

## Lecture One

2019-2020

### Solid Waste Definition

Sources and types of solid wastes

Physical and chemical composition of solid wastes

Solid waste generation rates and the influencing factors  
involved

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## **1. Introduction**

Solid waste is any solid material that is disposed of because it has no further use to society in its present form. In more specific terms, the U.S. EPA has defined solid waste as "any discarded material resulting from industrial, commercial, mining, agricultural operations and from community activities.

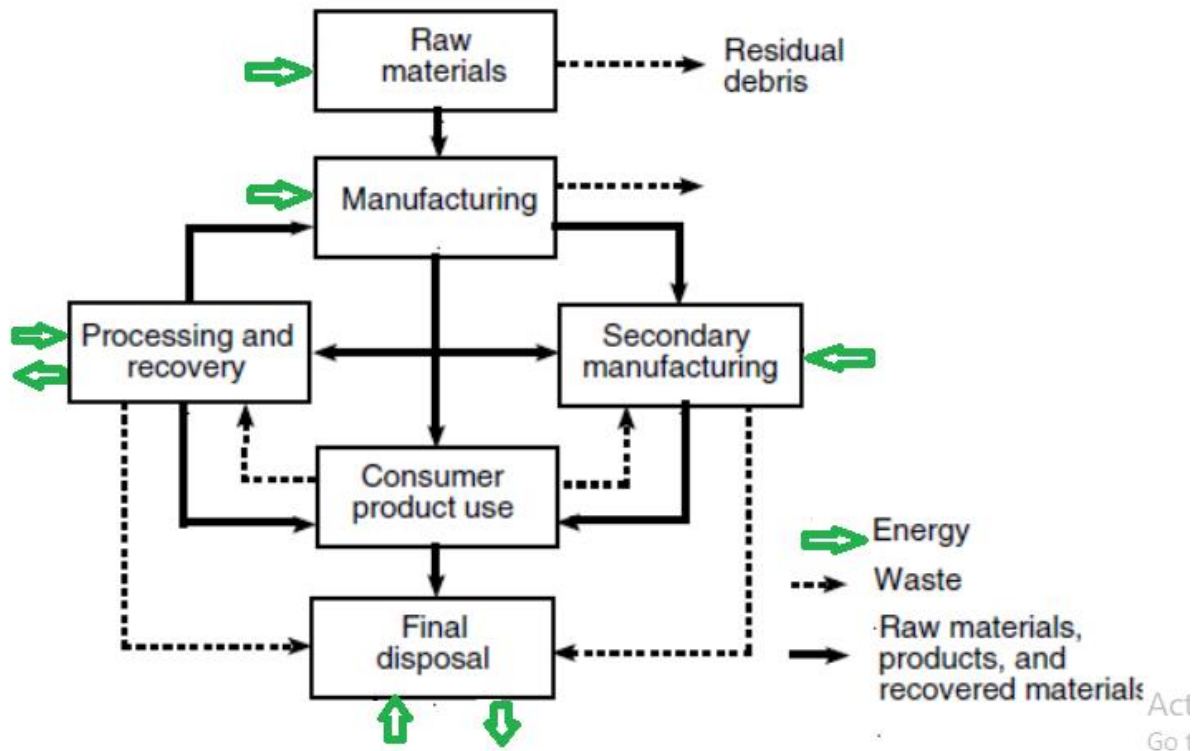
Other authors define solid wastes as all the wastes arising from human and animal activities that are normally solid and that are discarded as useless or unwanted. It encompasses the heterogeneous mass of throwaways from residences and commercial activities as well as the more homogeneous accumulation of a single agricultural or industrial activity.

Solid wastes are produced wherever man is found: farms, mines, stores, offices, factories, homes, hospitals, streets, and even the primitive encampments of traditional nomads. The aim of this chapter is to identify:

- a) The sources and types of solid wastes,
- b) To examine the physical and chemical composition of solid wastes,
- c) And to discuss solid waste generation rates and the influencing factors involved.

