institutional wastes are those arising from institutions such as schools, universities, hospitals and research institutes. It includes wastes which are classified as garbage and rubbish as well as wastes which are considered to be hazardous to public health and to the environment.

- **Construction and Demolition Wastes:**

Construction and demolition wastes are the waste materials generated by the construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. It mainly consists of earth, stones, concrete, bricks, lumber, roofing materials, plumbing materials, heating systems and electrical wires and parts of the general municipal waste stream, but when generated in large amounts at building and demolition sites, it is generally removed by contractors for filling low lying areas and by urban local bodies for disposal at landfills.

- **Industrial Wastes:**

In the category are the discarded solid material of manufacturing processes and industrial operations. They cover a vast range of substances which are unique to each industry. For this reason, they are considered separately from municipal wastes. It should be noted, however, that solid wastes from small industrial plants and ash from power plants are frequently disposed of at municipal landfills.

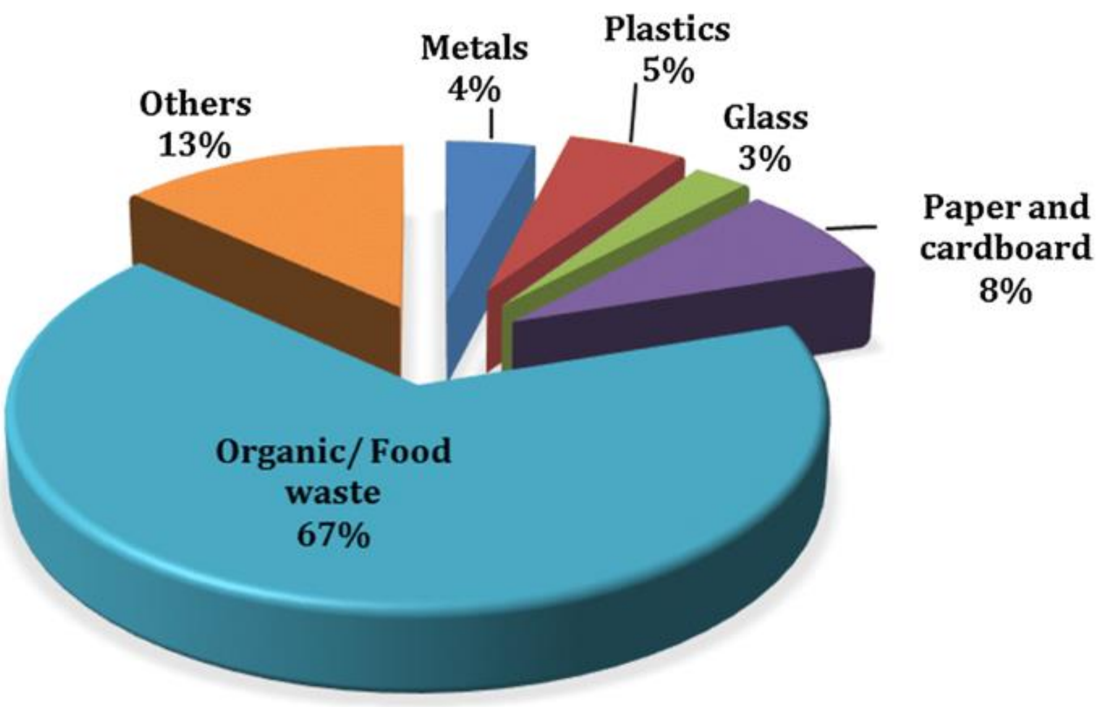
- **Hazardous Wastes:**

Hazardous wastes may be defined as wastes of industrial, institutional or consumer origin which, because of their physical, chemical or biological characteristics are potentially dangerous to human and the environment. In some cases, although the active agents may be liquid or gaseous, they are classified as solid wastes because they are confined in solid containers. Typical examples are: solvents, paints and pesticides whose spent containers are frequently mixed with municipal wastes and become part of the urban waste stream. Certain hazardous wastes cause explosions in incinerators and fires at landfill sites. Others, such as pathological wastes from hospitals and radioactive wastes, require special handling at all times. Good management practice should ensure that hazardous wastes are stored, collected, transported and disposed of separately, preferably after suitable treatment to render them innocuous.

2.5. Waste Characterization

The success of any proposed technique for waste management greatly depends on the characteristics of the waste itself. The purpose of this section is to present the waste characterization carried out to identify the waste characteristics for any project. To ensure the success of the suggested SWM program or system, a reliable SW characterization must therefore be followed. The standard system followed can be selected based on its recurrent success and reliability, for which reasons a standard testing system such as the follows: -

- Egyptian code for solid waste management
- The ASTM method



2.6. MSW Sampling

Sampling is considered a crucial first step to the following procedures of the characterization. From previous experience and studies, using an insufficient number of samples can lead to bigger errors in sorting the MSW especially if the MSW moisture content is high, which is usually a feature of the mixed MSW in Egypt. Furthermore, it has also been acknowledged that the characteristics of MSW can vastly differ from one zone to another in a certain governorate in Egypt, and that relates to the vast differences available in social standards of living in different zones. That necessitated developing a sampling method to reach the most optimum results through the largest number of representative samples from different zones.

Sampling municipal solid waste (MSW) can be done to determine the composition and characteristics of the waste stream. This information can be useful for waste management planning, waste reduction and diversion programs, and facility design and operation.

Here are some steps to follow when sampling MSW:

1. Define the objectives of the study: Before starting the sampling, it is important to define the goals and objectives of the study, such as determining the composition of the waste stream, identifying sources of contamination, or evaluating the effectiveness of a waste reduction program.

2. Determine the sampling strategy: The sampling strategy will depend on the objectives of the study and the characteristics of the waste stream. For example, if the objective is to determine the composition of the waste stream, a representative sample should be collected that includes all waste types and sizes.
3. Select the sampling method: There are several methods for sampling MSW, including grab sampling, composite sampling, and stratified random sampling. Grab sampling involves taking a sample from a single point in the waste stream, while composite sampling involves combining multiple grab samples to create a representative sample. Stratified random sampling involves dividing the waste stream into different categories and taking samples from each category.
4. Determine the sample size: The sample size will depend on the objectives of the study and the sampling method used. A larger sample size will provide more accurate results but may be more time-consuming and expensive.
5. Collect the samples: Once the sampling strategy, method, and size have been determined, the samples can be collected. Samples should be collected at different times and locations to ensure a representative sample.
6. Analyze the samples: The samples can be analyzed for their composition, moisture content, calorific value, and other characteristics using laboratory analysis.

7. Interpret the results: The results of the analysis can be used to make informed decisions about waste management planning, waste reduction and diversion programs, and facility design and operation.

It is important to follow established protocols and guidelines when sampling MSW to ensure accurate and reliable results. The sampling process should also be documented carefully to ensure the validity and traceability of the results.

2.7. Sampling Method for MSW and Characterization (Egyptian Code)

According to the Egyptian code, MSW samples can either be collected from 100 apartments, or they can be collected from disposal sites. Accordingly, it is suggesting 100 samples to be collected from the targeted zones using the sampling method at the SW collection points by means of the procedures stated in the Egyptian code. Adapted from the Egyptian code, the sampling method used in both quantification and characterization studies, during a period of 7 days, can be described as follows:

➢ The test is carried out in any areas with three different social and economic levels:
    - High-income level (HL),
    - Medium-income level (ML),

- and Low-income level (LL).

These are identified with the help of local authorities. Each of these areas constitutes a population of 500, or 100 households. Of these 100 households, 30 are selected from each income level.

- A minimum number of 4 random samples are to be taken daily from each collection site, each of which is to be 25 Kg in weight.
- Daily MSW characterization by means of composition is to be carried out on each sample.
- The MSW is to be collected from the households directly to containers to the location where the measurements are carried out.
- At the location of the measurement, the MSW is weighed, and the weight is recorded.
- The generation rate can then be estimated for each are using the following equation.

$$\boldsymbol{Generation\ rate\ \left(\frac{Kg}{person.day}\right) = \frac{Quantities\ of\ MSW\ (Kg)}{Number\ of\ collection\ days\ \times population\ of\ the\ selected\ households}}$$

$$\boldsymbol{Relative\ weight\ of\ the\ area = \frac{population\ of\ the\ level\ indicated\ (A, B, or\ C)}{population\ of\ the\ entire\ city\ or\ goe}}$$

Finally, the generation rate for the entire governorate can be calculated using the following equation:

$$\textbf{Average generation rate} \left(\frac{Kg}{person.day}\right) = \sum \textbf{generation rate of area} \times \textbf{relative weight of area}$$

2.7.1.Characterization by composition

One of the greatest challenges relating to SW generated in Egypt from different sources is its mismanagement from the source of generation. This usually occurs due to the lack of awareness, social engagement in the process, and censorship at the disposal collection points. Eventually, the MSW may end up being collected to open dumps or disposal locations with only a minimized quantity of recyclables, and a magnified quantity of food waste. Experience also showed that the organic fraction, or food waste, in the MSW is usually more than 50% by weight. So much so, the literature showed that possible solutions to the MSW generated in developing countries like Egypt are "organic waste buyback programs, with compost or biogas production" technologies. This shows the importance of determining the quantity of organic fraction alone.

Another challenge relating to the SW generated in Egypt is that it can be mixed up with all different kinds of other types of waste such as construction and demolition Waste (C&DW) as well as medical or hazardous waste. This also occurs due to the unavailability of an applied integrated system, and lack of censorship on each type of SWM generated at the source. It may also occur due to the lack of technologies and facilities for the treatment and disposal of these types of waste separately at the source before getting mixed up with MSW. Eventually, the vehicles responsible for collecting the MSW may end up being obligated to mix the MSW with the C&DW.

Considering these challenges and the nature of MSW in Egypt, the Egyptian code proposes characterization by means of 19 major components that can be found. The Egyptian code carefully considers the fact that the MSW can be found in the collection point, the collection vehicle, or the disposal site mixed up with other types of SW such as medical waste or C&DW. These components are described, according to the Egyptian code, in **Table *1***.

Table 1: Items to be classified in the MSW Characterization (The Egyptian Code Ch.3 – p.17)

Zone: ....(1/3) .... | Day: .... | Date: .... | Recorded by:					
#	العنصر	توصيف	HL [kg]	ML [kg]	LL [kg]
1	Paper	جميع الأنواع			
2	Cardboard	جميع الأنواع			
3	PET	زجاجات مشروبات شفافة			
4	HDPE/PP	منظفات/غير شفافة/كشري			
5	LPDE	أكياس/فوم			
6	PVC	خراطيم/مواسير			
7	Glass	جميع الأنواع			
8	Ferrous	جميع الأنواع			
9	Aluminum	جميع الأنواع			
10	Organic	بقايا طعام/حيوانية			
11	Agricultural	أشجار/قش/أحطاب			
12	Textiles	جميع الأنواع			
13	C&D Waste	تكسير/مواسير/...			
14	E-Waste	معدات/أسلاك/بطاريات			
15	Hazardous	دهانات/مبيدات/سرنجات/...			
16	Rubber	أحذية/حقائب/إطارات			
17	Wood	جميع الأنواع			
18	Diapers	حفاضات/مناديل			
19	Other	كناسة الشوارع/غير مصنفة			
Total					

According to the Egyptian code, the MSW characterization process can be carried out to identify the components at the source and destination, and a schedule can be prepared for each selected representative zone as follows:

1. Selection of the sampling categorization sites: a location in either the transfer area, landfill, or an empty site to drop the

collected quantities from the selected locations, and the containers are to be separated and tested randomly.

2. A 25 Kg sample size is weighed and prepared for analysis.
3. The workers unload the bags and sort the waste manually then classify it into 20 items according to **Table *1*** and load it to the assigned containers.
4. The weight of each container is measured and recorded.
5. The process is repeated for the 4 samples daily over a period of seven days, and 28 weights of each component are collected.

The percentage of each component are then calculated according to the following equation:

$$\boldsymbol{Percentage\ of\ Waste\ Component}\ (\%) = \frac{\boldsymbol{Weight\ of\ Component\ in\ sample}\ (\boldsymbol{Kg})}{\boldsymbol{Total\ Sample\ Weight}} \times \mathbf{100\%}$$

2.8. Sampling Method for MSW and Characterization Study

According to the ASTM D5231 method suggested, a certain number of mixed samples should be first identified to achieve the most appropriate and reliable results for the waste characterization procedures. While small samples are easier to handle and take much less sorting time, bigger samples can lead to bigger errors in sorting the MSW especially if the MSW moisture content is high. Waste characterization studies and applications, through time, have helped engineers reach a consensus that the optimum sampling size should be between 91 Kg to 136 Kg, which is typically the sampling size suggested by the ASTM D5231. To obtain this size for a sample in a characterization study, there are several approaches used by scientists and engineers in the field as follows (Rugg 1999):

• Assembling a composite sample from material taken from predetermined points in the load (such as each corner and the middle of each side)

• Coning and quartering

• Grabbing the sample from a randomly selected point using a front-end loader

• Manually collecting a column of waste from a randomly selected location

Two approaches for this study seemed most suitable due to the nature of waste to ensure randomization and homogeneity of the results: coning and quartering approach, and the grab sample approach. The coning and quartering approach, illustrated in **Figure 1**, shows how the method involves complete randomization by mixing a large amount of waste and then dividing it into four quarters, two of which are discarded, and then the process is repeated until 100 Kg is reached (Rugg 1999, Lenkiewicz and Webster 2017).

The 'grabbing' method, however, is a more commonly used approach that involves grabbing a pile of MSW using a loader and the facility personal without being biased towards a certain type of waste material in the pile. To homogenize the waste in the pile in the grab sampling method, a shovel can be used for mixing before grabbing a pile that is approximate to the required weight. Being quicker and more practical, the latter method of grab sampling was used for this study.

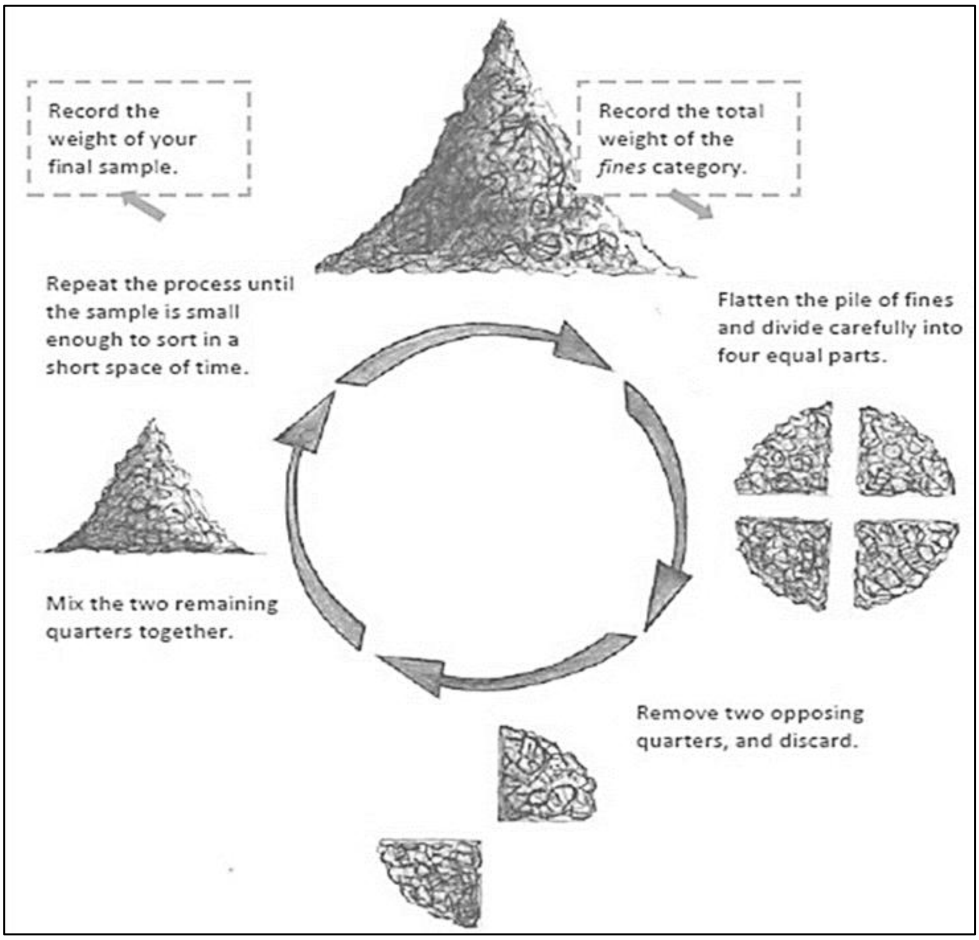


Figure 4: Coning and Quartering Sampling Approach

2.8.1. Characterization by Composition

The MSW characterization is carried out using the ASTM D5231 as follows:

a) Sorting is then done manually to separate different materials according to the categories specified in the datasheet.

b) Each container of the sorted materials is then placed on the scale and the weight is recorded.

Table 2: MSW Characterization by Composition

Zone: ....(2/4)	Day:	Date:	Recorded by:				
#	**Category**	**توصيف**	**Sample #1 [kg]**	**Sample #2 [kg]**	**Sample #3 [kg]**
1	Paper	جميع الأنواع			
2	Cardboard	جميع الأنواع			
3	PET	زجاجات مشروبات شفافة			
4	HDPE/PP	منظفات/غير شفافة/كشري			
5	LPDE	أكياس/فوم			
6	PVC	خراطيم/مواسير			
7	Glass	جميع الأنواع			
8	Ferrous	جميع الأنواع			
9	Aluminum	جميع الأنواع			
10	Organic	بقايا طعام/حيوانية			
11	Agricultural	أشجار/قش/أحطاب			
12	Textiles	جميع الأنواع			
13	C&D Waste	تكسير/مواسير/...			
14	E-Waste	معدات/أسلاك/بطاريات			
15	Hazardous	دهانات/مبيدات/سرنجات/...			
16	Rubber	أحذية/حقائب/إطارات			
17	Wood	جميع الأنواع			
18	Diapers	حفاضات/مناديل			
19	Other	كناسة الشوارع/غير مصنفة			
		Total			

2.8.2. Field Work

The purpose of this section is to present the followed procedures in detail to conduct the characterization study for the MSW coming from the regions of Giza Governorate to the three sites under consideration.

Step 1A: Preliminary Calculations

According to the ASTM D5231 method for 2003, the governing equation that is used to calculate the number of samples (n) required for the study per week is as follows:

$$\mathbf{n} = \left[\frac{\mathbf{t^{*}.\ s}}{\mathbf{e\ .\bar{x}}}\right]^{2}$$

1. The variables are firstly identified as follows:

t* = desired level of confidence,

S = estimated standard deviation,

e = desired level of precision, and

$\bar{x}$ = estimated mean.

2. The level of confidence is then selected as 90% or 95%.
3. Suggested values (by ASTM) of s and of $\bar{x}$ for waste components are listed in the following table, Table 3. These mean values and standard deviations are adapted from field test data reported for MSW sampled during weekly sampling periods at several locations around the United States while values of t*

is presented using several n values and levels of confidence. According to this method, several n values can be used and levels of confidence (90% or 95%) are selected accordingly.

4. The number of samples is then calculated using a method of trial-and-error iteration. According to ASTM, an infinite number of values is first selected using and the value of t* that was recorded (once for 90% level of confidence and again for 95%).
5. The values of s and of $\bar{x}$ can be obtained using the organic fraction, which is the dominant fraction in Giza waste, or the plastic fraction that is the most favorable fraction for the incineration plants due to its high calorific value. Having these values and with an assumed primary value of e (precision factor) 0.10, a primary value of n (no) is calculated.

Table 3: Values of Mean (x̅) and Standard Deviation(s) for Within-Week Sampling to Determine MSW Component Composition (ASTM International, 2016) and Values of t Statistics (t*) as a Function of Number of Samples and Confidence Interval

Component	Standard Deviation (s)	Mean (x̅)
Newsprint	0.07	0.10
Corrugated	0.06	0.14
Plastic	0.03	0.09
Yard waste	0.14	0.04
Food waste	0.03	0.10
Wood	0.06	0.06
Other organics	0.06	0.05
Ferrous	0.03	0.05
Aluminum	0.004	0.01
Glass	0.05	0.08
Other inorganics	0.03	0.06
TOTAL		1.00

Number of Samples, *n*	90 %	95 %
2	6.314	12.706
3	2.920	4.303
4	2.353	3.182
5	2.132	2.776
6	2.015	2.571
7	1.943	2.447
8	1.895	2.365
9	1.860	2.306
10	1.833	2.262
11	1.812	2.228
12	1.796	2.201
13	1.782	2.179
14	1.771	2.160
15	1.761	2.145
16	1.753	2.131
17	1.746	2.120
18	1.740	2.110
19	1.734	2.101
20	1.729	2.093
21	1.725	2.086
22	1.721	2.080
23	1.717	2.074
24	1.714	2.069
25	1.711	2.064
26	1.708	2.060
27	1.706	2.056
28	1.703	2.052
29	1.701	2.048
30	1.699	2.045
31	1.697	2.042
36	1.690	2.030
41	1.684	2.021
46	1.679	2.014
51	1.676	2.009
61	1.671	2.000
71	1.667	1.994
81	1.664	1.990
91	1.662	1.987
101	1.660	1.984
121	1.658	1.980
141	1.656	1.977
161	1.654	1.975
189	1.653	1.973
201	1.653	1.972
∞	1.645	1.960

6. This value is then used to obtain a new value of t* and the equation is again used to calculate n1. If the difference between n1 and no is approximately equal to or less than the precision value e, then the number n1 is correct. If not, the process is

repeated several times until the correct number of samples is reached.

2.9. Determining MSW Bulk Density

Part of the characterization of the MSW involves determining the bulk density of the MSW generated in the region. The weight per volume of the MSW on this site was determined using the ASTM E1109-86 standard method, and the following tools as suggested:

- Balance—A digital balance or scale with accuracy within 0.1% of the test load at any point within the range of use. The balances used for each of the locations have been therefore calibrated to be of range for use, and it was emptied during the experimentation to ensure correct measurement of the weights.

- Container–with known internal dimensions, which are approximately 120 L provided with handles. The interior surfaces of the container used is non-absorbent to moisture.

For this stage, the following equation was used to calculate the bulk density:

$$\rho_B = {(W_F - W_T)}/{V}$$

ρ_B = Bulk Density of the MSW, in Kg/m3

W_F = Weight of the filled container, taken in Kg

W_T = Weight of the empty container, taken in Kg

V = Volume of the container, in m3

2.10. Lab test analysis

2.10.1. Moisture Content (MC):

To determine the moisture content (MC) of the waste collected from the location, the substrate should be analyzed using a CEN/TS 15414-1 method. In this experiment, the waste can be dried by subjecting it to a temperature of 105°C in an accurate oven, and the difference of mass can be calculated. It is worth mentioning that, however, due to the heterogeneous nature of the waste, the weighted average method can be effectively applied in determining the initial MC of the mixed waste. Since it is quite impossible to get a typical representative sample from the heterogonous mixture of the waste, the procedure can be carefully repeated several times at different intervals of time.

2.10.2. Net Calorific Value and Ash Content:

To determine the Net calorific value of the solid waste acquired from the field visits and testing, the substrate can be tested using EN 15400 method. According to this method, the substrate is tested through an isoperibol, aneroid, air-jacketed isoperibol, or adiabatic bomb calorimeter and by using electronic temperature sensors, and automatic calorimeter controllers. This should be followed by an analysis of the residue for ash. The ash content can then be measured using the EN 15403 method.

CHAPTER 3

WASTE COLLECTION: EQUIPMENT AND TRUCKS

3.1. Introduction

Proper collection and transport of waste is a critical aspect of waste management that is essential for maintaining public health, protecting the environment, conserving resources, minimizing costs, and complying with regulations. Waste collection constitutes the technical interface between the waste generated and the treatment and disposal system and hence waste collection may determine which technologies may be feasible and successful in the further processing of the waste.

3.2. Collection tools

Manually handled containers for waste are typically small bins or bags that are designed to be carried and emptied by hand. These receptacles are commonly used in households and small businesses and are usually made from plastic or metal. They may have lids to help contain odors and prevent spillage.

Large containers for waste are designed for larger quantities of waste and are usually placed in public spaces, such as streets or parks. These containers can be emptied using mechanical handling equipment, such as a truck with a crane or a forklift. Large containers for waste are typically made from metal or plastic and can range in size from a few hundred liters to several cubic meters.

Containers for recyclables are designed to collect specific types of waste that can be recycled, such as paper, plastic, glass, or metal. These receptacles are often color-coded to help users easily identify which types of waste should be placed in each bin. They may be manually handled or mechanically handled and can be placed in public spaces or in households.

Containers for biodegradable organics are designed to collect organic waste, such as food scraps or garden waste, which can be composted. These receptacles may be manually handled or mechanically handled and are often made from biodegradable materials, such as paper or cardboard.

Underground bins are typically used in urban areas where space is limited. These bins are placed underground and can be accessed using special collection vehicles that can lift and empty them. Underground bins can be used for both waste and recyclables and are often equipped with odor control systems to prevent unpleasant smells. Bins and sacks are commonly used in households and small businesses for the collection and storage of non-recyclable waste.

3.2.1.Manually Handled Receptacles

Bins come in a variety of sizes and shapes, ranging from small, kitchen-sized bins to large, outdoor bins. They are typically made from plastic or metal and may have lids to help contain odors and prevent spillage. Bins can be placed indoors or outdoors, depending on their size and the amount of waste generated. Bags are another common type of receptacle for waste storage. They are typically made from plastic and are available in a variety of sizes and colors. Bags may be used for both recyclable and non-recyclable waste and can be manually handled and taken to the collection vehicle for disposal. Both bins and sacks are relatively inexpensive and easy to use, making them a popular choice for waste storage in households and small businesses. However, they may not be suitable for large-scale waste storage, as they can be difficult to empty and transport when filled with large quantities of waste. In these cases, larger containers or underground receptacles may be more appropriate (see **Figure 5**).

Figure 5 : Bags for residual waste

3.2.2.Bins with Wheels

These bins are designed to be mechanically lifted and emptied by collection vehicles, reducing the physical workload on waste collectors, and increasing productivity. **Two-wheeled** plastic bins are commonly used in households and small businesses for the collection of non-recyclable waste. They are lightweight, easy to maneuver, and come in a range of sizes to accommodate different levels of waste generation. Two-wheeled plastic bins typically have a capacity of up to 400 liters and can be fitted with lids to help contain odors and prevent spillage.

Four-wheeled bins are larger and more durable than two-wheeled bins and are designed for use in larger households, commercial and industrial settings. They can be made from plastic or metal and can range in size from 400 to 1100 liters or even more, depending on the amount of waste generated. Four-wheeled bins are equipped with wheels and handles for easy transport and are designed to be lifted and emptied by collection vehicles. The use of these larger, mechanized bins can offer several benefits over smaller, manually handled receptacles. They can help to reduce the physical workload on waste collectors, as well as increase collection efficiency and productivity. In addition, they can help to reduce the amount of waste spillage and litter, as they are equipped with lids that help to contain odors and prevent waste from blowing away. Overall, the use of larger, mechanized bins can help to improve the effectiveness and efficiency of waste collection and management.

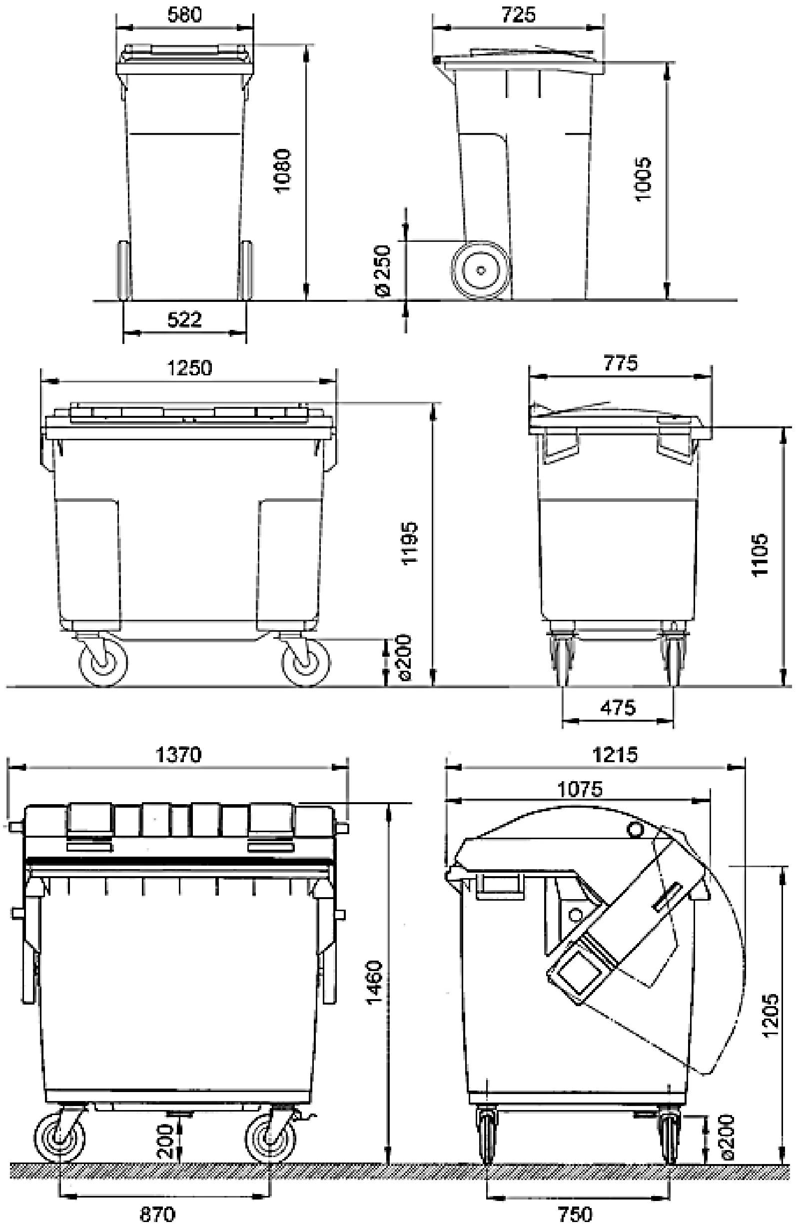


Figure 6: Bins made of polyethylene (PE) for waste collection.

Large containers are used for waste storage and collection in commercial and industrial settings, as well as in densely populated residential areas. These containers are typically made from metal or plastic and come in a range of sizes, from 2 to 12 cubic meters, depending on the amount of waste generated. The larger containers, with a volume of 2-12 m3, are typically emptied into collection vehicles using hydraulic lifting equipment, like the mechanism used for four-wheeled bins. This allows for efficient and quick collection of large volumes of waste. These containers are commonly used in commercial and industrial settings, such as factories, shopping malls, and hospitals, where large amounts of waste are generated on a regular basis.

Containers larger than 10 m3, on the other hand, are transported individually to the treatment or disposal facility, as they are too large to be emptied into a collection vehicle. These containers are typically used for the storage and collection of bulky waste, such as construction and demolition waste, as well as for the storage of hazardous waste. Large containers offer several advantages over smaller receptacles, such as bins and sacks. They can hold larger volumes of waste, reducing the frequency of collection and the associated costs. In addition, they are more durable and weather-resistant than smaller receptacles, reducing the risk of damage or degradation over time.

However, they can be more difficult to move and maneuver, and may require specialized lifting equipment for collection and transport.

Figure 7 :Typical roll-off containers

3.2.3. Underground Receptacles

Underground receptacles can be a practical solution for cities facing space constraints for waste management. These receptacles are typically large containers placed below ground level, and are designed to hold different types of waste, such as general household waste, recycling, and organic waste. One of the advantages of underground receptacles is that they can be placed in locations where traditional above-ground bins cannot, such as narrow streets and pedestrian areas. Additionally, they can be designed to be odor-proof and insect-proof, reducing the risk of attracting pests and unpleasant smells.

Underground receptacles also require less frequent emptying, as they have larger storage capacity than traditional bins. This can result in cost savings for waste management authorities, as well as reducing the amount of carbon emissions from collection vehicles. However, underground receptacles require specialized equipment for collection and maintenance, which can be expensive. They also require careful planning and design to ensure they are accessible to waste collection vehicles, as well as being safe for pedestrians and other users. Overall, underground receptacles can be a viable solution for cities with limited space for waste management. Careful planning and implementation can ensure that they are effective, efficient, and safe for both waste management authorities and the public.

Figure 8: The underground container

3.3. Waste collection vehicles

Waste collection vehicles are specialized vehicles designed to collect and transport waste from various sources to designated disposal sites. These vehicles come in different types and sizes, depending on the nature and quantity of waste being collected. Some common types of waste collection vehicles include:

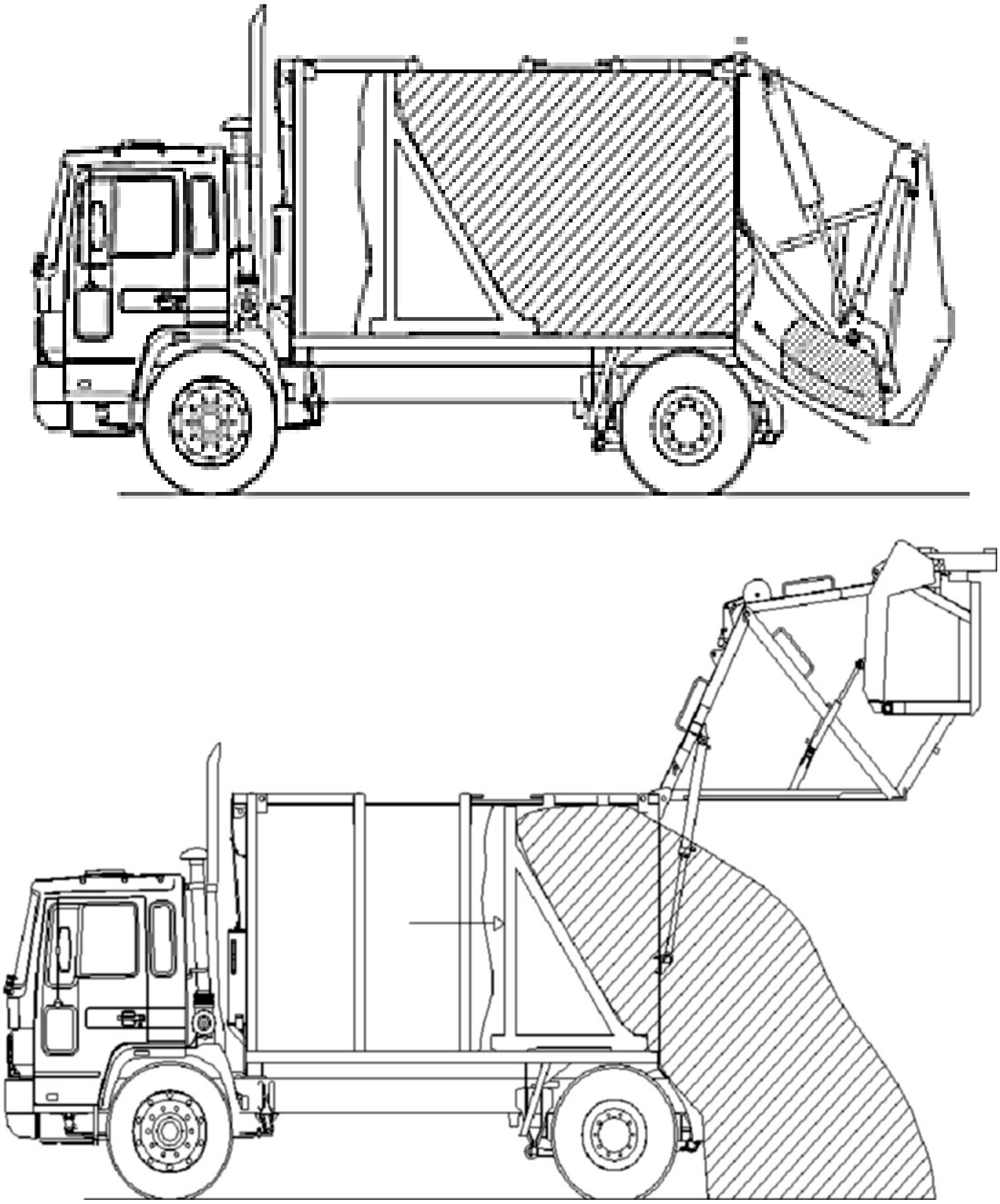
1. Rear-loading garbage trucks: These trucks have a large opening at the rear, which allows waste workers to load waste bags and bins into the truck's compactor.
2. Front-loading garbage trucks: These trucks have a hydraulic lift at the front that picks up large, wheeled bins and empties them into the truck's compactor.
3. Side-loading garbage trucks: These trucks have a hydraulic arm that extends from the side to pick up and empty wheeled bins into the truck's compactor.
4. A container truck with a hook and hydraulic arm is a specialized vehicle designed to transport heavy-duty containers for compacted waste. These trucks are commonly used by waste management companies, construction sites, and other industries that require the transportation and disposal of large quantities of waste materials. The hook and hydraulic arm on the truck are used to lift and secure the container onto the truck bed, making it easier to transport the container from one location to another.

The hydraulic arm is operated by a control system located inside the truck cabin, allowing the operator to adjust the height and angle of the arm as needed to properly position the container.

5. Vacuum trucks: These trucks are used to collect liquid and sludge waste from septic tanks, grease traps, and other sources.

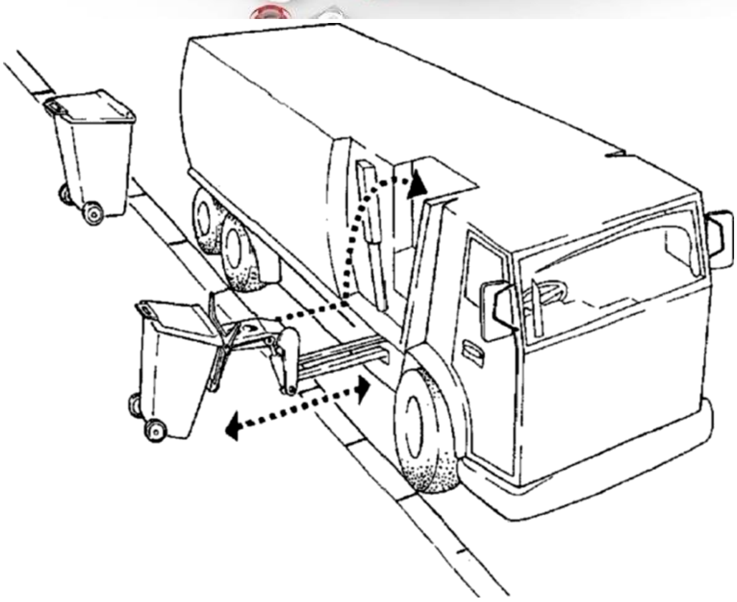
It is important for waste collection vehicles to be properly maintained and operated to ensure they are safe and effective. Regular maintenance, such as cleaning and sanitizing the vehicles, can help prevent the spread of disease and unpleasant odors as shown in Figure 9.

Waste collection vehicles can also contribute to air pollution and greenhouse gas emissions. Many cities are exploring alternatives, such as electric or hybrid waste collection vehicles, to reduce emissions and improve air quality. Additionally, waste reduction and recycling programs can help reduce the amount of waste that needs to be collected and transported, further reducing the environmental impact of waste collection vehicles.

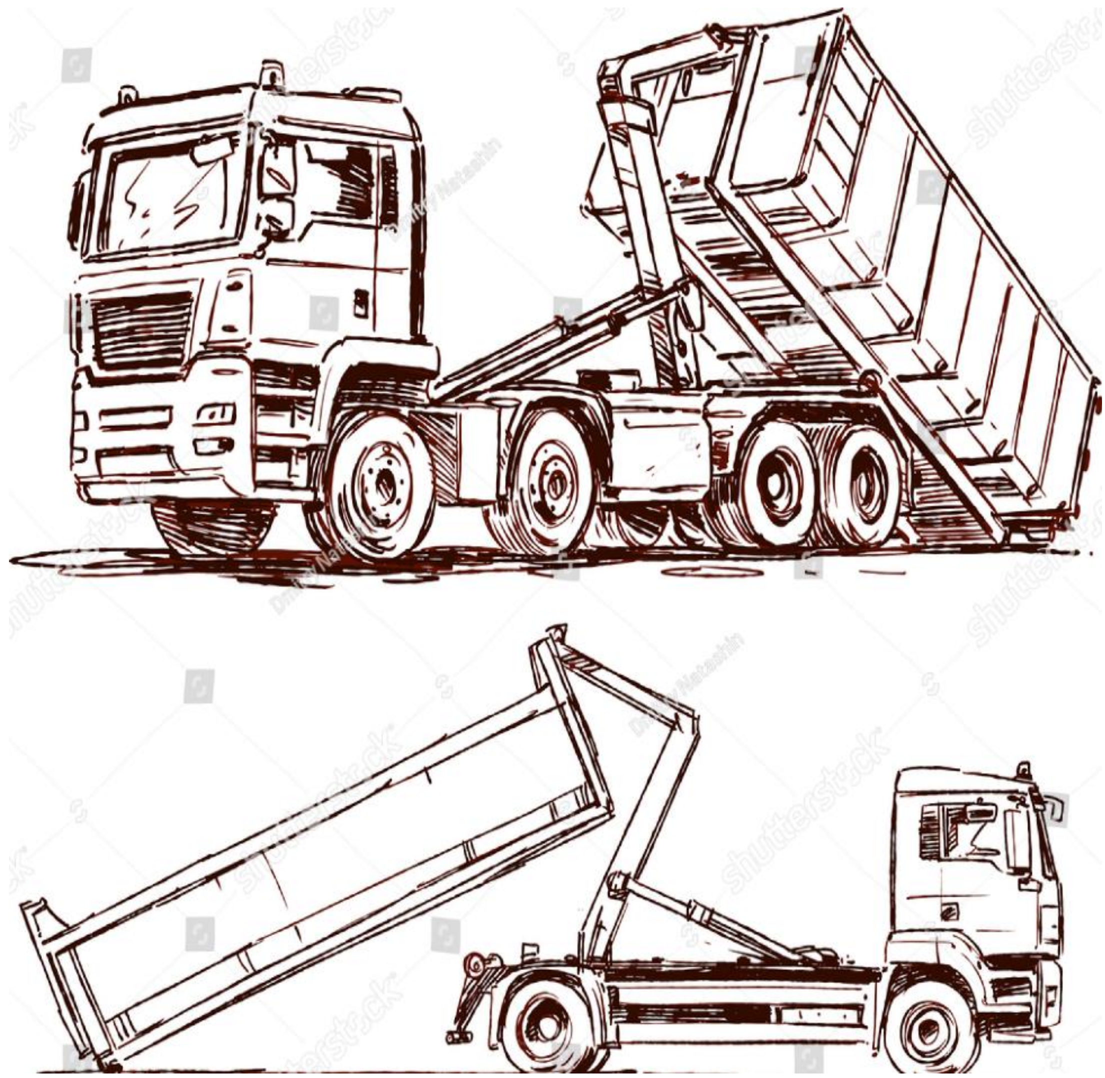


Rear-loading garbage trucks

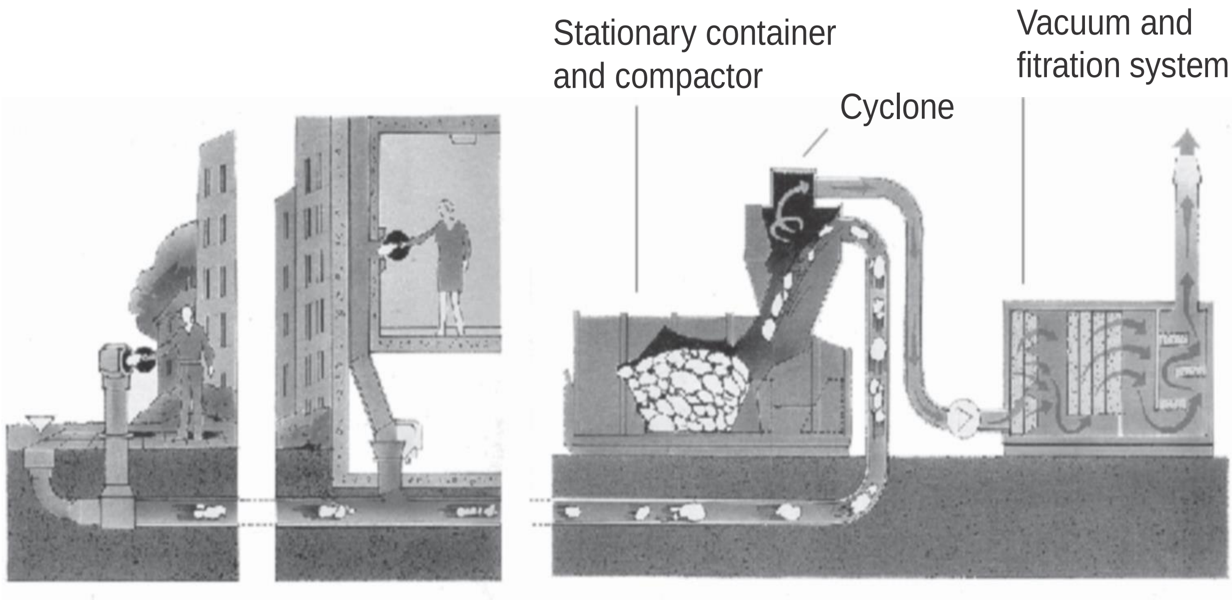
Front-loading garbage trucks



Side-loading garbage trucks



A container truck with a hook



Vacuum trucks

Figure 9: Different types of waste trucks

CHAPTER 4

WASTE TRANSFER STATIONS

The transportation and collection of waste often incur the highest expenses in a waste management system. If waste needs to be transported over long distances or for extended periods, it may be more cost-effective to transfer the waste from collection vehicles to more efficient transportation methods. This process occurs at transfer stations, which can also be used by individuals and households for the disposal of bulky waste, hazardous materials, and recyclables. During waste collection, transfer may also occur from small satellite vehicles to larger compacting vehicles that cannot maneuver through narrow residential streets or alleys in inner cities. However, this chapter focuses only on stationary transfer stations and does not cover mobile transfer processes. This chapter describes the main features of waste transfer stations, including some considerations about the economic aspects on when transfer is advisable.

In urban areas where the distance to disposal sites is greater than 15 km from the collection zone, it is cost-effective to establish transfer stations as additional storage sites to minimize transportation time and fuel consumption. These transfer stations can also include a material recovery facility where recyclable materials are sorted and sent for further processing or to recycling markets. Typically, transfer stations feature large containers ranging from 15 to 25 m^3, along with a ramp to ease the unloading of vehicles or dumper placer containers directly into larger vehicles or containers located below the ramp. Additionally, transfer stations can include a hopper for the transfer of waste, which can then be compressed using a static compactor and loaded onto a large hauling vehicle or container.