## **2. Materials Flow and Waste Generation**

An indication of how and where solid wastes are generated in our society is shown in the simplified materials flow diagram



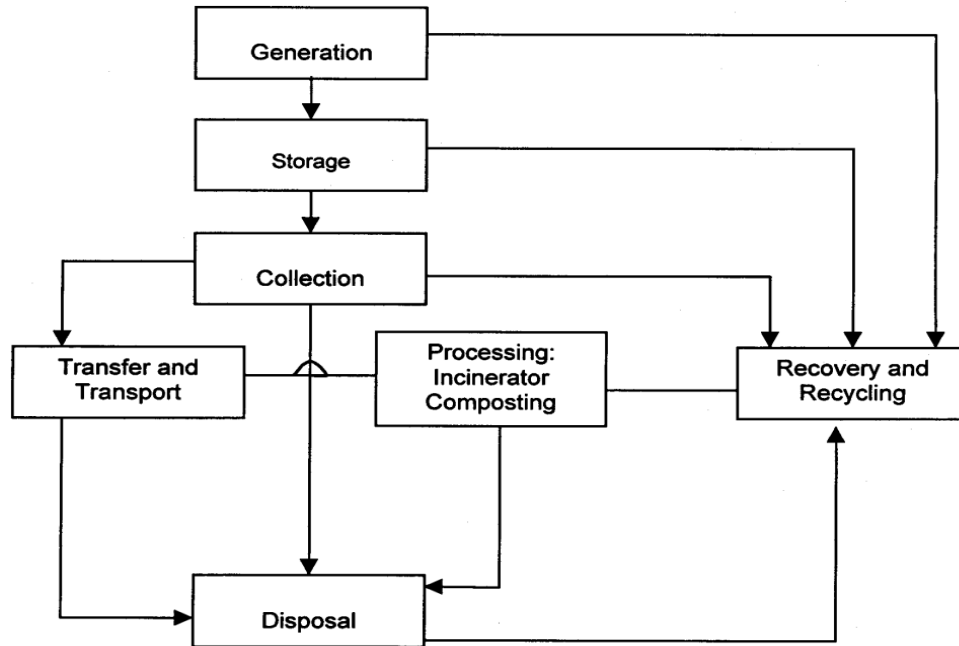
**Figure .1.** Material flow and generation of solid wastes in a technological society

### **3. Solid waste management system (SWMS):**

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

The functional elements that constitute the system are:

1. Waste generation
2. Waste storage
3. Waste collection
4. Transfer and transport
5. Processing
6. Recovery and recycling
7. Waste disposal



**Figure 2. Typical SWM System: Functional Elements**

The sources of municipal solid waste has historically been consistent. The sources and types of municipal solid waste are reported in Table 1.

**Table 1 General sources of municipal solid wastes**

<b>Source</b>	<b>Typical facilities, activities or locations where wastes are generated</b>	<b>types of solid wastes</b>
<b>Residential</b>	<b>Single-family, multi-family dwelling; low-, medium-, and high-rise apartments...etc.</b>	<b>Food wastes, rubbish, ashes, special wastes.</b>
<b>Commercial</b>	<b>Stores, restaurants, markets, office buildings, hotels, demolition and construction, print shops, auto repair shops. medical facilities and institutions etc.</b>	<b>Food wastes, rubbish, ashes, special wastes.</b>
<b>Municipal</b>	<b>As above</b>	<b>As above</b>
<b>Industrial</b>	<b>Construction fabrication, light and heavy manufacturing, refineries, chemical plant</b>	<b>Waste, special waste, hazardous waste</b>
<b>Open areas</b>	<b>Streets, alleys, parks, vacant lots, playground, beaches, roads, recreational areas etc.</b>	<b>Rubbish, special wastes.</b>
<b>Treatment plants</b>	<b>Water, waste water, industrial treatment processes etc.</b>	<b>Treatment plants, residual sludge.</b>
<b>Agricultural</b>	<b>Resulting from diverse agricultural activities such as planting, field harvesting, tree and vine crops. The production of milk, production of animals for slaughters and the operation of feedlots are collectively called agricultural wastes.</b>	<b>Food wastes , wastes, rubbish, hazardous wastes</b>

## Types of solid waste

**Food waste** is the animal, fruit or vegetable residue resulting from the handling, preparation, cooking, and eating of foods (all called garbage). The most important characteristic of these wastes is that they are highly putrescible and will decompose rapidly, especially in warm weather. (Often, decomposition will lead to the development of offensive odors.