4.1. The primary objectives of using MSW transfer stations.

1) To reduce transportation time and cost: Transfer stations can be strategically placed closer to the waste generation points, reducing the time and cost of transporting waste directly to the disposal site.
2) To increase efficiency: Transfer stations allow for larger, more efficient hauling vehicles to be used to transport waste to disposal sites, reducing the number of trips required and increasing the overall efficiency of the waste management system.
3) To improve waste separation: Transfer stations can be equipped with sorting and separation equipment to separate recyclable materials and other valuable waste, reducing the amount of waste sent to landfills and increasing recycling rates.
4) To provide flexibility: Transfer stations can offer flexibility in waste management, allowing for the handling of various types of waste streams and the option to divert waste to different disposal methods.

5) To minimize environmental impact: Transfer stations can help to reduce the environmental impact of waste management by reducing the distance waste has to travel, increasing efficiency, and improving waste separation, resulting in a reduced need for landfill space and a lower carbon footprint.

There are several types of MSW (Municipal Solid Waste) transfer stations. Some of the common types are:

- Stationary Transfer Stations: These transfer stations are permanently located and are usually designed for medium to large waste volumes.
- Mobile Transfer Stations: These transfer stations are temporary and can be moved from one location to another, providing flexibility to the waste management system.
- Transfer Stations with Material Recovery Facilities (MRFs): These transfer stations are equipped with sorting and separation equipment to recover recyclable materials and other valuable waste.
- Automated Transfer Stations: These transfer stations use advanced technology, such as conveyors, sensors, and automatic compactors, to improve the efficiency and safety of waste handling.

The type of transfer station used depends on the specific needs and requirements of the waste management system.

4.2. Main Features of Transfer Stations

Waste transfer stations can be categorized according to three main features:

- The waste delivery.
- The waste transfers.
- The transportation of the reloaded waste.

Several sketches of waste transfer stations are shown in Figure 10.

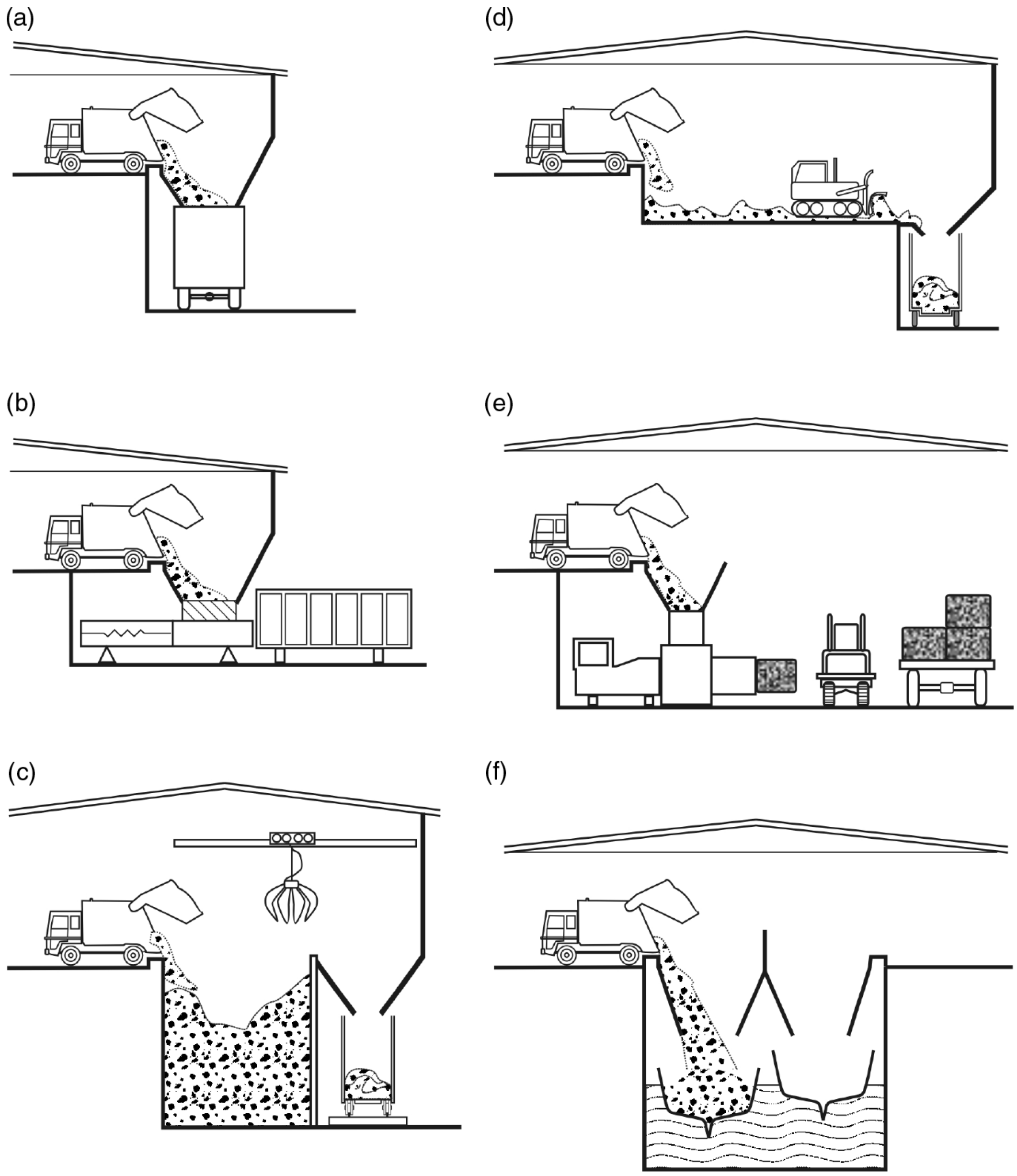


Figure 10: Sketches of waste transfer stations. (a) Direct transfer into open semitrailer. (b) Transfer via compacting into containers. (c) Transfer via bunker and reloading by crane into railroad car. (d) Transfer via floor and pushing by dozer into open semitrailer. (e) Transfer by baling and hauling by truck. (f) direct transfer into barge.

CHAPTER 5

Solid Waste Technology & Management

The effective management of municipal solid waste (MSW) and the implementation of processing technologies are contingent upon the volume and properties of the waste produced in an urban local body (ULB). To ensure successful project implementation, it is essential for local authorities to possess the financial resources and internal capabilities required.

5.1. The hierarchy of Integrated Sustainable Waste Management (ISWM)

The hierarchy of Integrated Sustainable Waste Management (ISWM) is a waste management framework that organizes various waste management strategies according to their environmental benefits. It emphasizes the implementation of sustainable and integrated approaches to waste management that prioritize waste reduction and resource recovery, while also minimizing environmental impacts and ensuring public health and safety. The hierarchy generally consists of the following waste management strategies, listed in order of priority: waste reduction, reuse, recycling, energy recovery, and disposal as in **Figure 11**.

The following sections will detail the processing technologies and disposal alternatives for MSWM, following the sequence specified by the ISWM hierarchy. ***It should be noted that waste minimization is the top priority for any waste management system.***

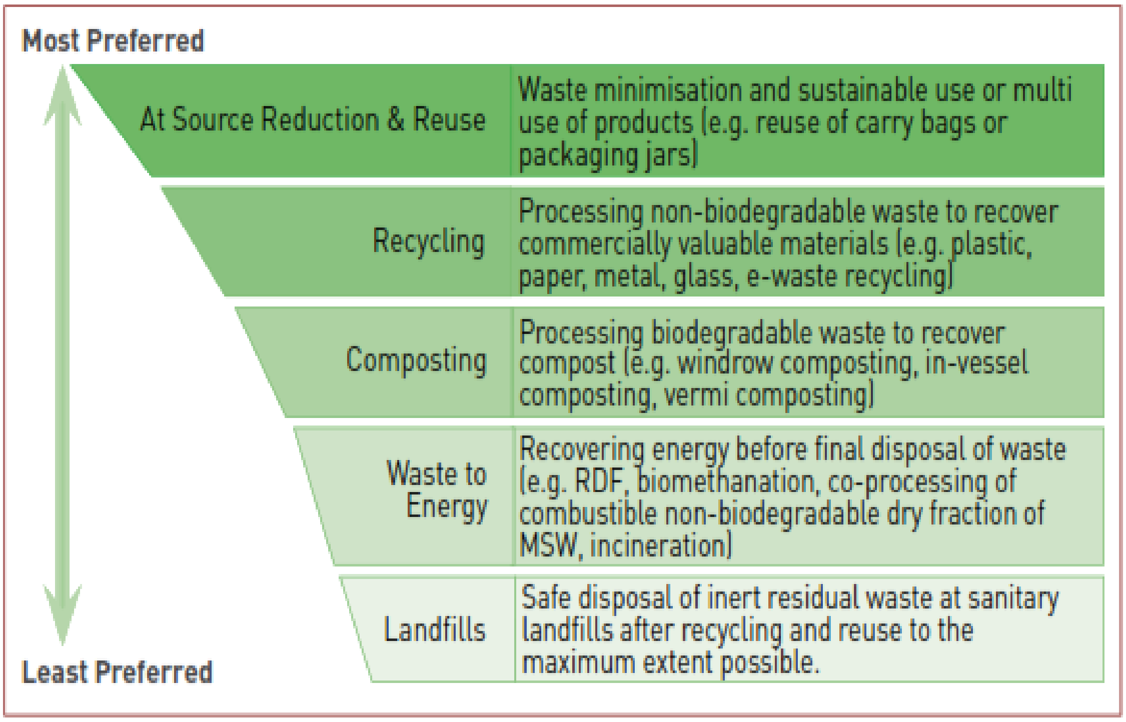


Figure 11: Integrated Solid Waste Management Hierarchy

5.2. Recycling And Recovery

According to the Solid Waste Management (SWM) Rules of 2016, recycling refers to the process of converting separated solid waste into either a new product or a raw material for manufacturing new products. Additionally, the rules specify that an arrangement must be made to supply segregated recyclable materials to the recycling industry through waste pickers or other authorized agencies engaged by the urban local body for this purpose.

According to the ISWM hierarchy, recycling is a preferred waste management strategy after source reduction and reuse. Recycling systems should be adopted before planning for any waste processing or treatment facilities.

5.3. Advantages of Recycling

The process of recycling plays a critical role in preventing a considerable portion of municipal, institutional, and bulk waste from being dumped or landfilled. This not only helps in conserving scarce resources but also reduces the environmental impacts and the burden of waste management on public authorities. If suitable market mechanisms are put in place, recycling can also generate revenue, thereby contributing to the overall cost recovery for municipal solid waste service provision.

- **For the residential areas:**

– Reduces waste volume.

– Cost savings in collection, transportation, and disposal.

– Longer life span for landfills.

– Reduced environmental management efforts.

- **For the economy:**

– Reduction of imports of raw materials, fertilizers etc. and hence foreign currency required.

– Livelihood opportunities for recyclers in the recycling industry.

- For the environment:

– Sustainable use of resources

– Reduced amount of waste going to storage sites and reduced requirement of land.

– Reduced environmental impacts including impacts of climate change.

Recycling plays a vital role in reducing the quantity of waste, increasing resource recovery, and minimizing the financial and environmental burden of MSWM.

5.4. Assessment Of Recyclables - Characterization and Quantification

A thorough waste analysis or characterization is essential for developing an effective and sustainable municipal solid waste management strategy, including recycling. The waste analysis helps in understanding the composition, characteristics, and quantities of waste generated in a particular city or locality.

By analyzing the waste composition, it is possible to identify the different types of materials that are present in the waste stream and estimate the potential for recycling of each material. This information can then be used to design a recycling program that is tailored to the specific waste composition and characteristics of the city. For example, if a significant portion of the waste stream is comprised of organic waste, such as food waste and yard waste, then a composting program may be a viable recycling option. Similarly, if there is a significant amount of paper and cardboard in the waste stream, a paper recycling program may be appropriate (see **Figure 12**).

In addition to helping identify recycling opportunities, waste analysis also provides valuable information for designing other components of a municipal solid waste management system, such as waste collection, transportation, and disposal. Overall, a thorough waste analysis is essential for developing an effective and sustainable waste management strategy that maximizes recycling and minimizes the environmental impact of waste.

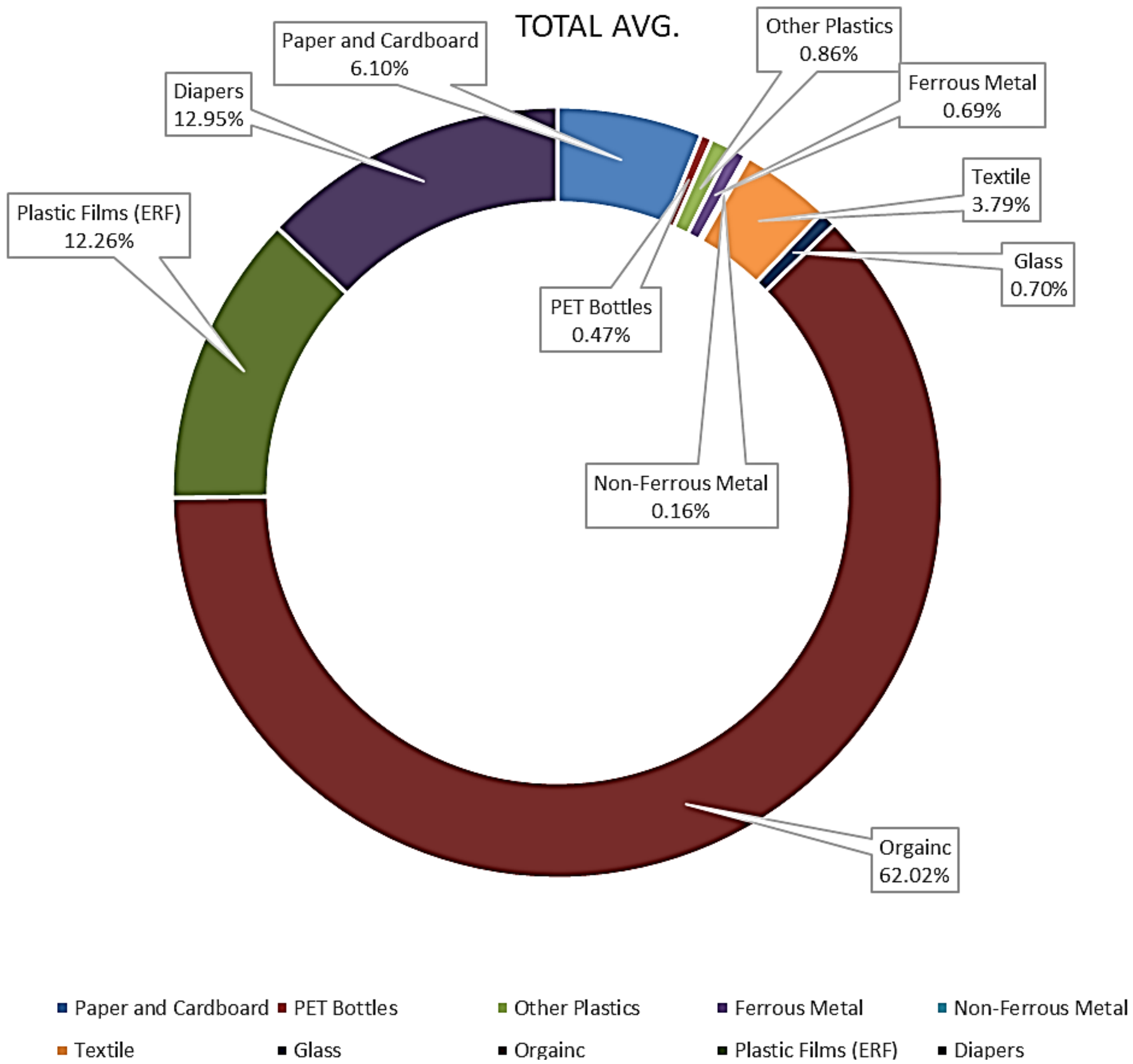


Figure 12: Municipal Solid Waste Characterization (In Suhag for example)

MATERIAL	RECYCLING POTENTIAL	SPECIAL CONDITIONS
Aluminum	• It has a high market value. • It can be recycled easily by shredding and melting. • It can be recycled indefinitely. • because it does not deteriorate through reprocessing. • It requires significantly less energy than producing aluminum ore.	Separate collection is important
Batteries	• It recovers valuable metals. • It protects environment from heavy metals such as lead, cadmium, and mercury	• There is a large variety in types and sizes of batteries. • Only some types allow adequate material to recover
Construction and demolition waste	• Demolition waste can be sorted, crushed, and reused for production of pavement material, flooring tiles, road	• Standards for recycled products are yet to be stipulated

	construction, landscaping, and other purposes. • Due to the amounts of demolition waste, its recycling allows significant reduction of otherwise required disposal capacities.	
Glass	• It has a moderate market value. • It can be melted and sorted into colors. • Recycling glass saves energy compared with processing raw material. • It can be recycled indefinitely because it does not deteriorate through reprocessing	Broken glass can contaminate and eliminate opportunities for recycling of other material such as paper
Paper and cardboard	• It is easily recycled. • Paper or cardboard from recycled paper requires less energy during	Recycling potential is reduced with each recycling cycle

	production and helps protect the forests.	through deterioration of fibers.
Polyethylene terephthalate (PET	It can be recycled if segregated from other waste	• Quality of recycled product decreases with every processing cycle. • Recycled products have specific designated uses and cannot be used for other purposes
Metal (steel, copper, nickel, zinc, silver, etc.	• Scrap metal has a high market value, especially steel, copper, and silver. • It can be recycled indefinitely because it does not deteriorate through reprocessing.	High value metals, such as copper and silver, are incorporated in electronic devices, but extraction can cause severe environmental impacts, if uncontrolled.

CHAPTER 4

MECHANICAL BIOLOGICAL TREATMENT MBT

Mechanical treatment of waste is a crucial part of waste management, and it involves various unit processes to recover valuable materials from waste streams. The primary purpose of mechanical treatment is to separate the waste into different streams to optimize other processes, remove contaminants, or homogenize the waste.

Mechanical unit processes are designed to physically alter the waste without changing its chemical composition. This chapter describes the common unit operations that are used in waste management, such as screening, shredding, sorting, and compacting. Screening involves the use of screens to separate the waste into different sizes, and it is often used to remove large items, such as rocks or construction debris. Shredding is used to reduce the size of waste materials and make them easier to handle and transport. Sorting involves separating the waste into different streams based on their physical characteristics, such as size, shape, density, or magnetic properties. This process can be done manually or using automated systems such as optical sorters, eddy current separators, or magnetic separators.

Combinations of mechanical treatment unit processes are often used to create Material Recovery Facilities (MRFs). These facilities use a combination of unit operations to recover valuable materials from waste streams, such as paper, plastics, metals, and glass. The recovered materials can then be sold as raw materials to manufacturers, reducing the need for virgin materials and reducing the environmental impact of production.

In conclusion, mechanical treatment of waste is an essential part of waste management, and it involves various unit processes to recover valuable materials from waste streams. Combinations of unit operations are used to create MRFs, which are designed to recover materials that can be sold as raw materials to manufacturers.

4.1. Mechanical biological treatment MBT

MBT stands for Mechanical Biological Treatment, which is a waste management process that combines mechanical and biological processes to treat and recover materials from mixed waste streams. The goal of MBT is to reduce the amount of waste that is sent to landfill while recovering as much value as possible from the waste.

The mechanical process involves sorting, shredding, and separating the waste into different fractions based on size, density, and other physical properties. The biological process involves treating organic waste fractions, such as food and garden waste, using biological methods like composting and anaerobic digestion to recover energy and nutrients.

The main benefits of MBT include reducing the amount of waste sent to landfill, recovering valuable materials such as metals, plastics, and organic matter, and generating renewable energy from the treatment of organic waste. MBT can also help to reduce greenhouse gas emissions and improve overall resource efficiency.

However, MBT can be expensive to implement and may require significant investment in infrastructure and equipment. In addition, MBT may not be suitable for all waste streams, and different waste streams may require different treatment processes. Therefore, it is important to carefully evaluate the feasibility and cost-effectiveness of MBT for each specific waste stream before implementing the process.

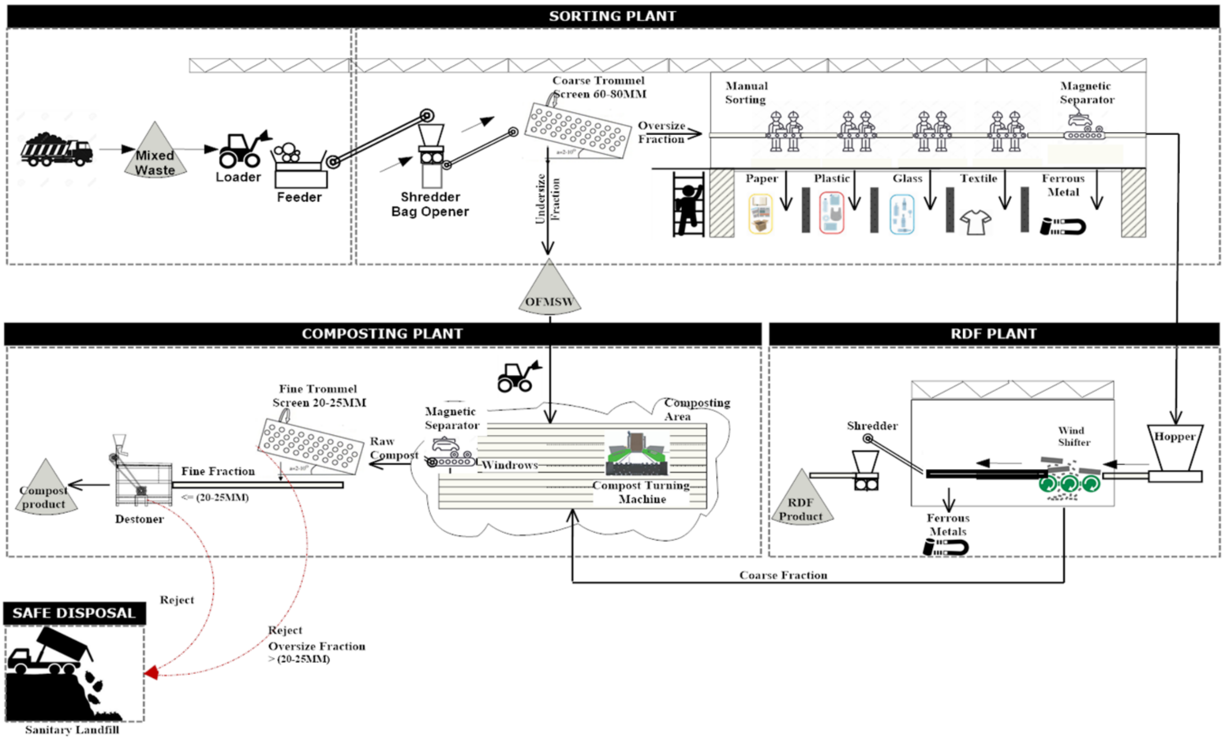
4.1.1.The component of the MBT

The MBT (Mechanical Biological Treatment) process typically involves several unit operations or components that work together to treat and recover value from mixed waste streams. These may include:

1. Pre-treatment: This may involve manual sorting, shredding, and/or size reduction of the waste to prepare it for subsequent treatment.
2. Mechanical treatment: This may include various types of mechanical unit operations such as screening, air classification, and/or magnetic separation to separate the waste into different fractions based on size, density, and/or magnetic properties.

3. Biological treatment: This typically involves the use of microorganisms to decompose organic waste and generate biogas, which can be used as a renewable energy source.
4. Post-treatment: This may involve additional mechanical or manual sorting to further refine the waste fractions and recover additional materials of value.
5. Energy recovery: This may involve the use of biogas generated during the biological treatment process to generate electricity and/or heat.

Overall, the MBT process is designed to optimize recovery of valuable materials from mixed waste streams while minimizing the amount of waste sent to landfill. By recovering valuable materials and generating renewable energy from waste, MBT can help to create a more sustainable and circular economy.


SORTING PLANT
Mixed Waste
Loader
Feeder
Shredder
Bag Opener
Coarse Trommel
Screen 60-80MM
Oversize
Fraction
Undersize
Fraction
Manual
Sorting
Magnetic
Separator
Paper
Plastic
Glass
Textile
Ferrous
Metal
OFMSW
COMPOSTING PLANT
RDF PLANT
Fine Trommel
Screen 20-25MM
Magnetic
Separator
Composting
Area
Raw
Compost
Windrows
Fine Fraction
<= (20-25MM)
Compost
product
Destoner
Compost Turning
Machine
Shredder
Wind
Shifter
Hopper
RDF
Product
Ferrous
Metals
Coarse Fraction
Reject
SAFE DISPOSAL
Reject
Oversize Fraction
> (20-25MM)
Sanitary Landfill


مساحات بنائية
مساحات مخصصة
لتشغيل السماد

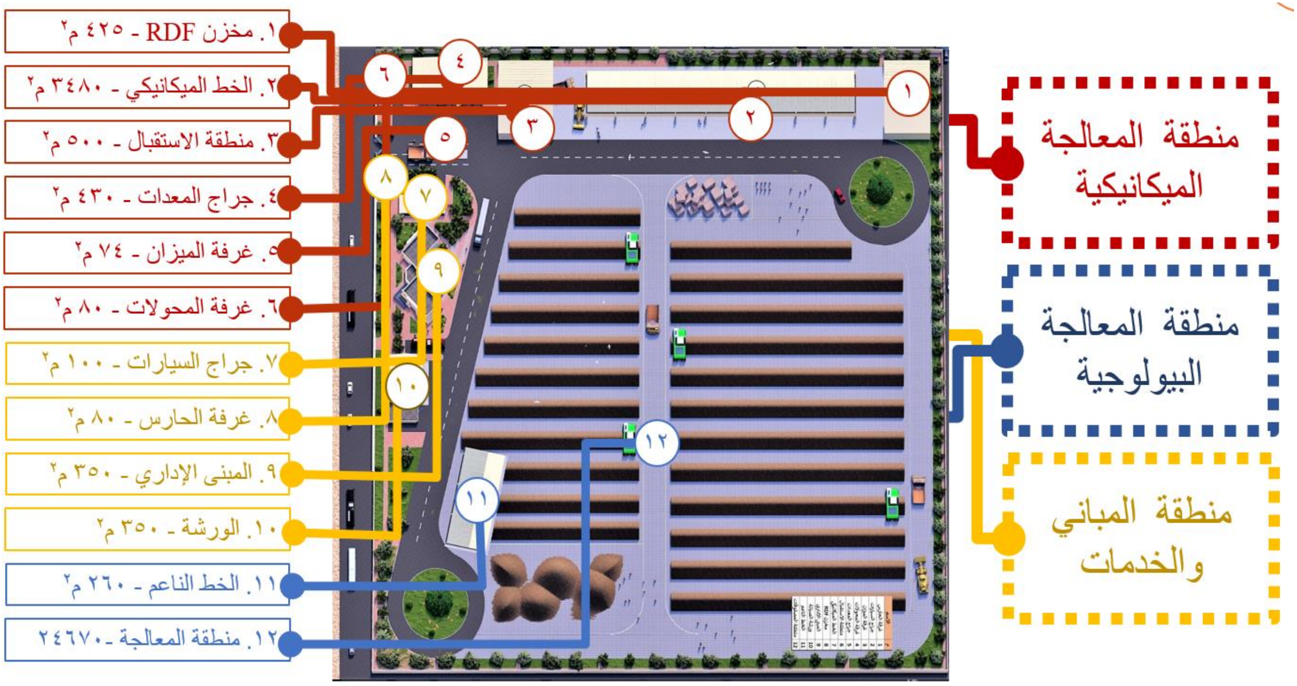


Figure 13 : MBT floe process

A key advantage of MBT is that it can be configured to achieve several different aims. Some typical aims of MBT plants include the:

- Pre-treatment of waste going to landfill.
- Diversion of non-biodegradable and biodegradable MSW going to landfill through the mechanical sorting of MSW into materials for recycling and/or energy recovery as refuse derived fuel (RDF);
- Diversion of biodegradable MSW going to landfill by:
  - Reducing the dry mass of BMW prior to landfill.

- Reducing the biodegradability of BMW prior to landfill.

* Stabilization into a compost-like output for use on land.
* Conversion into a combustible biogas for energy recovery; and/or
* Drying materials produce a high calorific organic rich fraction for use as RDF.

4.2. Size Reduction

Size reduction refers to the conversion of waste into smaller particles. This homogenizes the particle distribution, increases the surface area of the particles, and furthermore mixes the waste.

4.2.1. Bag opener (Shredder)

An MSW shredder bag opener is a piece of equipment used in the mechanical treatment of municipal solid waste (MSW). Its primary purpose is to open plastic bags containing MSW, allowing the waste to be processed more efficiently. The bag opener typically consists of a conveyor belt that carries the waste into a shredder. Before entering the shredder, the bags are opened by a series of rotating discs with sharp edges that cut through the bags. The waste spills out of the bags and onto the conveyor belt, where it can then be processed by the shredder. Opening the bags is an important step in the processing of MSW because it allows for more efficient separation and sorting of the waste. Without the bag opener, the bags would need to be manually opened, which is time-consuming and labor-intensive. Additionally, leaving the bags unopened can result in inefficient processing, as the shredder may not be able to break down the waste as effectively.

The bag opener is often used in conjunction with other mechanical treatment processes, such as screening and sorting, to separate the waste into different streams for further processing. By opening the bags and breaking down the waste, the bag opener plays an important role in the overall efficiency of the MSW treatment process as shown in **Figure 14**.

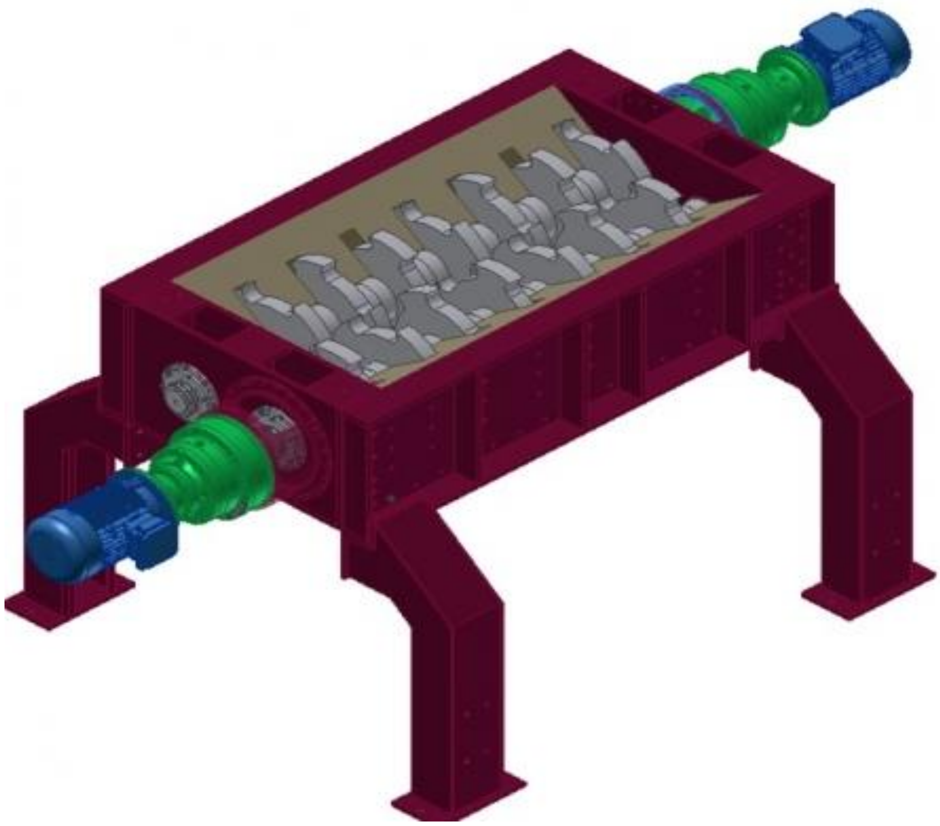


Figure 14 ;MSW bag opener shredder

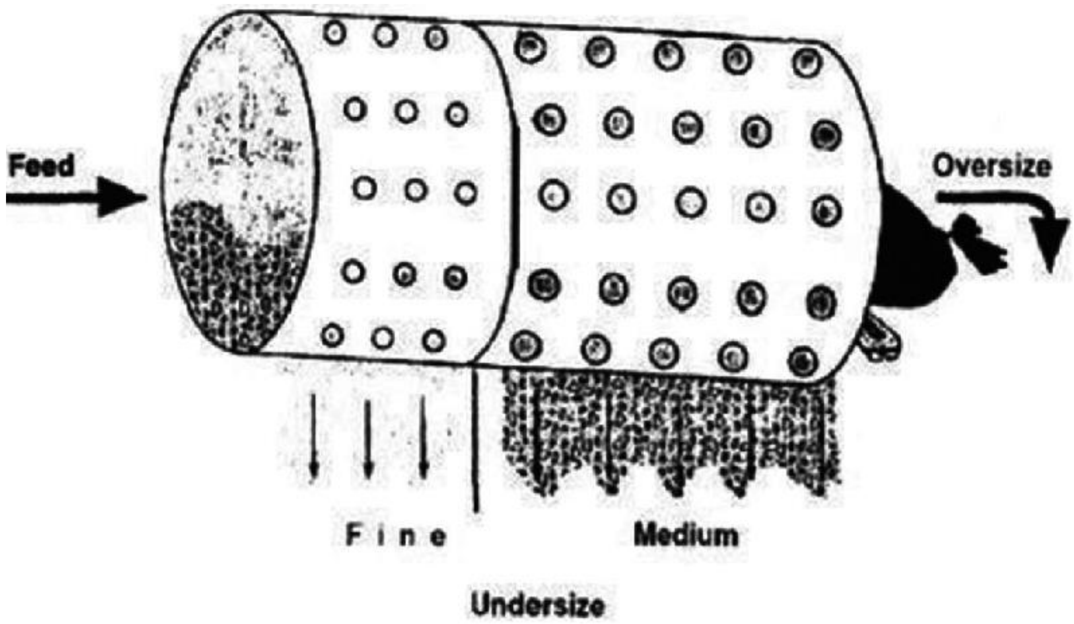
4.2.2. Screening (Trommel screen / Stare screen)

Screening is a process of separating material of various sizes into specific particle size ranges. It is commonly used in waste management to separate and classify different materials based on their size. The screening process is performed by passing the material over a screened surface with openings of a specific size. Particles smaller than the screen openings fall through and are classified as the fine fraction, while those that are too large to pass through the openings are considered the oversize fraction. However, there are several factors that can influence the screen recovery and affect the efficiency of the screening process. These factors include the size and shape of the screen openings, the type and size of the material being screened, the speed and amplitude of the screen motion, and the angle of the screen. Additionally, design flows or wearing of the screen surface can allow oversize particles to fall in with the fine fraction, and particles with about the same diameter as the screen openings can get stuck and cause wear on the screen. These particles are termed outsized, and they can reduce the overall efficiency of the screening process.

To optimize the screening process and maximize screen recovery, it is important to carefully consider these factors and choose the appropriate screen size, motion, and angle for the specific application.

4.2.1.1. Trommel screen

The trommel screen is a proven technology and can be used for primary as well as final size screening. **Figure 15** illustrates a basic trommel screen design. Input and separation efficiency of a trommel screen are controlled by the size of the screen openings, the trommel diameter (8:10 cm), the rotational speed (up to 20 rpm), the type and number of baffles, and the inclination (4:10 dgree) of the cylinder.



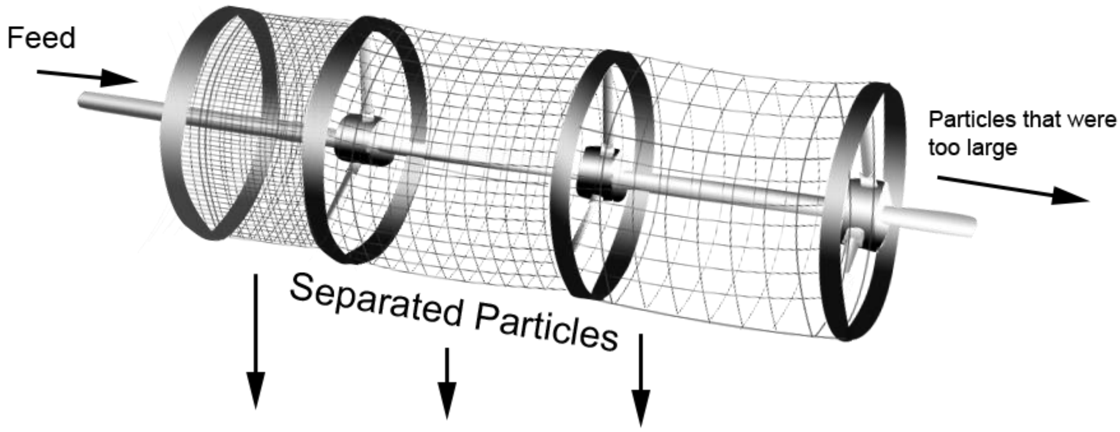


Figure 15 :Trommel screen

4.2.1.2. Disc screen

A disc screen is a type of screening method used in waste management that consists of sorting grates with partially screened surfaces comprised of rows of six-sided discs mounted on shafts.

The discs are positioned so that each disc is spaced in the open notch of the neighboring shaft, and the interstitial distance between the discs determines the size of the screen opening of each grate. The discs are designed with rounded edges and concave corner areas to prevent any jamming of the waste and to enable a rolling action that can partly break up the waste on the screen.

The waste material is fed onto the disc screen, and as it cascades down the sorting grates, the smaller particles fall through the screen openings and are separated from the larger particles. The larger particles continue down the grates until they are sorted by their size and shape.

Disc screens are commonly used in waste management to separate materials such as compost, wood chips, and paper fibers from other waste materials. They are designed to be highly efficient and durable, with minimal maintenance required. The discs can be easily replaced or repositioned to adjust the screen opening size, making them versatile and adaptable to different waste management applications.

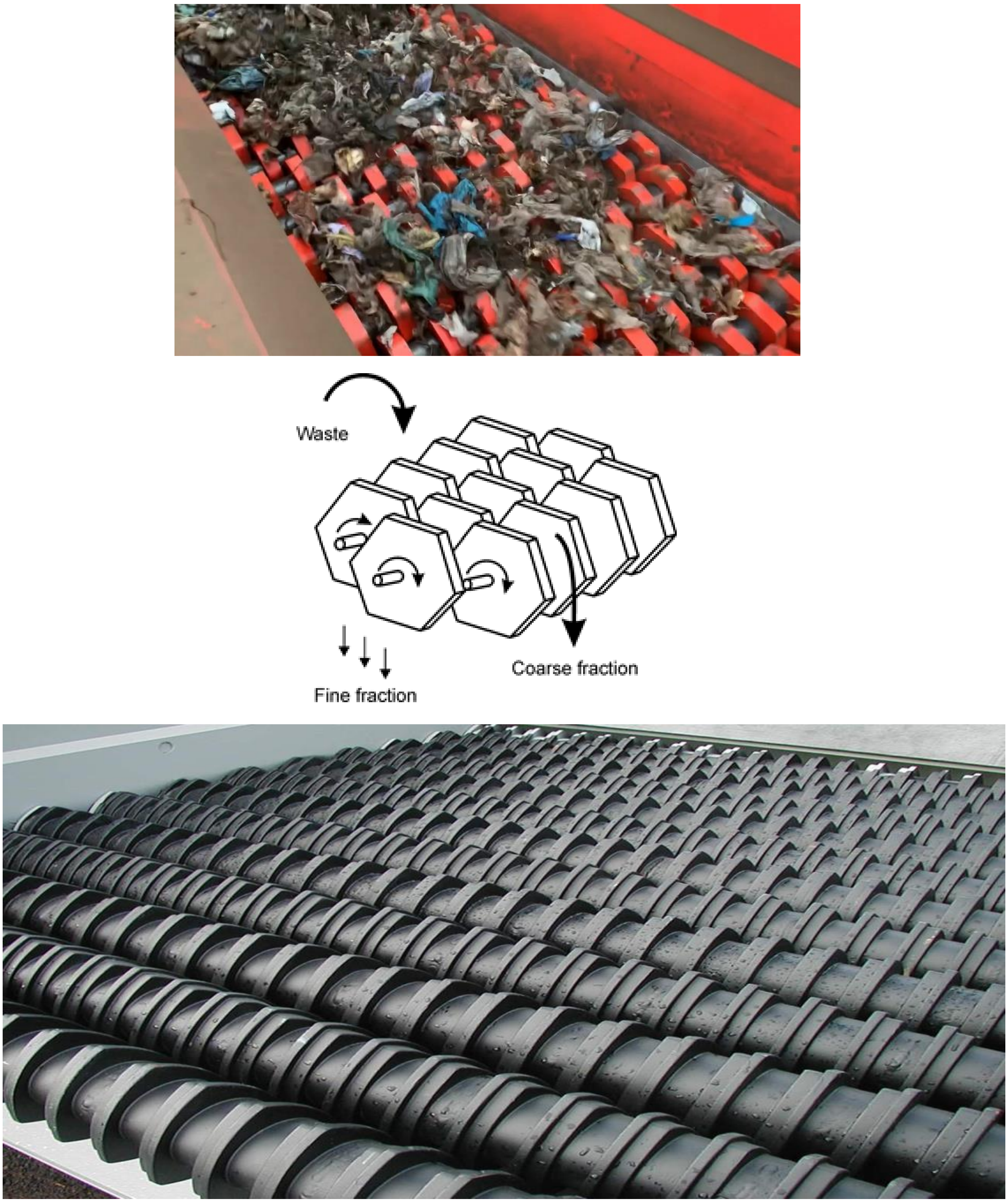


Figure 16 :Disc screen

4.2.1.3. Star screen

An MSW star screen is a type of screening machine used in the processing of municipal solid waste (MSW). It is designed to separate larger waste materials such as wood, plastic, and metal from smaller materials such as soil and organic waste. The star screen consists of a series of rotating shafts with multiple star-shaped discs attached to them. As the waste material is fed onto the screen, it is spread out and moved across the rotating shafts. The star-shaped discs grab and lift the larger materials, while the smaller materials pass through the gaps between the discs and fall through the screen.

The star screen is typically used as a primary screening device in MSW processing systems, where it is used to remove large contaminants and prepare the waste material for further processing. It can also be used as a standalone unit to screen various types of waste material, including compost, construction and demolition waste, and industrial waste. One advantage of the star screen is that it can separate a wide range of materials with different sizes and shapes. The rotating discs create a tumbling action that helps to break up clumps of waste material and prevent clogging. Additionally, the star screen is designed to be low maintenance and can operate continuously for long periods of time, making it an efficient and cost-effective solution for waste processing (**Figure 17**).

Figure 17: Star screen

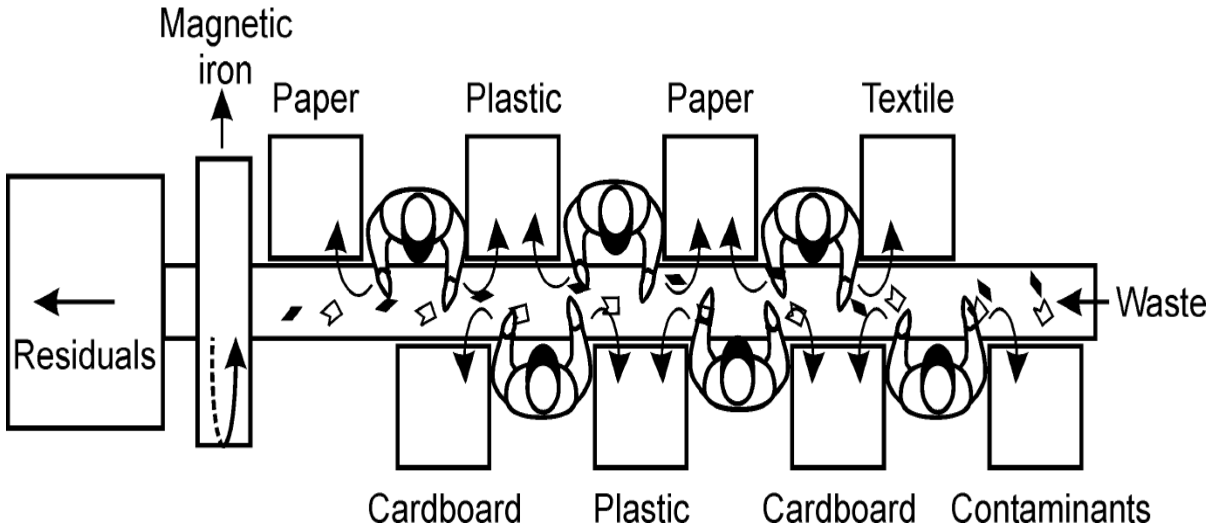
4.2.1.4. Manual sorting

Manual sorting is a waste management method that involves the use of human labor to physically separate different types of waste materials from a mixed waste stream. This process is typically performed in waste sorting facilities, where workers sort through the waste by hand to identify and separate recyclable and non-recyclable materials.

Manual sorting is an important part of the waste management process because it allows for the recovery of valuable materials that might otherwise be lost in the waste stream. For example, workers can separate paper, glass, plastics, and metals for recycling, while also removing contaminants and other non-recyclable materials (**Figure 18**).

While manual sorting is a labor-intensive process, it can be highly effective in recovering recyclable materials and reducing the amount of waste that is sent to landfills. In addition, manual sorting can help to create jobs and provide employment opportunities for workers in the waste management industry.

However, manual sorting can also be dangerous and pose health risks to workers if proper safety precautions are not taken. As a result, it is important for waste management facilities to provide adequate training and protective equipment to workers to ensure their safety and well-being. Manual sorting brings the workers in close contact with the waste and hence exposes them to injuries by sharp items, chemicals, pathogens, and toxins. Precautions in terms of protective equipment and ventilation as well as strict safety and emergency procedures must be implemented.