**Rubbish** consists of combustible and non - combustible solid wastes or other highly putrescible material, typically combustible rubbish consists of material such as paper, cardboard, plastic, textiles, rubber, leather, and garden trimmings. Non-combustible rubbish consists of items such as glass, crockery, tin cans, aluminum cans, ferrous and other non-ferrous metals and dirt

**Ashes and residues** **Materials** remaining from the burning of wood, coal and other combustible wastes at homes, stores institutions, and industrial and municipal facilities for purposes of heating, cooking and disposing of combustible waste are categorized as ashes and residues. Residues from power plants normally are not included in this category.

**Demolition and construction wastes** from razed building and other structures are classified as demolition wastes, wastes from the construction, remodeling, and repairing of individuals residences, commercial buildings and other structures are classified as construction wastes. The quantities produced are difficult to estimate and variable in composition, but may include dirt, stones, concrete bricks, and plumbing, heating and electrical parts.

**Special wastes** such as street sweeping, roadside litter, from municipal litter containers, debris, dead animals, and an abandoned vehicles are classified as special wastes.

**Treatment plants** the solid and semisolid wastes from water, wastewater, and industrial waste treatment facilities are included in this classification. The specific characteristics of these materials vary, depending on the nature of the treatment process.

**Hazardous wastes** They are any waste or combination of waste that pose substantial danger now or in the future, to human, plant or animal life otherwise they cannot be handled or disposed of without special precautions.

Hazardous wastes are the wastes with at least one hazardous characteristic (explosive, flammable, liable to oxidation, acutely poisonous, infectious, and liable to corrosion releases poisonous gases in contact with air or water

**Table 2.** Classification of materials comprising municipal solid wastes.

Type	Description
<b>Garbage</b>	<b>Results from food marketing, preparation and consumption (also called food wastes). It contains putrescible organic materials and will decompose rapidly, especially in warm weather. It needs especial consideration due to its nature of attracting vermin and of producing very strong odors</b>
<b>Rubbish</b>	<b>This category consists of paper and paper products, plastics, cans, bottles, glass, metals, ceramics, dirt, dust, yard and garden wastes...etc. It also includes park and beach refuse. Except for garden wastes, these materials are nonputrescible.</b>
<b>Ashes</b>	<b>This is the residue from any combustion process (i.e. fireplaces, wood or coal heating units etc.) resulting from households activity and onsite incineration.</b>
<b>Bulky waste</b>	<b>This category includes furniture, appliances, mattresses, springs, and similar large items. They require special handling and collection.</b>
<b>Demolition/ construction</b>	<b>This class of refuse include the lumber, bricks, concrete, plumbing, waste electrical wiring etc. associated with the destruction of old buildings and the construction of new ones.</b>
<b>Special wastes *</b>	<b>Wastes resulting from normal street cleaning operations such as, street sweeping, roadside litter, catch-basin debris, dead animals and abandoned vehicles.</b>
<b>Treatment plant wastes</b>	<b>Include the solid and semi-solid wastes from water, wastewater and industrial waste treatment facilities.</b>



## **Industrial wastes**

Industrial wastes are wastes arising from activities. They include rubbish, process wastes, ashes, demolition and construction wastes, special wastes and hazardous wastes. Industries create refuse trash, and garbage just as municipalities do, but there is no one number represent industrial waste generation, yet there is waste generation rate for each kind of industrial process still more specific grouping for each industry would give more precise data. Industrial waste generation in general reported as average weight generation rates per employee per day for industry group.

Many solid wastes generated by industry are utilized directly. They contain significant amount of valuable materials like steel, aluminum, copper and other metal which, if they are recovered and reused would reduce the volume of the wastes to be collected and at the same time would yield significant salvage and resale income and will help to save valuable natural resources.

## **Prosperities of SW**

### **Physical Properties**

- Constituent (Composition)
- Particulate size
- Density
- Moisture content

### **Physical composition**

Information and data on the physical composition of solid waste are important in the selection and operation of equipment and facilities, in assessing the feasibility of resource, energy recovery, and in the analysis and design of disposal facilities.

#### **a. Individual components (Composition)**

The percentages of municipal solid waste components vary with location, season and economic conditions. Table (3) shows typical solid waste composition.