Magnetic
iron
Paper
Plastic
Paper
Textile
Residuals
Waste
Cardboard
Plastic
Cardboard
Contaminants

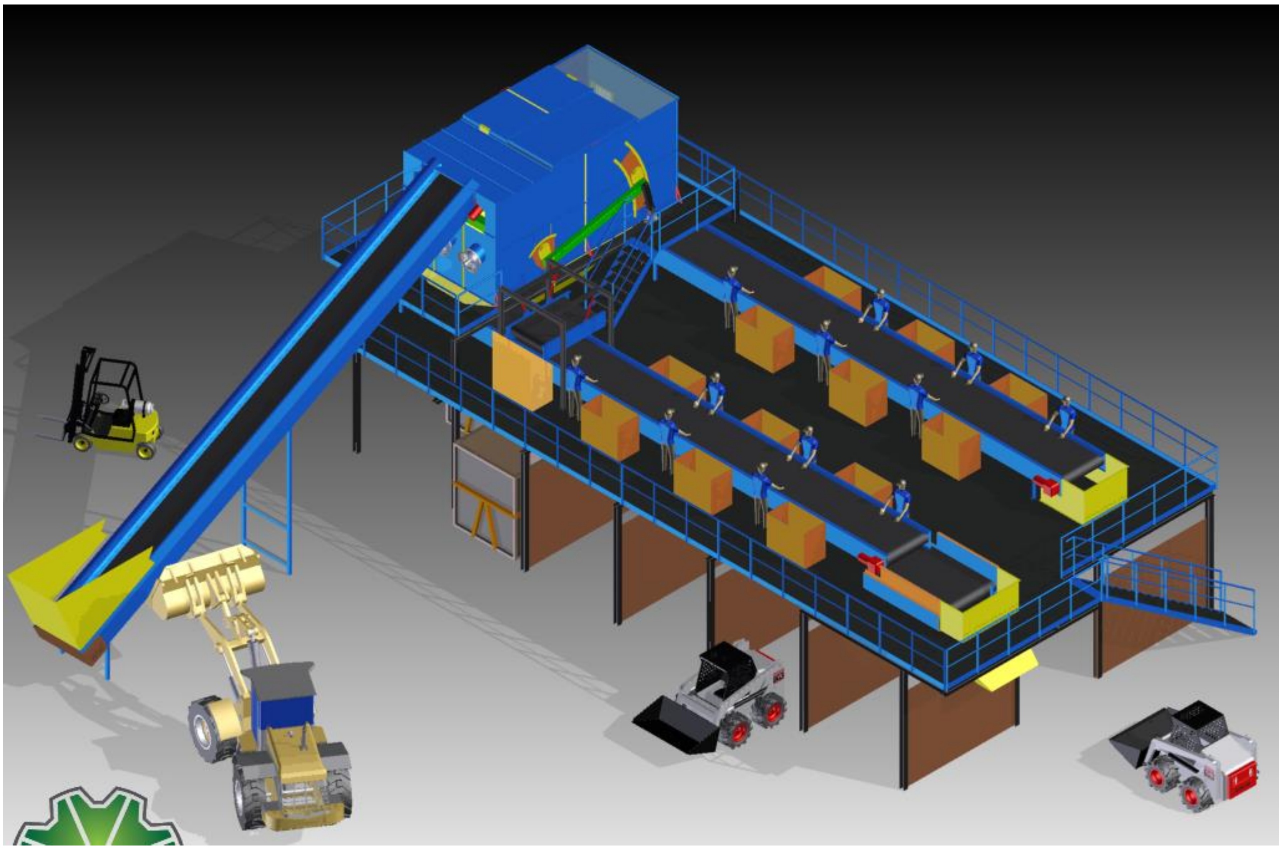
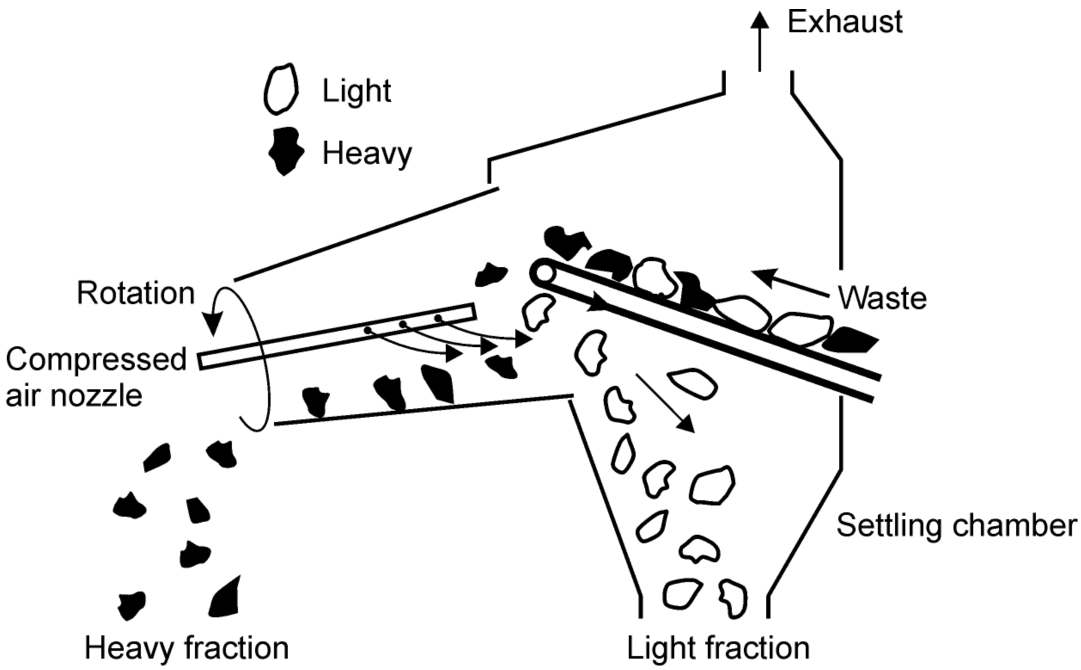


Figure 18 :Manual sorting line

4.2.1.5. Rotary Air Classifier (Wind shifter)

The rotary air classifier consists of three basic components: a rotating drum, a screened settling chamber, and a compressed air system (see **Figure 19**). The drum is conically shaped towards its upper end and is inclined approximately 15◦ from a horizontal plane. Shredded and pre-sorted waste is conveyed via a chute to the upper end of the drum. Compressed air is injected parallel to the axis of the drum. Lightweight material becomes airborne and is blown down toward the settling chamber. Heavy particles are further transported and dropped from the drum's smaller, lower end. Air is pumped into the lower end of the drum to provide constant airflow. Particle size cut-off can be determined by adjusting the air volume, compressed air flow, drum inclination and input rate. To minimize air emissions, the majority of the air can be recirculated.



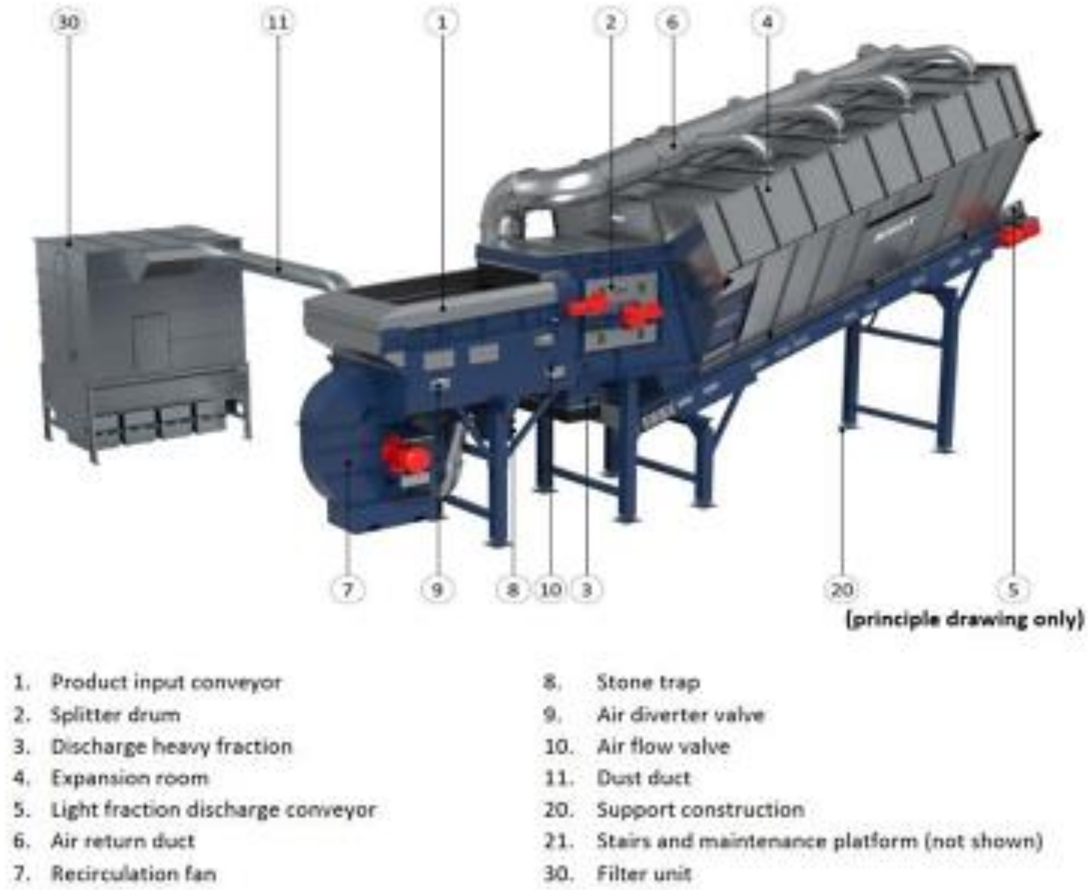


Figure 19 :Wind shifter

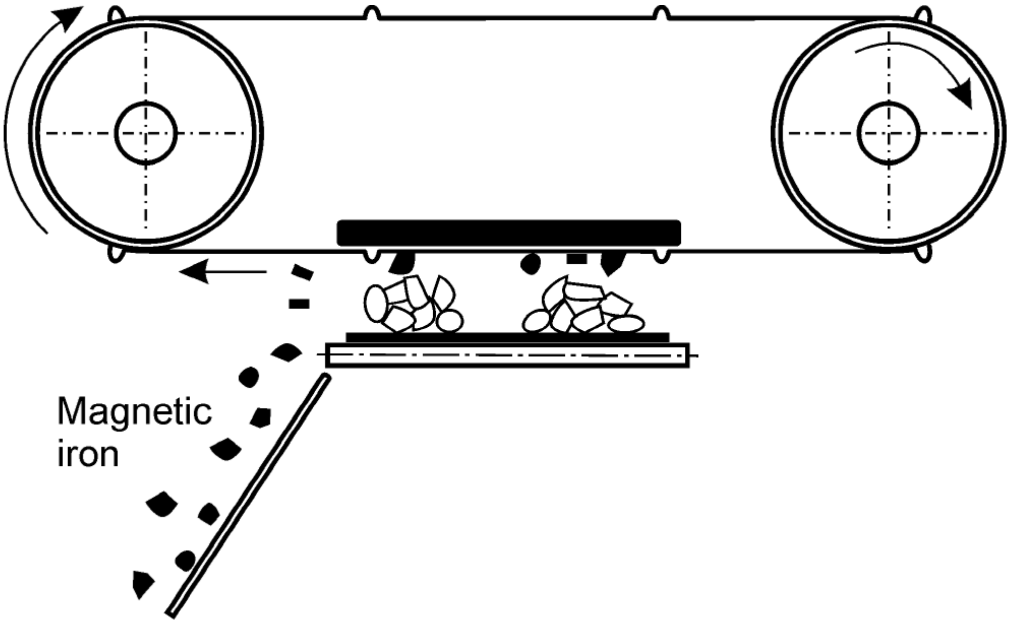
4.2.1.6. Magnetic separators

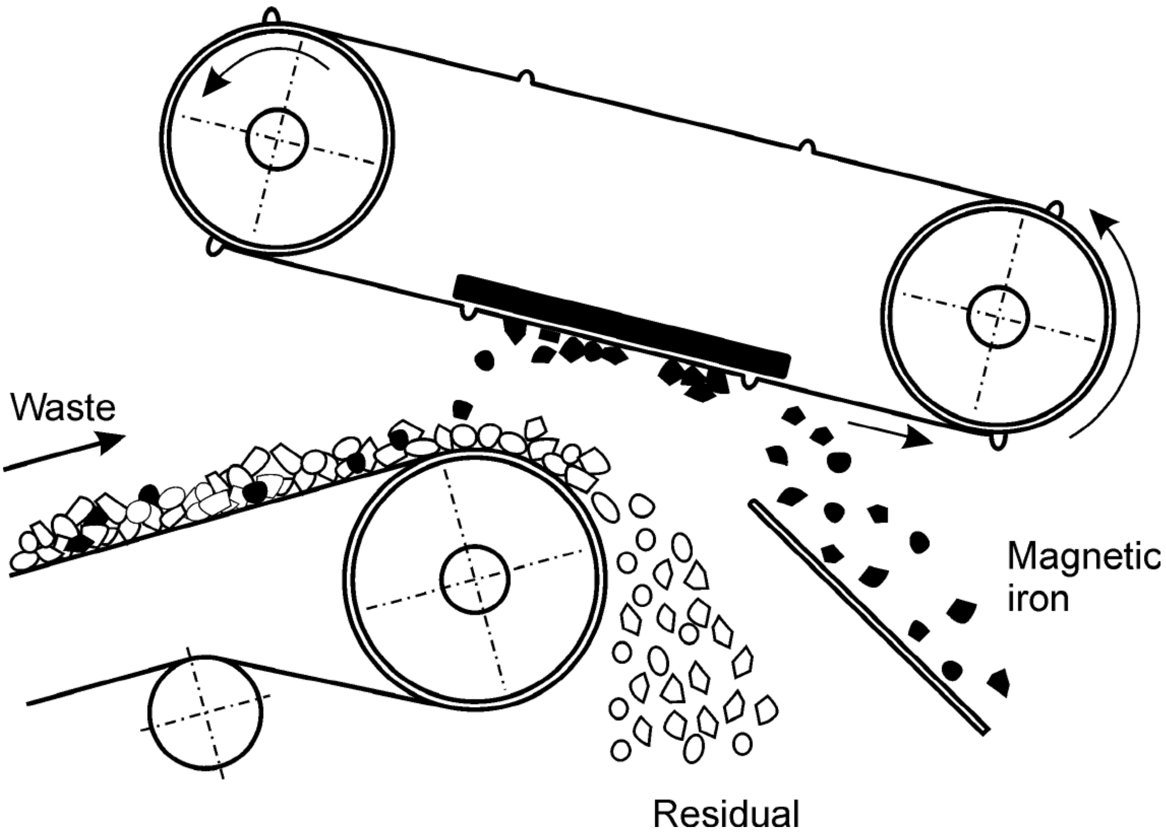
Magnetic separators are commonly used in waste management to separate magnetic ferrous metals from other waste materials. This technology involves an overhead magnetic separation system that attracts ferrous material and conveys it away either perpendicular or parallel to the waste transport direction.

To effectively use magnetic separators, the waste material must first undergo size reduction and shredding to separate ferrous materials from other waste materials. Once the waste material is shredded, it is passed through the magnetic separator, which attracts and removes any magnetic ferrous metals.

Magnetic separators can be used in both shredded and non-shredded municipal solid waste, as well as in other waste materials such as construction and demolition waste, electronic scrap, and industrial waste. They are highly efficient and can separate even small ferrous particles from non-ferrous materials.

Magnetic separators are available in various sizes and configurations, depending on the specific waste management application. Overhead systems are commonly used in pre-sorting shredded or non-shredded waste, while other types of magnetic separators, such as pulleys and drum separators, are used for more specific applications. **The ideal particle size for magnetic separation ranges from 10 to 100 mm. However, this size range is rarely generated from conventional size reduction equipment.**


Magnetic
iron


Waste
Magnetic
iron
Residual

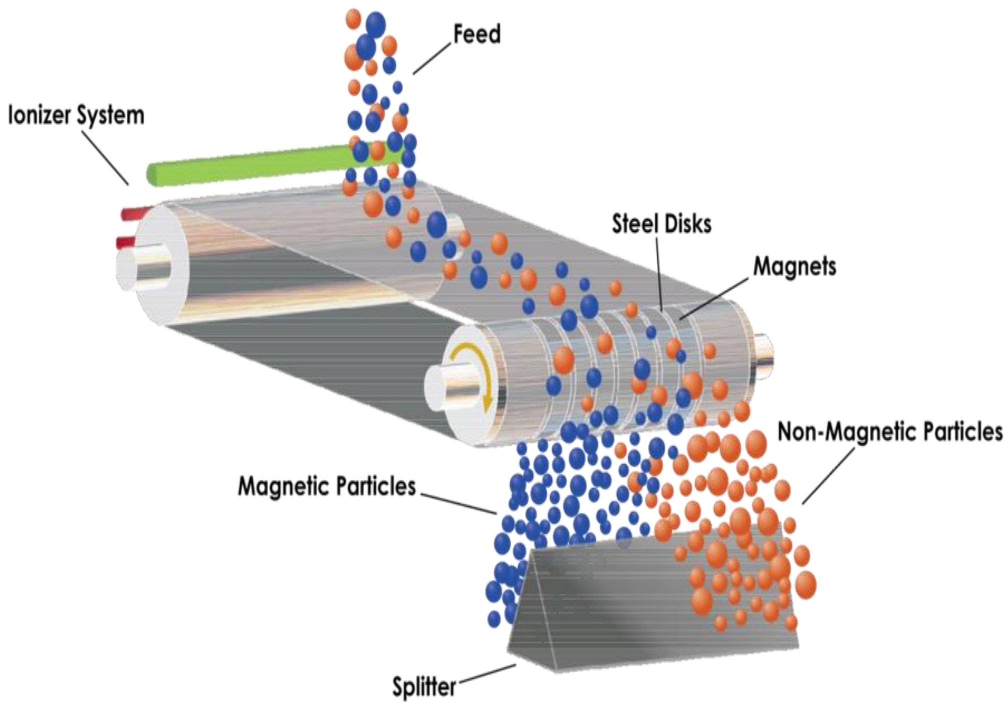
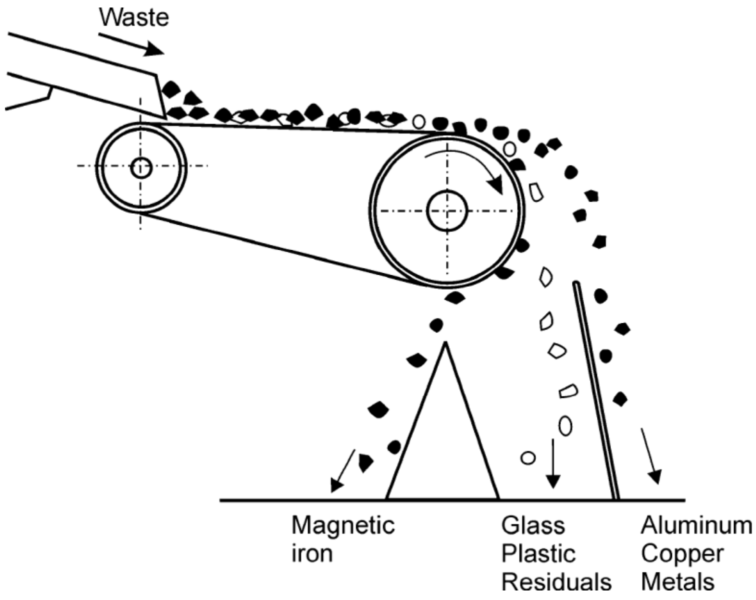


Figure 20 : Magnetic separator

4.2.1.7. Eddy current separators

An eddy current separator is a type of magnetic separator that is used to separate non-ferrous metals from other waste materials. This technology works by inducing a magnetic field into a rotating drum, which generates eddy currents in the non-ferrous metal particles. The eddy currents create a magnetic field that repels the non-ferrous metal particles, causing them to be ejected from the stream of waste material. The non-ferrous metals are then collected in a separate container for recycling. Eddy current separators are commonly used in waste management to separate non-ferrous metals such as aluminum, copper, and brass from other waste materials such as plastics, glass, and paper. They can also be used to separate non-ferrous metals from shredded automobile scrap, electronic scrap, and other types of industrial waste. Eddy current separators are highly efficient and can separate non-ferrous metals with a high degree of accuracy, even in large volumes of waste material. They are available in a variety of sizes and configurations, depending on the specific waste management application.

Eddy currents are created when conductive objects are in or exposed to a spatially or temporally alternating magnetic field. Eddy current flows in closed loops within the conductor. According to Lenz's law, the induced electric current produces a magnetic field opposite the field to which it is exposed. A force is produced against the conductive object, which hurls the object out of the magnetic field. Less conductive objects require less force. With increasing density, greater hurling force is necessary due to the mass inertia of individual objects.



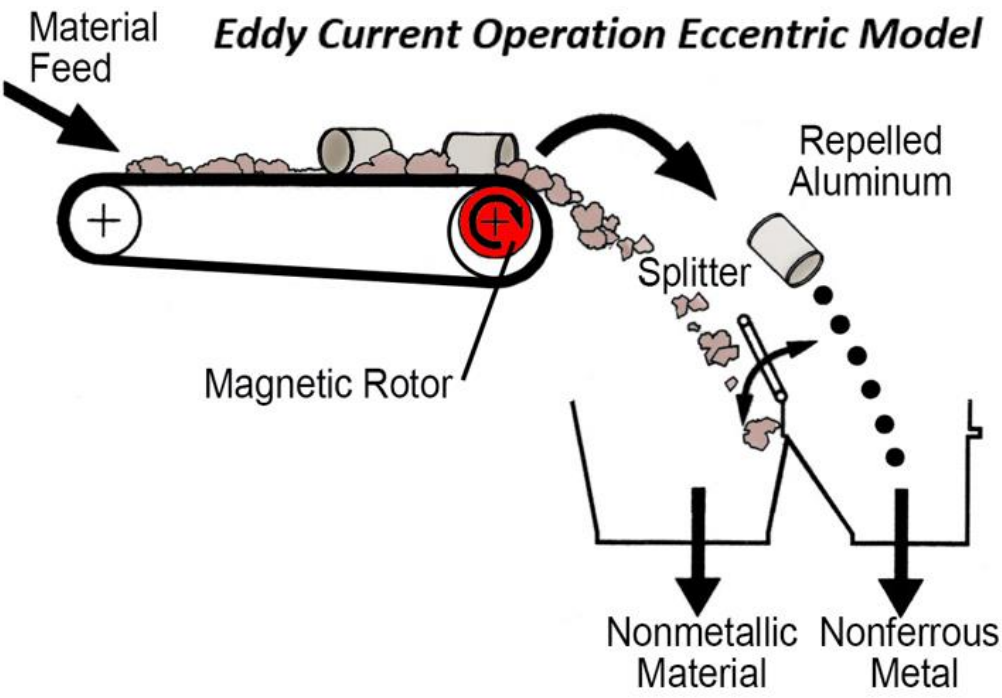


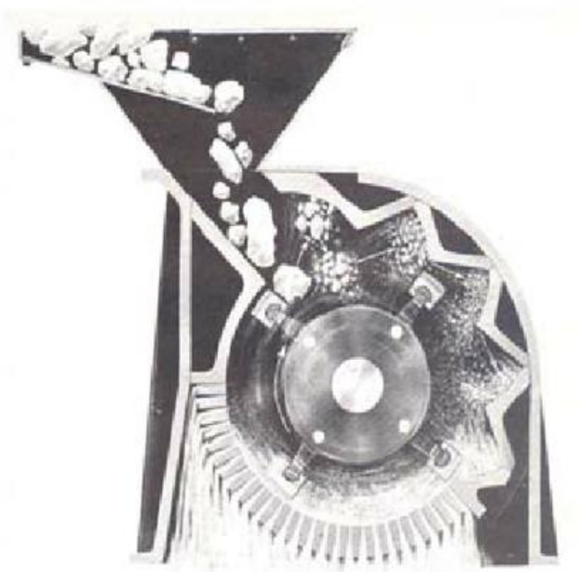
Figure 21 : Eddy current seperator

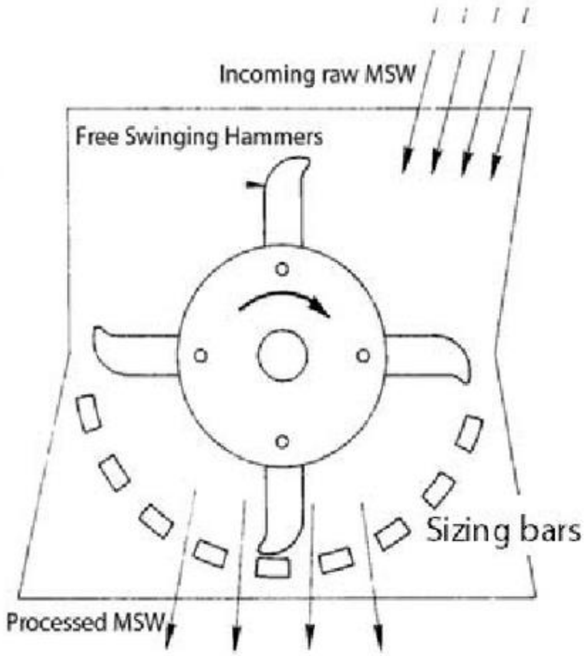
4.2.1.8. Refused derived fuel shredder (RDF)

An RDF (Refuse-Derived Fuel) shredder is a type of industrial shredder used to reduce the size (5cm x 5cm) of RDF material, which is made from municipal solid waste (MSW) or other waste streams such as industrial or construction waste. RDF shredders are typically designed to handle a wide variety of waste materials and can effectively shred and reduce the volume of large and bulky items such as furniture, appliances, and construction debris.

RDF shredders may use different shredding technologies, such as hammer mills, shear shredders, or single-shaft shredders, depending on the specific application and material being processed. These shredders typically have high torque and slow speed, allowing them to effectively shred and process tough materials with minimal wear and tear on the shredding equipment.

The shredded RDF material can be used as a fuel source in waste-to-energy (WTE) facilities, cement kilns, or other industrial processes. By converting waste into a fuel source, RDF shredders can help to reduce the amount of waste sent to landfill and provide a renewable energy source, contributing to a more sustainable and circular economy.




Incoming raw MSW
Free Swinging Hammers
Sizing bars
Processed MSW

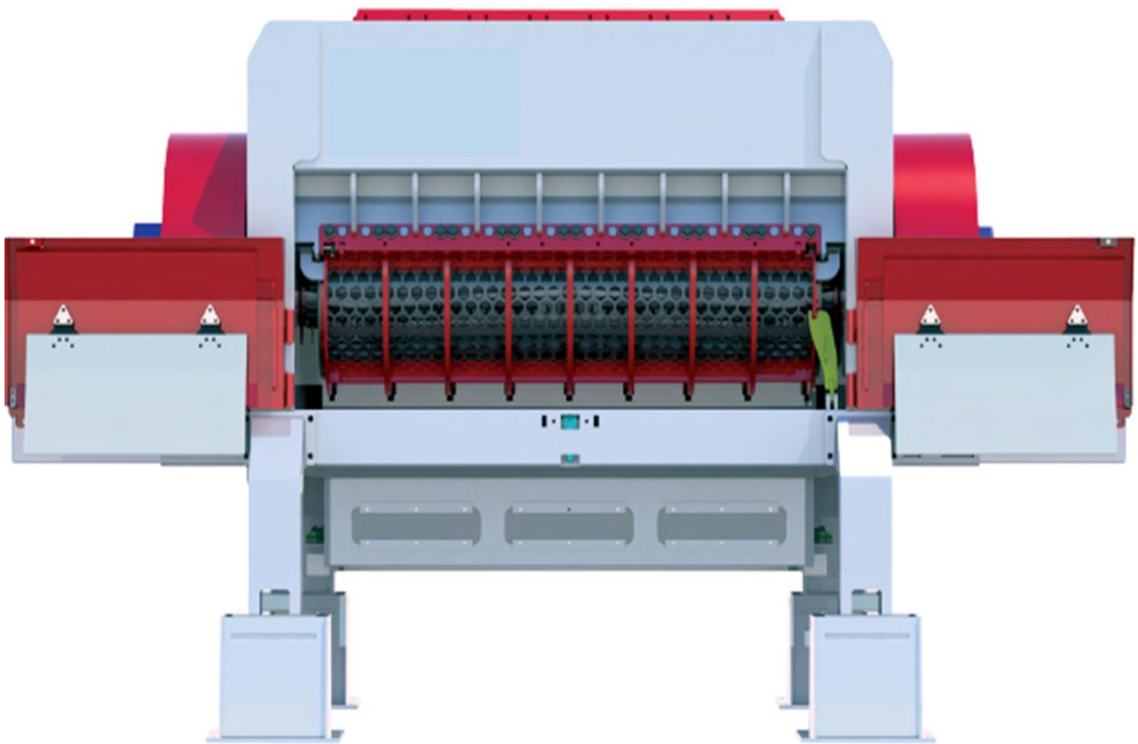


Figure 22: RDF shredder

CHAPTER 5

THERMAL TREATMENT (INCINERATION)

5.1. Incineration: Process and Technology

Municipal Solid Waste (MSW) incineration is a waste management process that involves the combustion of municipal solid waste materials to generate energy while reducing the volume of waste. This approach offers a solution to the challenges of growing urban waste, providing an environmentally sound method for waste disposal. The process involves advanced technologies to ensure efficient combustion and environmental protection. Waste incineration is thermal conversion of waste with a surplus of air. This releases energy and produces solid residues as well as a flue gas emitted to the atmosphere. This chapter describes the basic issues of the incineration process and the technologies.

5.2. Process Overview

1. Waste Reception and Handling:

- MSW incineration begins with the reception and handling of municipal solid waste at the incineration facility.
- Waste is sorted to remove recyclables and hazardous materials, leaving a homogeneous waste stream for combustion.

2. Combustion Chamber

- The waste is then fed into the combustion chamber, where controlled burning takes place.
- Combustion is typically carried out at high temperatures (usually exceeding 850°C) to ensure thorough destruction of organic materials.

3. Energy Recovery:

- The heat generated during combustion is harnessed to produce steam or hot gases.
- This thermal energy is used to drive turbines and generate electricity or provide district heating, making MSW incineration a form of waste-to-energy (WtE) technology.

4. Air Pollution Control:

- Advanced air pollution control technologies are employed to minimize emissions of pollutants such as particulate matter, nitrogen oxides (NOx), sulfur dioxide (SO2), and heavy metals.
- Bag filters, electrostatic precipitators, and scrubbers are commonly used to capture and neutralize these pollutants.

5. Residue Treatment:

- After combustion, the remaining ash undergoes treatment to extract any remaining metals and reduce the volume of the waste.

- Residue management is a critical aspect, and some incineration plants utilize technologies like vitrification to stabilize the ash.

6. Emission Monitoring:

- Continuous emission monitoring systems are implemented to ensure compliance with environmental regulations.
- Regular testing and monitoring help to verify the effectiveness of pollution control measures.

5.3. Design requirements for municipal solid waste incineration stations

The design of incinerators should meet the following specifications:

- Shall be equipped with adequate technical means to control ash and emissions to be within permitted limits.
- Utilize maximum energy when burning waste.
- Contains separation technology for hazardous or recyclable materials.
- Include mechanized feeding devices, that can control the waste feed rate.
- Contain mechanisms to ensure that the system is continuously supplied with solid waste, and that the waste is continuously moved into the combustion chamber.

- Waste enters into the combustion chamber only when it reaches the targeted moisture content. Drying devices or bio drying should be employed for mixed waste exceeding 30% moisture.
- The waste feed system should have a disconnect to prevent the entry of waste into the combustion chamber in the event combustion chamber temperatures fall below the minimum required.
- Provide means to control the combustion process by:

  Control the ratio of oxygen mixing with air.

  Control the amount of air that is pumped into the combustion chamber (excessive air)

  Heat distribution in the combustion chamber.
- Use an additional ignition unit when starting, closing, or maintaining oven temperature, especially when feeding high moisture residues.
- Utilization of hot gases, whether through a boiler for power generation or direct heating.
- Control measures for the emissions for limited components stated in Table 4.
- Install any combustion unit with a gas filtration system to control the emitted acidic gases, particulate matter and other air pollutants according to the required air quality.

- Reduction of dioxins and furans by a combination of the following measures:
  - Ensure that the system does not operate in the range of 200-400 °C.
  - Identify and control the type of waste received.
  - Use of burning controls.
  - Utilization of designs and operating methods that prevent the formation of dioxins and furans
  - The use of gas cleaning and control systems that eliminate any traces of dioxins and furans.
- Control ash which is considered hazardous, by the following conditions:
  - Gaps in the furnace should be narrow to avoid excessive ash dropout.
  - Provide a feeding system that feeds the waste at a rate that allows for good turning within the furnace, and sufficient time for full combustion at an appropriate temperature to reach a total organic carbon in ash less than 3% of weight.
  - Sorting out iron and metals from ash using mechanical equipment.
  - Moisturizing ash before transport to reach a moisture content of not less than 25%.
  - Treatment and purification of liquid effluent from gas cleaning system.

Table 4: Acceptance Criteria for Emissions from Incinerators and Thermal Waste Treatment Plants

Emissions	mg/m3, measured in 8 hours of Normal Operation
Total suspended particles	10
Sulphur dioxide SOx	100
Nitrogen oxides NOx	200
Hydrochloric acid	11
Dioxin and furans	0.1
Cadmium/thallium	0.05-0.1
Carbon monoxide	50-150
Mercury	0.05
Total metals (including lead, copper a chromium)	0.5-1
Hydrogen fluoride	1
Fly ash	0.5

5.4. Requirements for the operation of waste incineration stations

The following conditions must be met when operating waste incineration stations:

1) Utilization of the released gases heat in waste or water preheat before cleaning and releasing it to air.
2) Burn the waste inside furnaces under a temperature not less than 800 °C.
3) Ensure that after the burning process is complete, the size of the waste has been reduced by at least 15% of its original size.

4) Maintain adequate combustion conditions where good ventilation, constant temperature preservation in waste incineration devices, good ignition conditions of 800-1200 °C and 6%oxygen concentration should be maintained.
5) Regular change of filters for the absorption of particulates and pollutants from combustion gases.

5.5. Assessment specifications for heat treatment gaseous effluent (exhaust)

Factors influencing gaseous emissions from waste incinerators should be reviewed prior to the assessment of the assumed emissions, these factors are: waste composition and gas cleaning system. The measures required during operation are:

1) Measure the pollutants in the waste that are released during combustion, such as

heavy metals and hydrochloric acid.

2) Measure pollutants produced during the process of burning waste such as SOx,

NOx and flue-ash

3) Measure exhaust composition (carbon dioxide, carbon monoxide, dust and ash

particles, ammonia, chlorine and furans compounds, dioxins and furans, volatile organic compounds, volatile metals (mercury), hydrocarbons). The above measurements should comply with the standards set for the permitted level of emissions allowed for the pollutants shown in Table 4.

5.6. Requirements of Mechanical Treatment Plants for production of alternative fuel

Mechanical treatment plants include three types as follows:

- Refuse-Derived Fuel (RDF): It is required to be a component of solid waste with high thermal content and comply with the requirements.
- Solid Recovered fuel (SRF): is mix of different waste that has specific and high thermal content. SRF must be shredded and have to comply with Table (18).
- RDF pellets: is further processed RDF where after shredding RDF are shredded, dried and then pelletized to be uniform in size.

    - All alternative fuels production lines from MSW must be equipped with separation equipment able to dispose of 100% of the stones, glass, and metals and most wet organic materials.
    - The physical and chemical properties of alternative fuels, whether SRF or RDF, must be analysed for each 1500 tons.
    - Transportation of alternative fuel be carried out in a safe and secure manner.

5.7. Waste as a Fuel

Waste incineration plants are designed to treat waste with great variation in the composition of the incoming waste. This is the primary difference between waste incineration and other combustion systems, and it has large implications on the design of the incineration plant.

The practical design of incineration systems, however, limits the allowable variations of the waste composition. For the design of a waste incineration plant, the best available data on the amount and composition of each waste type is needed, and the effect of expected future changes in the waste management system should be taken into consideration, for example the introduction of source segregation or pretreatment. The waste being led to the incineration plant often consists of several types of waste, such as household waste, some bulky waste, commercial and institutional waste and some industrial waste. In some cases also clinical waste and sewage sludge are incinerated. Street sweepings and construction and demolition waste containing a large fraction of incombustible matter are less suited for incineration. The different waste types received at the incinerator have significantly different characteristics, in particular in terms of heating value, moisture content and ash content. These are the three key variables in characterizing waste as a fuel.

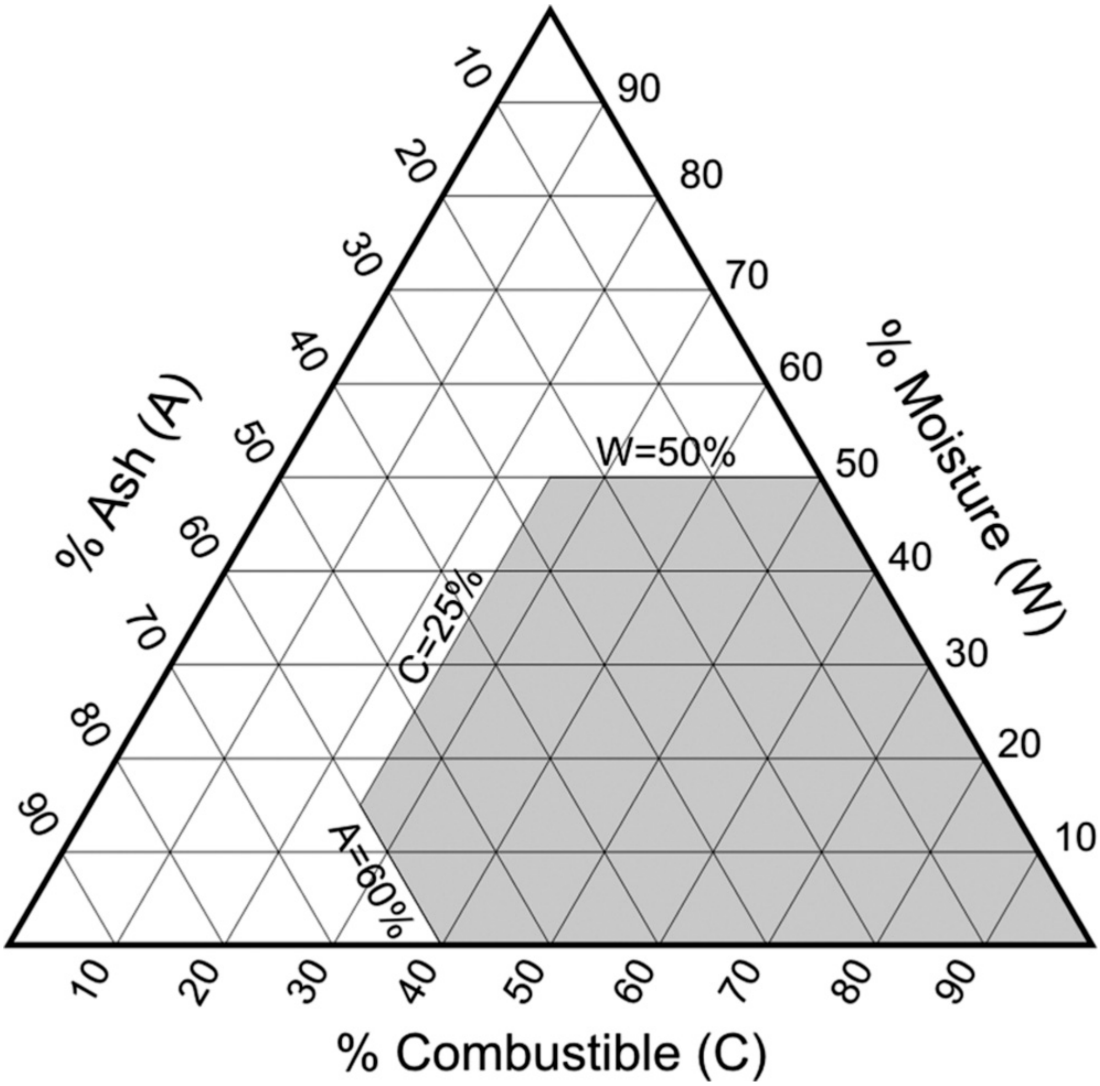


Figure 23: Waste within the shaded area can be combusted without auxiliary fuel

The lower heating value of the waste (the energy content available from complete combustion when assuming no energy losses) is the most important variable for determining whether the waste can sustain the combustion process without supplementary fuel. The theoretical maximum energy content is expressed by the higher heating value, which includes the heat of condensation of water vapor released in the combustion process. The minimum lower heating value required for a controlled incineration depends on the furnace design. Low-grade fuels require a furnace design minimizing heat loss and allowing for drying of the waste prior to ignition, and the air needed for the combustion process should be preheated. When the heating value is high, the furnace design should allow for extraction of heat from the furnace, e.g. by integrating the boiler in the furnace. The heating value is therefore an important parameter for the planning and design of a waste incineration plant.

5.8. The Incineration Process in General

Figure 24 is a simplified cross-section of a typical waste incineration plant with a moving grate furnace and horizontal steam boiler generating energy in the form of both power and heat. It should be noted that the flue gas cleaning system is one of many potential layouts. In the furnace, the overall result of the incineration process is that the combustible components react with the oxygen of the combustion air, releasing a significant amount of hot combustion gas. Furthermore the moisture content of the waste is evaporated in the initial stage of the incineration process, and the incombustible parts of the waste form solid residues (bottom ash, fly ash). Through the incineration process in the furnace, the solid constituents of the waste undergo a range of processes as a result of exposure to heat and contact with the combustion air: drying, pyrolysis and gasification (in which combustible gases are formed), ignition and combustion of these gases and burnout of the solids.

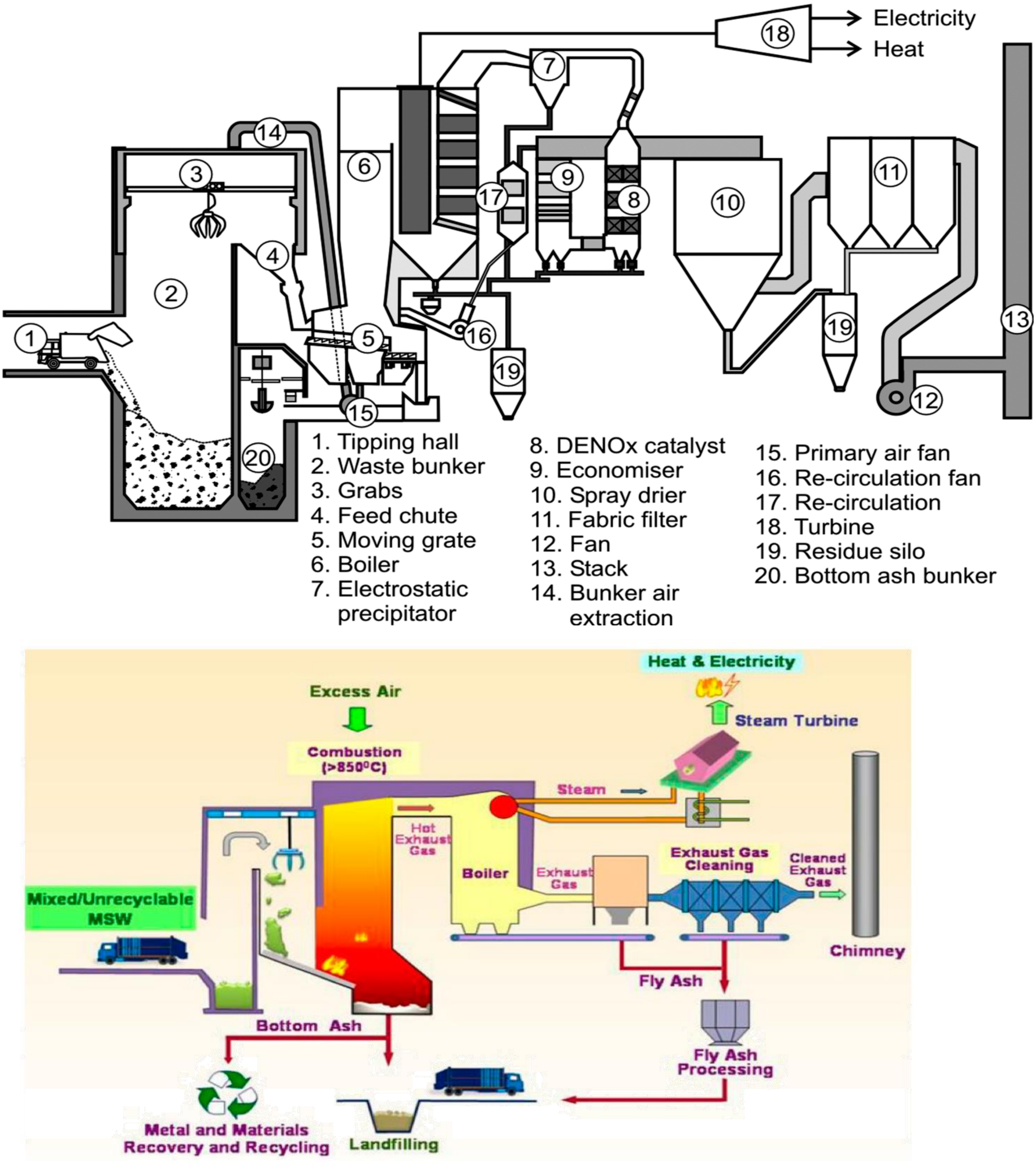


Figure 24: Cross-section of a typical waste incineration plant with a moving grate furnace

5.8.1.Processes and Energy Recovery

The combustion gases pass from the furnace to the afterburning chamber. For the purpose of ensuring complete burnout, legislation usually sets a minimum temperature for the combustion gases in the afterburning chamber (within the EU 850 ◦C for municipal waste and 1100 ◦C for certain types of hazardous waste). It is required that this temperature is maintained for a certain minimum of time (2 s in the EU) as measured from the last injection of combustion air. In the EU it is furthermore a requirement that no waste is fed into the incinerator before the required temperature has been reached and that the feeding of waste is interrupted when the temperature drops below the required minimum temperature of 850 ◦C or 1100 ◦C. Air emissions of CO and total organic carbon (TOC) relate exclusively to the quality of the combustion process. Improper furnace design or operation which results – even locally – in too low a combustion temperature, a lack of oxygen or too short a flue gas residence time at high temperature causes the limit values of CO and/or TOC to be exceeded. The content of CO and TOC (before inlet to the flue gas cleaning system) is therefore a good indicator of the efficiency of the combustion process. Box 8.1.4 includes a calculation of the amounts of combustion air and flue gas as well as the basic composition of flue gas.

The flue gas is cooled by radiation and convection to the walls and other heating surfaces of the furnace and boiler. In the boiler pressurized water is heated and in the case of a high-pressure steam boiler it is evaporated, and the steam may be superheated (i.e. heated above its saturation temperature). The purpose is to exploit its energy content by expansion in a steam turbine, which is connected to a power generator. In a combined heat and power plant, typically 25 % of the steam's energy content is transformed into electrical power. The remaining energy is regained by condensation of the exhaust steam from the turbine in a heat exchanger, thereby potentially generating hot water for district heating purposes. The condensate is transferred back to the feed water tank, from which the water is reused for the boiler, thereby generating a closed circuit. The water and steam circuit of the high-pressure boiler is called the Rankine process. Typical power generation efficiency would be 20–25 % of thermal input for a combined heat and power waste to energy plant, increasing to 25–35 % in the case of power production, only.

5.8.2.Flue Gas Volume

Incineration of municipal solid waste generates large volumes of flue gases. The raw flue gases carry a wide range of pollutants harmful to nature and human health. The pollutants present and their concentration depend on the composition of the waste incinerated as well as on the combustion conditions. Ash, heavy metals and a variety of organic and inorganic compounds, however, are always found. The volume of flue gas is closely related to the thermal input to the incinerator and the excess air level and is a major factor in dimensioning the air pollution control measures

5.9. Energy Recovery Technology

A main benefit of solid waste incineration is the possibility of recovering the energy in the waste and by its utilization substitute energy production from other sources, preferably fossil fuels.

The flue gases carrying the energy released in a waste incineration furnace have to be cooled in a boiler before the air pollution control system. The boiler is also a necessary technical installation for energy recovery. The type of boiler, however, depends on the intended energy use:

- Hot water for district heating.
- Process steam for various types of industries.
- Electricity or combined heat and power.

The choice between the various end use possibilities depends on the local energy market conditions, including:

A. Existing infrastructure for energy distribution, e.g. the availability of a power grid and district heating network.

B. Annual energy consumption pattern (the energy output from MSW incineration plants is usually determined from waste disposal requirements and is therefore fairly constant over the year).

C. Prices of the various types of energy and possible agreements with the consumer(s).

The overall thermal efficiency of a MSW incineration plant equipped for energy recovery depends on the end use of the energy recovered. The production of electricity only has a low thermal efficiency, resulting in expensive energy, whereas hot water for district heating is considered cheap energy, but the overall thermal efficiency of hot water generation is high and the complexity and the costs of the necessary technical installations are relatively low.

5.10. Overall Energy Balance for an Incineration Plant

The overall energy balance of the furnace/boiler is depicted in Figure 25. The thermal input by waste is the mass flow rate (t/h) times the lower heating value (GJ/t), cf. If the combustion air is heated above the chosen reference temperature (usually 25 ◦C), its energy content may also be considered a thermal input. The thermal efficiency is the thermal output (steam) relative to the thermal input. It is typically some 85 %, and it can be above 90 % for a highly optimized system.

The largest loss is the flue gas loss, representing the energy content of the flue gas when it leaves the boiler, i.e. the potential additional energy extraction in the boiler, had the flue gas been cooled to the reference temperature. It is calculated from: flue gas flow rate (Nm3/h) times density (kg/Nm3) times heat capacity [kJ/(kg*◦C)] times flue gas temperature (◦C), minus 25 ◦C (because 25 ◦C is the chosen reference temperature). The flue gas loss may be reduced by reducing the amount of flue gas through optimization of the incineration process so that the excess air level can be reduced and by supplementing the boiler with a corrosion-proof economizer (heating for instance district heating water) or air preheater, which cools the flue gas to for instance 100 ◦C. Thereby, the loss may be reduced to approximately 5 % of the thermal input.

The bottom ash causes a loss determined as the sum of the energy content of the bottom ash when it drops from the grate to the cooling water and the energy content represented by its remaining content of organic matter. The radiation and convection loss is the heat loss from the surfaces of the furnace and boiler. For a large, well insulated incinerator, this loss may be as little as 1 % of the thermal input.

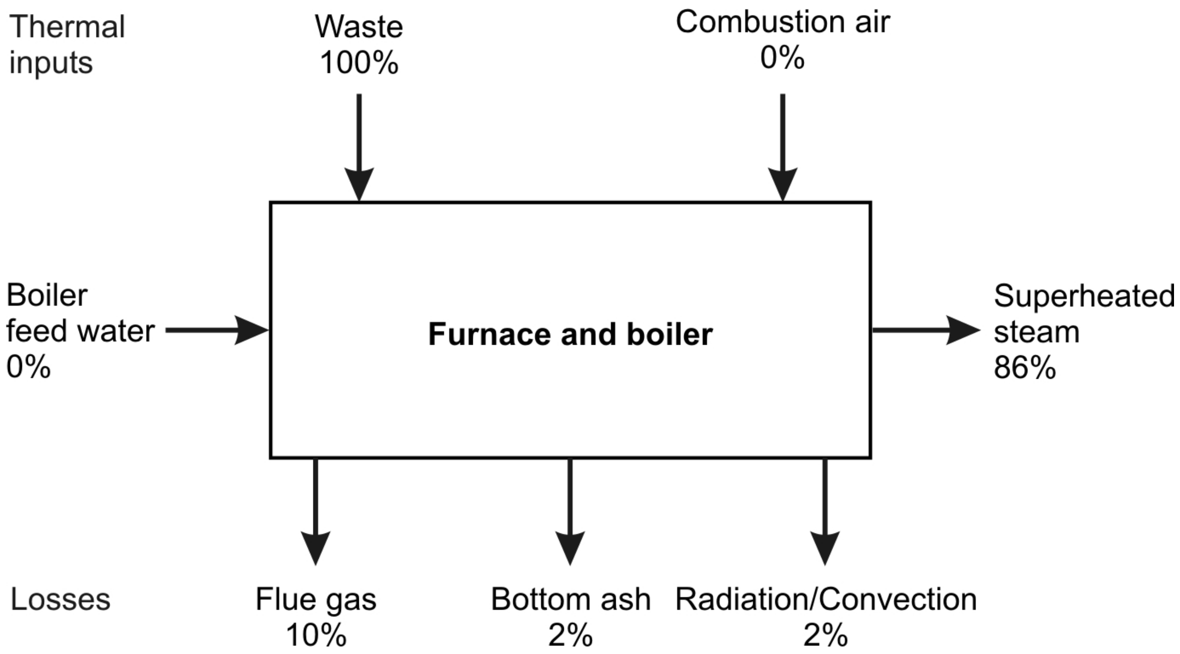


Figure 25: Energy balance of the furnace/boiler with typical values

In the waste incineration process, about 80 % of the waste is transferred into the flue gas. This flue gas must be extensively cleaned before being released to the atmosphere through the stack of the plant. The most problematic components in the flue gas are dust/particles, acidic gases (HCl, HF, SO2), NOx, heavy metals and organic pollutants (e.g. dioxins, furans, PCDD/F). Flue gas cleaning aims at bringing the release of these components down to an acceptable level. This chapter describes the most important strategies and technologies for flue gas cleaning associated with municipal waste incineration

5.11. Case Study: Abou-Rawash Plant 1200 ton/day – 30 MWh

- The daily MSW Incineration capacity is designed by 1360 tons, and the maximum is 1495 tons.
- Two mechanical grate incinerators with the capacity 680t/d are applied for this project,
- equipped with one 36MW condensing air cooled steam turbine and one 38MW generator, as
- well as supporting production and office facilities.
- Project Location：Abu Rawash WtE is located in Abu Rawash industrial area. The Project is
- located on Mohamed El Shaarany road, which connects the site to the 26 of July corridor, and to
- Alexandria desert road.
- Project service scope：MSW is transported to the site by waste trucks, by contractors (Giza
- governorate), from the transfer stations.

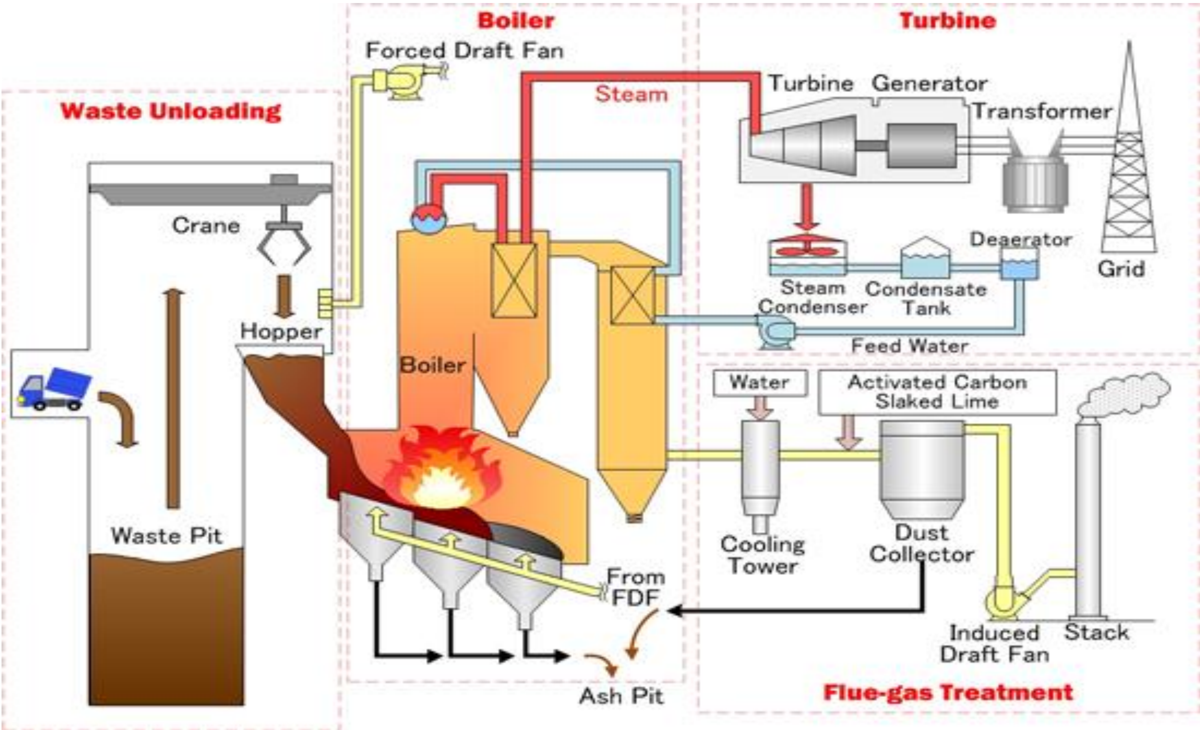


*Figure 26: **WASTE TO ENERGY PROJECT - GIZA -ABOU RAWASH – 1200 tons/day – 30MWh***

<u>W2E Challenges and Concerns:</u>

1. Environmental Impact
2. High Initial Costs
3. Waste Composition and Variability
4. Energy Efficiency Concerns
5. Limited Feedstock Supply
6. Public Perception and Opposition
7. Long-Term Sustainability

Studies needed for the development and execution of waste-to-energy

Feasibility Study

- Waste Composition Analysis
- Environmental Impact Assessment (EIA)
- Site Selection and Land Use Study
- Technology Assessment
- Regulatory and Permitting Analysis
- Operation and Maintenance Plan
- Social Impact Assessment
- Risk Assessment and Management

Project Benefits:

- Renewable Energy Generation
- Land Use Efficiency
- Waste Reduction and Management
- Greenhouse Gas Emission Reduction
- Resource Recovery
- Job Creation
- Reduced Reliance on Fossil Fuels
- Compliance with Waste Reduction Targets
- Community and Public Health

CHAPTER 6

THERMAL TREATMENT (PYROLYSIS & GASIFICATION)

Pyrolysis and gasification include processes that thermally convert carbonaceous materials into products such as gas, char, coke, ash, and tar. Overall, pyrolysis generates products like gas, tar, and char, while gasification converts the carbon- containing materials (e.g. the outputs from pyrolysis) into a mainly gaseous output. The specific output composition and relative amounts of the outputs greatly depend on the input fuel and the overall process configuration. Although pyrolysis processes in many cases also occur in gasification (however prior to the gasification processes), the overall technology may often be described as gasification only. Pyrolysis, however, can also be employed without proceeding with gasification.

Gasification is by no means a novel process; in the 19th century so-called 'town gas' was produced by the gasification of coal and for example used for illumination purposes. In Europe during World War II, wood-fueled gasifiers (or 'gas generators') were used to power cars during shortages of oil-based fuels. Sparked by oil price crises in 1970s and 1980s, further development in gasification technologies focused mainly on coal as a fuel to substitute for oil-based products. Today gasification is used within a range of applications, the most important of which are conversion of coal into syngas for use as chemical feedstock or energy production; but also gasification of biomass and waste is gaining significant interest as emerging technologies for sustainable energy.

From a waste management perspective, pyrolysis and gasification are of relatively little importance as an overall management option. Today, gasification is primarily used on specific waste fractions as opposed to mixed household wastes. The main commercial activity so far has been in Japan, with only limited success in Europe and North America (Klein et al., 2004). However, pyrolysis and gasification of waste are generally expected to become more widely used in the future. A main reason for this is that public perceptions of waste incineration in some countries is a major obstacle for installing new incineration capacity, but also a better ability of gasification over incineration to preserve the chemical energy of the waste is important. This chapter provides an overview of pyrolysis and gasification processes related to waste, the technology involved, energy recovery options, and important environmental aspects.

6.1. Benefits and Drawbacks

The public perception aspect mentioned above is in some countries just as important as the technical aspects: waste incineration may simply fail to be a politically viable solution, hence other technologies are investigated. However, today waste incineration is a robust and mature technology that has been proven on a wide range of waste fractions, including very heterogeneous and mixed household wastes. As such, waste incineration is the technology that gasification is generally evaluated against, despite public perceptions. The main potential benefits and advantages of pyrolysis and gasification of waste with respect to incineration are:

- The possibility and flexibility to recover chemical energy in the waste as hydrogen and/or other chemical feedstocks rather than converting this energy into hot flue gases.
- Potentially better overall energy efficiency.
- Less trouble with corrosion.
- Less need for flue gas cleaning: smaller volumes of flue gas with a better quality.
- Potentially better options for CO2 capture.
- Potentially lower emissions of dioxins.
- Improved quality of solid residues, particular for high-temperature processes.
- Gasification units operating with a low fuel load, potentially facilitating small plants producing less than 1 MW.
- Potentially lower costs

The main drawbacks of the current technology for pyrolysis and gasification are:

- Relatively homogeneous fuels are needed. Either specific material fractions can be fed to the gasifier, or mixed waste can be pretreated and homogenized.
- Although theoretically possible, the pyrolysis and gasification processes are complicated to control and troubles with

slagging, tar production, and contaminants in the produced gas are not uncommon.

- Numerous waste related pyrolysis and gasification technologies exist, many of these only demonstrated in small scale and/or only applicable to specific fuel types. This requires careful review of the appropriateness of a specific technology for a particular waste mix, local conditions, etc.

Overall energy conversion efficiencies of existing installations have been unable to compete with modern waste incinerators.

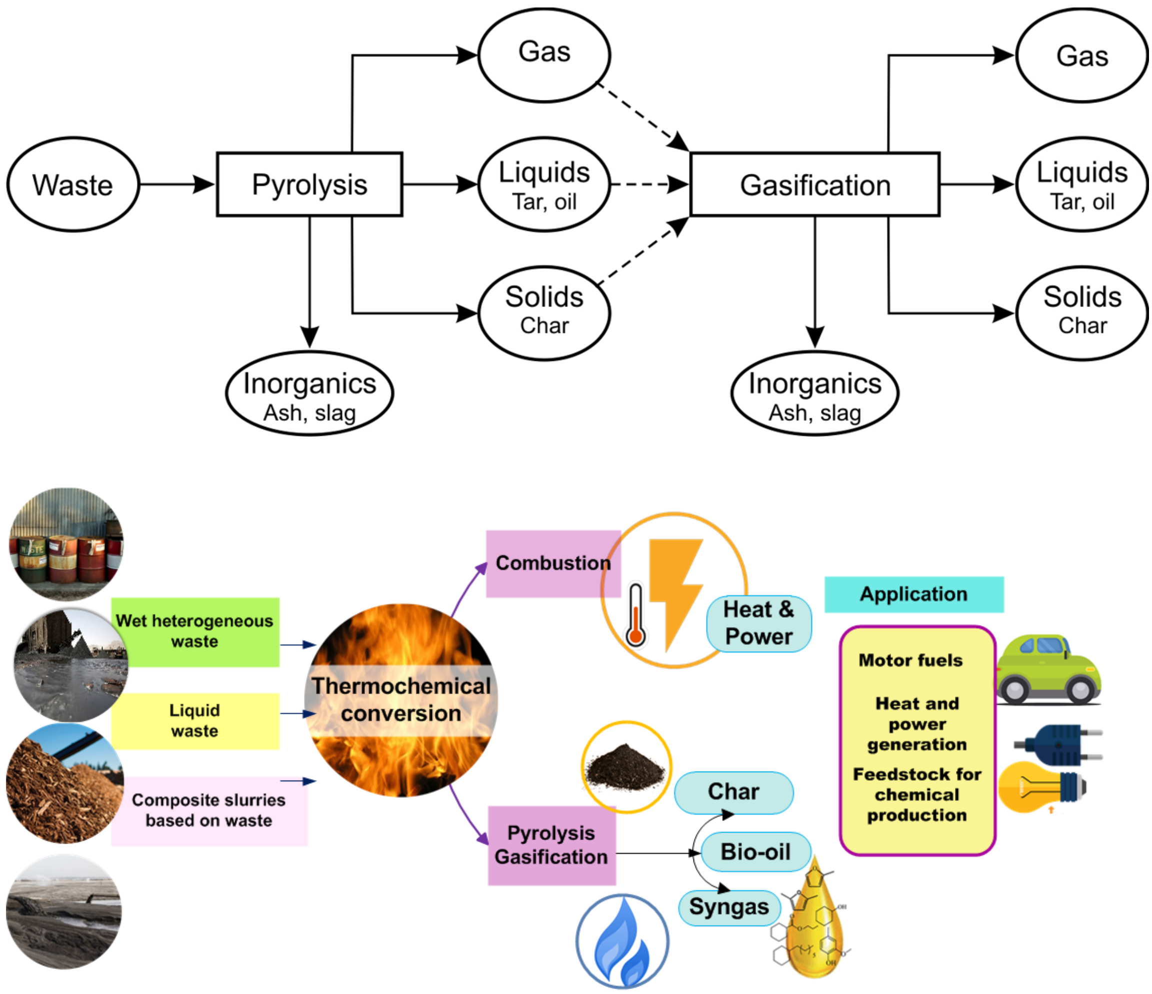


Figure 27: Schematic overview of pyrolysis and gasification processes including an outline of the outputs from these processes. Note that the two processes may not necessarily be combined as indicated here; however gasification processes generally include heterogeneous reactions involving the outputs from pyrolysis processes.

6.2. Pyrolysis

Pyrolysis represents the thermal degradation of organic material in the absence of oxidizing agents such as oxygen, steam, and CO2. Temperatures are typically around 300–800 ◦C. Overall the process is endothermal, i.e. energy is required for the pyrolysis process to proceed. The composition and energy contents of the products from pyrolysis are highly dependent of the waste input and may vary significantly.

Gas: a mixture of hydrogen, methane, carbon monooxide, carbon dioxide, as well as other volatile constituents from the waste. The gas yield may be around 20–50 % by weight of the input. The heating value may be around 3–12 MJ/Nm3.

Liquid: a mixture of tar, oil, and water containing a complex range of hydrocarbons such as for example organic acids, phenols, PAHs and alcohols. The aqueous phase may constitute a considerable portion of the liquid. The amount of liquid may be around 30–50 % by weight with heating values around 5–15 MJ/kg.

Solid: a char-like material containing the remaining solid products such as metals, glass, sand, etc. The char, in the order of 20–50 % by weight, may have a considerable ash content of 10–50 %. The heating value of the char may be up to 10–35 MJ/kg.

The mass yields and the heating values of pyrolysis products vary significantly from process to process and are also highly dependent of the waste input composition. The above values should be considered indicative only and generally reflect an upper limit with well-sorted refuse derived fuel, automobile shredder waste, or biomass waste as input to the process. Higher quality waste plastics and rubber (e.g. waste tires, automobile shredder waste) may facilitate higher ratios of oils and gases, while more mixed wastes may generate more char and solid (inorganic) residues. The water content of the waste input also affects the process conditions as well as the outputs, in particular the gas and liquid outputs.

In the pyrolysis process, the waste is dried and the moisture released by heating to about 100–120 ◦C. After this phase, a series of complex reactions occur by which volatile compounds are released and more complex carbon containing compounds are broken down into simpler ones. With increasing temperatures from about 200 ◦C up to 800 ◦C oxygen, hydrogen, and nitrogen bonds are broken in order to form the gaseous outputs

6.3. Requirements of waste Pyrolysis

Pyrolysis stations convert solid waste into three products, solid fuel known as biochar, liquid fuel and gaseous fuel. These plants should satisfy the following conditions:

- Pre-treatment of waste before entering the gasification reactor to reach the following specifications:
  - Thermal value not less than 5000 kcal per ton
  - Moisture not more than 20%
  - Harmonization in size and composition so that the size does not exceed 15 cm
  - Removal of chlorine-containing plastics (e.g. polyvinyl chloride or plastic)

- Removal of stones and heavy materials by air separators
- Sorting items of selling value such as plastic, metal and glass
- A dryer should be added to the pre-processing stage to reduce moisture to at least 20%

- Pyrolysis process should satisfy the following conditions:
  - have at least the following components/stages:

a) Pretreatmnt,

b) Pyrolysis reactor,

c) Synthetic gas cleaning system,

d) Power generation system

- The temperature of the treatment should be in the range of 350 to 650 °C, according
- to the target products. Low temperatures produce more liquid and solid substances than high temperature process.
- Treatment is completely isolated from air or oxygen
- Heating is done indirectly and without any direct burning of raw materials
- The excess heat generated by the generator should be used for drying or preheating.
- The feeding system and the pyrolysis chamber must be controlled and isolated from t air during the treatment process. This is done through the use of gates with hydraulic shutters

- Pyrolysis outputs should comply with the following:
  - The content of the following flammable gases: carbon monoxide (CO);
  - hydrogen (H_2); and methane (CH_4); should not be less than 50% of the total gas generated.
  - The thermal value of gas generated should not be less than 2,800 Kcal per m3.
  - The energy conversion rate shall not be less than 400 kW per ton of pre-treated solid waste.
  - Water is removed from liquid fuel

6.4. Gasification

Gasification represents a thermal and chemical conversion of carbon based material into a mainly gaseous output by partial oxidation with a gasification agent (typically air, steam, or oxygen). If gasification is following a separate pyrolysis, the outputs from the pyrolysis process (gas, tar, char) may then further be upgraded by partial oxidation of the more complex hydrocarbons, in particular those contained in the tar and char. Temperatures are in the range 800–1100 ◦C with air as oxidation agent and up to about 1500 ◦C with oxygen. Overall gasification processes are exothermal, i.e. producing heat, but some of the involved reactions are endothermal and require heat which may, for example, be supplied by steam as the gasification agent. The products from gasification are in general:

Gas: Similar to pyrolysis gas, however typically containing higher fractions of CO_2. The heating value depends on the gasification agent but could be around 3–12 MJ/Nm^3, highest with oxygen as gasification agent. The gas yield can be in the order of 30–60 % by weight of the input.

Liquid: In some cases smaller quantities of tar and oil, around 10–20 % by weight of the input.

Solid: Ashes containing nonvolatile metals and other inorganic components. Solids may be around 30–50 % by weight of the input.

Gasification products are, similar to pyrolysis products, highly affected by the waste input, temperatures, and process configurations in general. In particular the waste input is often poorly described in literature and in many cases the waste consists of specific industrial fractions rather than mixed MSW. The heating value for the gas output can therefore be considered as the upper limit for MSW.

By heating to higher temperatures than pyrolysis and introducing a gasification agent, tar and char produced by pyrolysis reactions are further converted to CO, CO_2, H_2, and CH_4 (see Table 8.8.2). The composition of the produced gas greatly depends on the gasification agent used and the heating value of the gas is highly affected by 'dilution' from the gasification agent, again depending on the agent used. Air gasification, for example, is cheaper than using pure oxygen as gasification agent, but results in a gas containing up to about 60 % nitrogen.

6.5. Biogas

The main components in the biogas, CO_2 and CH_4, are determined by the composition of the waste digested. Electron-rich (energy-rich) waste such as fats produce a biogas high in methane, while electron-neutral substrates such as carbohydrates produce biogas with equal amounts of carbon dioxide and methane. CO_2 is partially soluble in water and the biogas from anaerobic digestion of waste usually contains 55–65 % CH_4 and 35–45 % CO_2. Ammonia, H_2S and numerous volatile organic compounds usually constitute only less than 1 % of the biogas.

The energy content in biogas is significant and usually exceeds the amount of energy used technically in running the anaerobic digester. The biogas can be used directly for producing electricity and heat or can be converted to a fuel, making the digester a net energy producer. In addition, the energy originating from recently plant-based materials synthesized by photolysis, can be considered neutral with respect to global warming potentials. However, CH_4 escaping the process or the energy utilization unit should be captured, since unconverted CH_4 emitted to the atmosphere is a significant green house gas contributing to global warming approximately 25 times more than CO_2. Capturing methane is usually done by flaring at the plant and by covering after-storage tanks in order to retrieve residual biogas production. After-storage biogas production has been found to constitute 5–25 % of the total biogas production of the plants.

The biogas process include different biochemical processes:

- **Hydrolysis,** a reaction in which a molecule is split, and the hydrogen and hydroxide ions from a water molecule are attached to the separate products'
- **Fermentation,** Sugars and amino acids are converted to volatile fatty acids (VFA), alcohols, hydrogen, and CO_2 in a process called fermentation. The amino acids release ammonium during fermentation. This process is not obligated to use an external electron acceptor. Electrons from oxidative processes can be directly utilized in coupled reductive processes. This often means that multiple products are produced. Long-chain fatty acids from the hydrolysis of lipids are not converted in fermentation, but instead are oxidized during the following acetogenesis.
- **Acetogenesis,** The VFA (such as propionate and butyrate) and alcohol (such as ethanol) produced during the fermentation step are oxidized to acetate by obligate hydrogen producing acetogens (OHPA; see Table 9.4.2). Electrons produced from this oxidation reaction are wasted to hydrogen ions to produce H_2. By obligate, it is meant that there is no coupled reaction or external electron acceptor available, as wasting electrons by producing hydrogen is generally energetically unfavorable.

- **Methanogenesis,** Methane is generated primarily by two pathways: Hydrogenotrophic methanogenesis, which converts H2 and CO2 into CH4, and the aceticlastic methanogenesis, which converts acetate into CH4 and CO2.

6.6. Requirements for the design of biogas plants

- Non-biodegradable materials should not exceed 15% for dry digestion and 2% for wet digestion
- Wet digestion is used in the case of food wastes separated at source, and separated slurry from wet separation lines.
- Food waste slurry can be used in co-digestion with waste water treatment plants (WWTP) sludge and
- other agricultural waste.
- The control room must be heat-insulated and air conditioned and equipped with cable tunnels.
- The station should include heating systems for wet and dry fermenters, internal pipes should be of stainless steel, external pipes should be insulated.
- Pumps must be made of corrosion-resistant materials and can handle liquids with high concentrations of solids.
- The generator should be specially built for biogas fuel and equipped with a heat production unit used in the heating fermenters and other purposes (drying RDF in case of integrated plants

- The station should include a diesel-powered generator used in emergency and start-up operations for selected loads.

6.7. Safety and Environmental Conditions of Solid Waste Treatment Plants

The solid waste treatment system should satisfy the following minimum safety requirements:

6.7.1.Fire Reduction Procedures

- In case of piling waste leave a distance not less than 4 m around the pile.
- If dry residues are stored for more than a week, they should be placed remote from production lines.
- Organic waste must be moisturized constantly,
- Collect biogas and prevent leakage. Any excess from gas storage capacity should be burned automatically.
- Installation of fire alarm network in all facilities.
- Provide roads around the facility and between compost windrows to enable fire-fighting access across the entire site.
- Provide water outlets under adequate pressure around the site with fire hoses able to reach all potential points.
- Train fire-fighting personnel in the plant on waste isolation principles and how to avoid combustion risk of stored materials.

6.7.2.Environmental Monitoring Procedures

- The names of the EEAA inspectors must be specified and shall be engaged by the Operator to follow up and evaluate the extent of the compliance with the specifications stipulated in this chapter.
- The Operator is committed to allowing EEAA inspectors to access all treatment facilities and to walk around at all times without notice.
- Inspectors to review the form and content of the contractor's records to determine compliance with specifications and requirements.
- It is necessary to develop a grievance mechanism from residents near the facility. Any complaints received should be made available to the inspector and governorate environmental department, in addition to a record of any actions taken by the operator to close out grievances. The number of grievance reports recorded by governorate environmental department is used to measure the efficiency of the operator.

CHAPTER 7

LANDFILLING

Landfilling of waste historically has been the main management route for waste, and in many parts of the world it still is. Landfills have developed from open polluting dumps to modern highly engineered facilities with sophisticated control measures and monitoring routines. However, in spite of all new approaches and technological advancement the landfill still is a long lasting accumulation of waste in the environment. Much of current landfill design and technology has been introduced as a reaction to problems encountered at actual landfills. The solution was in many cases sought in isolation of the waste. Although this prevents immediate emission, isolation at the same time is a conservation of potential emission. This potential emission materializes when the isolation fails at some point in time. Therefore it is of importance in the striving for sustainable waste management solutions to understand the concepts, the processes and the long-term aspects of landfilling.

This chapter describes the main conceptual aspects of landfilling. The historical development is presented and key issues of time frames, mass balances and technical approaches are discussed.

7.1. Historical Development of Landfilling

The history of landfilling is the basis for understanding current approaches and technologies as well as the future challenges. The following coarse historical journey through the world of landfills may take its starting point in the 1950s when waste reflected the early industrialization of society and no longer was dominated by organics and ashes. The terms used in the following are descriptive and do not necessarily represent any standardized or legal terms.

1. **Open dumps** were often clay and gravel pits or other low-value land filled with what ever waste that might appear, including industrial and hazardous waste: the waste was dumped from the truck where possible. As long as the dumps were small and local waste disposal sites, the impacts and problems were often only local and tolerable, maybe except with respect to smells, rodents and local fires. However, as urbanization developed, the dumps grew bigger and urban areas often moved in close to the disposal sites making nuisances and esthetic issues important.
2. **The sanitary landfill** offered a more orderly appearance by limiting access to the site (fences), organizing the disposal activities and often covering of the waste with soil. Where land was plentiful, the sanitary landfill could be trenches dug into the ground. Less contact with the waste, less litter and organized rodent controls were a sanitary improvement. However, issues of gas and leachate were not very much in focus. But large

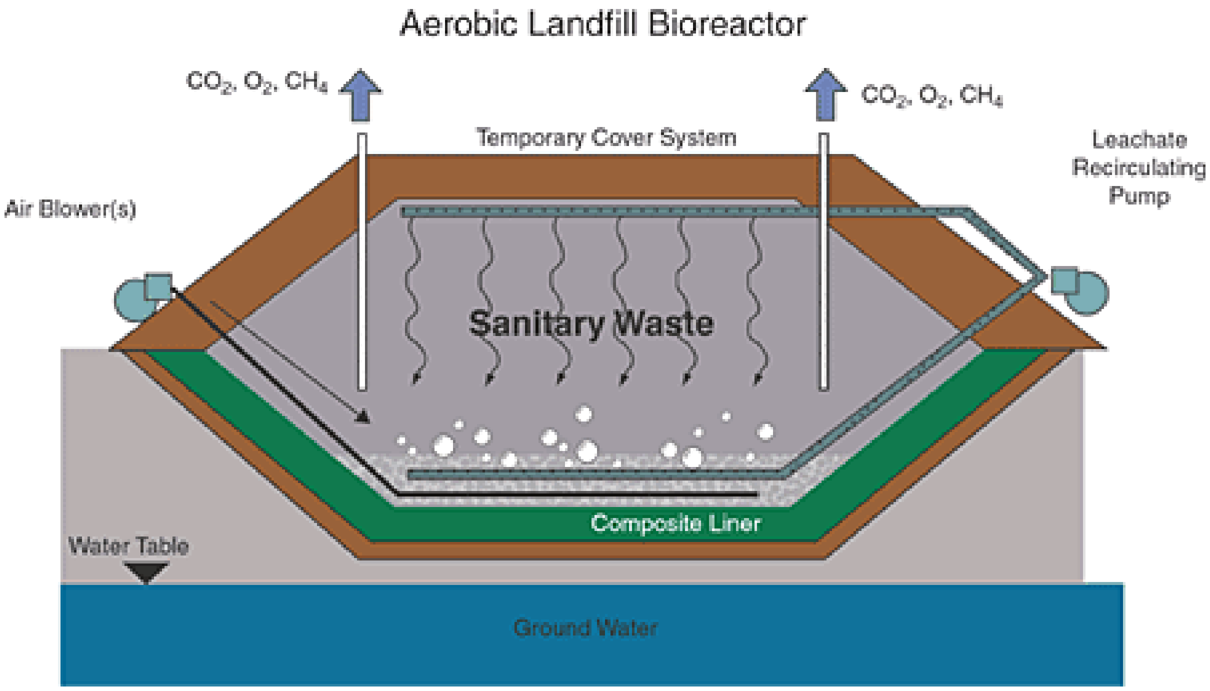
sanitary landfills would after some years start causing damages on vegetation and uncontrollable fires due to gas and pollute nearby streams by seeping leachate. The sanitary landfill site designed with consideration of leachate generation and migration was also called a 'dilute and attenuate' landfill.

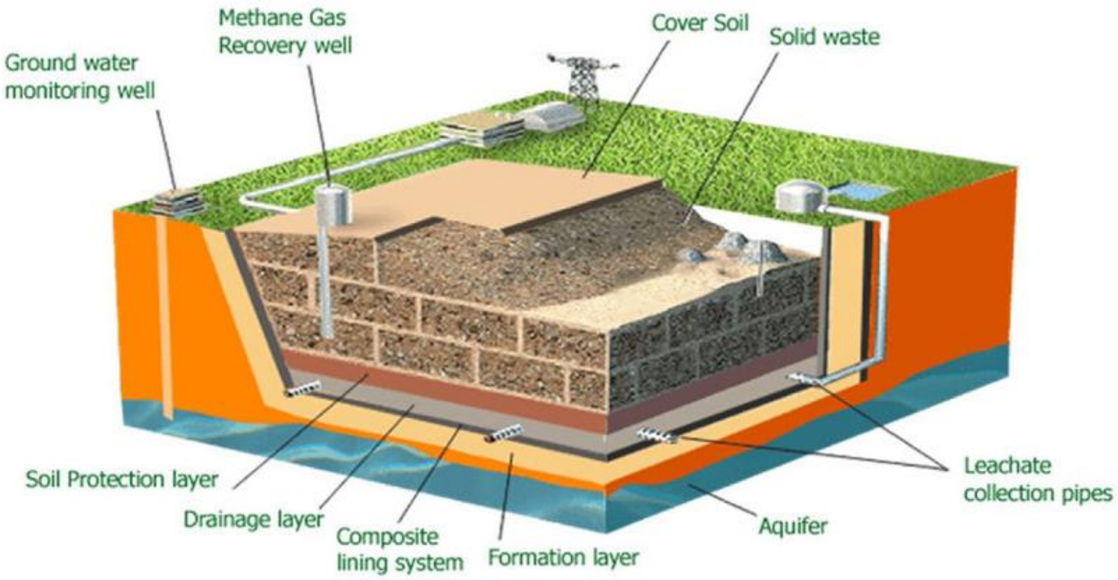
3. **The controlled landfill** offered controls on leachate and gas by introducing liners, collection systems and treatment facilities for leachate and gas. The protection of groundwater and surface water had high priority in many countries as cases of groundwater pollution around sanitary landfills appeared more frequently and the cost of remediation became high. Much focus was on how to construct liners and leachate drainage systems and how to treat the strongly polluted leachate. The gas issues were more local and controlling the gas led to flaring of the gas and soon also utilization. However, over the years it was experienced that liners may not stay impermeable, leachate collection systems may clog, and leachate from the methanogenic phase is difficult and expensive to treat prior to discharge. It was also learned that gas collection was not complete and landfill covers were needed to ensure efficient gas utilization. Leachate recirculation was in some cases introduced as a treatment option for leachate and an approach to enhance gas generation making collection and utilization more economic. Hazardous waste was not allowed in the controlled landfill, but

other restrictions on the waste were few. The controlled landfill and its later developments were also named ‘containment landfills’.

4. **The dry tomb** was a reaction to all the shortcomings of traditional technology. The concept was to cover the landfill completely in order to prevent water infiltration and leachate generation and to support full collection of landfill gas. However, the dry tomb leads to less degradation of the organic waste and less gas generation, and hence slower stabilization of the organic content because of low moisture content. Leaching is also minimum, thus leading to a conservation of the waste and a need for potentially eternal maintenance of the top cover.
5. **Various bioreactor landfill** technologies were suggested and in some cases introduced to enhance degradation and shorten the time for stabilization of the waste: the semiaerobic landfill (primarily in Japan) and the flushing bioreactor (primarily in the UK); the latter based on the understanding that nitrogen potentially is the most persistent pollutant in leachate and therefore removal of nitrogen should be enhanced.

In recent years quality requirements to the waste being landfilled and mandatory plans for closing of the landfill have been introduced in some countries as a consequence of the fact that potential impacts from landfilled waste may continue longer than most technical measures installed for their control may last. Financial deposits to pay for future remediation are often requested. This new type of landfill has still not gained a common name.





The location of the landfill site should be determined by following 4 steps as follows:

Step 1: Collect maps and exclude sites having any of the following exclusion criteria:

- Located in floods area
- The site is a collection point for rainwater
- Located in areas with a groundwater level close to the subsurface (≤1 m)
- The surrounding areas are planned as residential areas.
- The location is less than 500 m from the nearest residential area
- Located within an area where explosives are used or military activities Located in a landslide area
- Located in less than 1.5 km from the nearest airport

Step 2: Identify a list of potential sites taking into account the following:

- Limited use of groundwater for drinking or agriculture due to its high salinity. Sites away from populated areas more than 1.5 km
- Area availability compared to the quantity of waste that will be disposed over the lifetime of the landfill and the size of these wastes and the extent of the site's accommodation of the volume of waste in terms of depth and height of waste.
- Geological factors such as high soil permeability or low soil bearing capacity, which reduces waste height.

- Groundwater aquifer direction of flow determine the probability of contaminants moving to nearby and descending receptors such as wells and springs. The potential health impact of pollutants is reduced if the flow of groundwater exposed to the pollutants is away from the receiving locations.

Step 3: Review and evaluate the proposed sites

A field survey of all potential sites is carried out and evaluated according to Table 5. Rating system based on grading (1, 2, 3) according to the nature of the site most suitable for each criterion, the appropriate sites will take the highest score (3) and the non-appropriate one will take a low score (1). The site with the accumulative highest grade is selected.

Table 5: Criteria for Evaluation of landfill Sites

S	Evaluation Criteria	Site 1	Site 2	Site 3
1	Land ownership. Where ownership papers and the allocation decision are confirmed. Any obstacles in site, including the presence of private properties or houses or any other military or civilian entity.			
2	Site distance to the waste generating area and the impacts of the site on the collection and transport operations (need extra resources as transfer stations)			
3	Site distance to the main roads.			
4	Existing surface waters next to the site (rivers, streams, lakes).			
5	The ability of the site to hold rain water or Flood			
6	Groundwater level			
7	The existence of groundwater wells for drinking or agriculture.			
8	Flood path crossing the site			
9	Level of ground sealing materials required			
10	Availability of cover material from low permeability soil.			
11	Land use around the site. The boundaries of the site, the uses of neighboring lands, residents in the vicinity of the site and main potential problems of project construction			
12	The existence of power lines near the site, air hanged or underground			
13	There is a prospect for nearby archaeology or an archaeological area			
14	Traffic on roads leading to the site the main and sub roads surrounding the site, the effect of constructing and operating the site on these roads, need of access road			
15	Area available, capacity and lifetime			
16	Distance between the location and the nearest agricultural or residential activity around the site			
17	Cast of landfill construction (estimate)			
	Total Site Rating			

Step 4: The lifetime of the landfill can be estimated in planning phase using the following formula:

LS= (A x D x 2 x 0.9)/ {(Wgr x P x365 x dv)/ p}

Where:
LS= life time in years
A= Site Area (m^2)
D= depth of landfill
Wgr= Waste Generation Rate (kg/person/day)
P= population served by the landfill
Dv= diversion rate from landfill due to treatment and recycling activities
p= density of collected waste (kg/m^3)

- In the absence of waste generation field data, a rate of 0.7 kg/person/day is used.
- Density of landfilled waste is considered twice of density of fresh waste
- The formula is based on 10 cm daily cover each 1 m, and 1 m final cover.
- The density of generated waste can be used within 350 kg/m^3 for arid and semi-arid areas (Upper Egypt) while density of 400 kg/m will be used for Delta and north coastal areas.
- The formula is based on over ground and underground slope of 1:3, exact life time to be calculated according to final slopes of the side walls.

7.2. Selection of Landfill lining system

The type of landfill depends on site conditions and the feasibility study, one of the following types is selected:

i. Sanitary Landfill includes composite lining of clay (mineral lining) and geomembrane, leachate collection system and landfill gas collection system in addition to leachate treatment and gas flaring units. This type is used for areas with precipitation higher than 8 mm per year.
ii. Controlled Landfill includes a liner of compacted low permeability soil. This type is used for arid areas with less than 8 mm precipitation per year. This type is also used in case of non-hazardous rejected waste after organic extraction for compost.

7.3. Preparation of feasibility studies and environmental impact assessment

After identifying one preferred location, and type of landfill, environmental impact assessment study and feasibility study should be prepared, Site studies and EIAs should be presented as shown in Table (20) before the design process begins. The EIA should be prepared according to EEAA guidelines.

Environmental assessment should cover:

1) Impact of landfill gas migration from the landfill site to the surrounding areas, Considering the uses of the surrounding lands. Define precautions to be followed to Reduce this impact.
2) Impact of leachate migration from landfill to groundwater or surface water and the Precautions to be taken to reduce this impact.
3) Impact of site's visibility and how to reduce this impact.
4) Impact of noise during construction and operation of landfill.
5) Impact on fauna and flora in the landfill area.
6) Feasibility study should cover cost of investment, operation and maintenance. The owner of the landfill must ensure that the necessary funding and permits before start of construction.

7.4. Criteria for Landfill design

Landfills should be designed according to the following criteria:

- The site is divided into cells. Each cell will have a lifetime of minimum 5 years.
- Access roads to the cells and access ramps with suitable inclination for waste trucks.
- The main services are provided to employees including administrative offices and toilets
- A wire mesh fence around the site to prevent illegal access to the site

- Weigh bridge, capacity not less than 70 tons and length not less than 15 m equipped with solar cells shall be provided for operation 24 hours a day.
- In the case of shallow groundwater minimum distance of I meter between the higher (seasonal) groundwater level and the bottom sealing of the landfill is maintained.
- The design elements of the landfill are:
    1) Dimension, depth and inclinations
    2) Lining system.
    3) Leachate collection and treatment system
    4) Gas collection and treatment system
    5) Surface water management

7.5. Criteria for Design of Landfill Dimensions

The following criteria should be considered for the slopes of the landfill and when closing the landfill:

1) The slope of the cell sides with lining should not exceed 3 (horizontal): 1 (vertical)
2) Final cover slope should not exceed 3 horizontals: 1 vertical for the sides and 6% for capping.
3) The slope of the cell base should not be less than 3% inclinations in direction to the landfill drainage pipe.

4) The stability of the slopes and ability of base slopes to discharge the leachate must be guaranteed through stability and levelling calculations according to Egyptian Code of Geotechnical Engineering and Foundations.
5) An anchor trench must be designed to fix the geomembranes on top of the lining slope in order to achieve the stability of the sealing layer under loads and prevent it from sliding down the slope.

7.6. Criteria for Choosing the Lining System

The lining design depends on the type of waste and level of groundwater protection required. The level of protection required shall be determined according to the following:

- Minimum protection required (controlled Landfill): is applied in any of the following conditions:

a) when the level of the groundwater is more than 30 m deep
b) Ground water quality is not suitable for human or agricultural use
c) The site is located in arid climate where minimum leachate is generated due to absence of rain water.
d) Type of waste is not including or including very limited organic matter.
e) The hydrologic site prevents the spread of any leakage to the depth of the groundwater

f) Impermeable layer of rock exists

- Protection required (Sanitary Landfill): is applied in all cases not only other the six conditions listed above. The sanitary landfill has complete containment design to protect groundwater. The landfill includes collection and treatment of leachate and the lining should consist of successive layers from bottom up.

7.7. Conditions for the Constructing of Landfill

When constructing a landfill, the following should be considered:

- Clearing the site of landfill from any structure, bushes, trees, waste etc.
- Construction of the boundary along the outer perimeter of the cell.
- Levelling and compacting the bottom level and construction access ramps.
- Excavation soil to be kept in the site for later use as daily cover.
- The required moisture content shall be monitored, and water shall be added and the clay mixed properly when the moisture content is low according to the soil report for the clay. Water is added using mechanical sprayers to ensure uniformity of distribution and shall be under sufficient pressure to penetrate the compacted soil. It shall be accompanied by a good mixing process every time water is added. When water content reaches the moisture level indicated in the soil report it will be compacted.
- Use Sheep foot rollers for compaction of the lower layer and smooth roller for the final layer. Weights ranging from 8-10 tons; to achieve the final soil form required.
- The soil compaction is tested according to (Proctor Modified Test) and should achieve 95% of required value.

- A specialized and experienced geomembrane installation team.
- Surrounding the landfill by a fence at least 2.25 m height.
- Provision of mechanical equipment such as Soil compactor, track loader, dump truck, excavator and trucks for soil and water transportation.
- Provision of weigh bridge, and service building

7.8. Conditions for the operation of controlled or sanitary landfills

When operating the controlled or sanitary landfill, the following conditions must be considered:

7.8.1.Operation plan preparation and availability

The person responsible for the operation of the landfill and plans for the operation and maintenance of the landfill in addition to an emergency plan. This includes:

- The plan covers the period from the start of operation until the final closure of the landfill.
- The plan is reviewed and updated at least once a year or when required.
- The plan is available to the workers in the landfill.
- The plan should at least include the following topics:
  - The total time schedule for filling the landfill cells.
  - The main tasks to be completed by the Landfill Operations Team.

- The organizational structure of the workers in the landfill and the matrix of the distribution of tasks to the team.
- Control quantities and quality of waste in the landfill.
- Self-inspection of the operation of the landfill.
- Waste compaction and managing the cover materials.
- Maintenance of mechanical equipment.
- Surface water control.
- Fire control.
- Control of scattered waste, littering, insects and vermin.
- Monitoring and control of leachate.
- Monitoring and control of landfill gas.
- Records keeping, reporting and data management system.

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