**Table 3.** Typical physical composition of a solid waste

Component	Percent by mass
Food waste	15
Paper	40
Cardboard	4
Plastics	3
Textile	2
Rubber	0.5
Leather	0.5
Garden trimming	12
Wood	2
Glass	8
Tin cans	6
Non ferrous materials	1
Ferrous materials	2
Dirt, ashes, Bricks	4
Total	100

### **Determination of Components in the field (Sampling procedures)**

Because of the heterogeneous nature of solid wastes, determination of the composition is not an easy task. Strict statistical procedures are difficult, if not impossible, to implement. For this reason, a more generalized field procedure, based on common sense and random-sampling techniques, has been developed for determining composition.

1. Unload a truck of wastes in a controlled area away from other operations
2. Quarter the waste load
3. Select one of the quarters and quarter that quarter
4. Select one of the quartered quarters and separate all of the individual components of the waste into preselected component such as those listed in the table
5. Place the separated components in a container and weight
6. Determine the weight percentages of each component by mass

**b. Moisture content of solid wastes** usually is expressed as the mass of moisture per unit mass of wet or dry material

In equation form, the wet mass moisture content is expressed as follows:

$$\text{Moisture content (\%)} = \{(a-b)/a\} \times 100$$

Where a=initial mass of sample as delivered

b=mass of sample after drying

To obtain the dry mass the solid waste material is dried in an oven at 77 °C (170 F) for 24 hour. This temperature and time is used to dehydrate the material completely and to limit the vaporization of volatile materials

**Example 1:**

Estimate the overall moisture content with the typical municipal solid wastes based on 100 Kg.

Component	Percent by mass	Moisture content %
Food waste	15	70
Paper	40	6
Cardboard	4	5
Plastics	3	2
Textile	2	10
Rubber	0.5	2
Leather	0.5	10
Garden trimming	12	60
Wood	2	20
Glass	8	2
Tin cans	6	3
Non ferrous materials	1	2
Ferrous materials	2	3
Dirt, ashes, Bricks	4	8
Total	100	

Ans: 21.76%

### **C. Density**

Density data are often needed to assess the total mass and volume of waste that must be managed. The density of solid waste varies with its composition, its moisture content and its degree of compaction. Density of municipal solid waste as delivered in compaction vehicles has been found to vary from 180 to 450 kg/m<sup>3</sup> depending on the type of compaction equipment. A typical value is about 300 kg/m<sup>3</sup>. Typical non-compacted municipal solid waste is 130 kg/m<sup>3</sup>. For normally compacted landfill, the density is 450 kg/m<sup>3</sup> and 600 kg/m<sup>3</sup> for well-compacted landfill.

#### **Example 2:**

Estimate the overall density with the typical municipal solid wastes in the below Table. 1 lb/ft<sup>3</sup> = 16.018 kg/m<sup>3</sup>

Component	%mass	Density lb/ft <sup>3</sup>	Density kg/m <sup>3</sup>
Food waste	15	18.0	288.324
Paper	40	15.1	241.8718
Cardboard	4	3.1	49.6558
Plastics	3	4	64.072
Textile	2	4	64.072
Rubber	0.5	8	128.144
Leather	0.5	10	160.18
Garden trimming	12	6.5	104.117
Wood	2	15.0	240.27
Glass	8	12.1	193.8178
Tin cans	6	5.5	88.099
Non ferrous materials	1	10	160.18
Ferrous materials	2	20	320.36
Dirt, ashes, Bricks	4	30	480.54
Total	100		

## **Chemical composition**

Information on the chemical composition of solid wastes is important in evaluating alternative processing and recovery options. For example, consider the incineration process. Typically, wastes can be thought of as a combination of semi moist combustible and non-combustible materials. If solid wastes are to be used as fuel, the four most important properties to be known are:

1. Proximate analysis
  - a. Moisture (loss at 105<sup>0</sup>C for 1 h)
  - b. Volatile matter (additional loss on ignition at 950<sup>0</sup>C)
  - c. Ash (residue after burning)
  - d. Fixed carbon (remainder)
2. Fusing point of ash
3. Ultimate analysis, percent of C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (Sulphur), and ash
4. Heating value.

A proximate analysis for the combustible components of municipal solid wastes as discarded is presented in Table 4.

**Table 4 Typical Proximate Analysis for  
Municipal Solid Wastes**

Component	Value, percent Typical
Moisture	20
Volatile matter	53
Fixed carbon	7
Glass, metal, ash	20

## Fusing Point of Ash

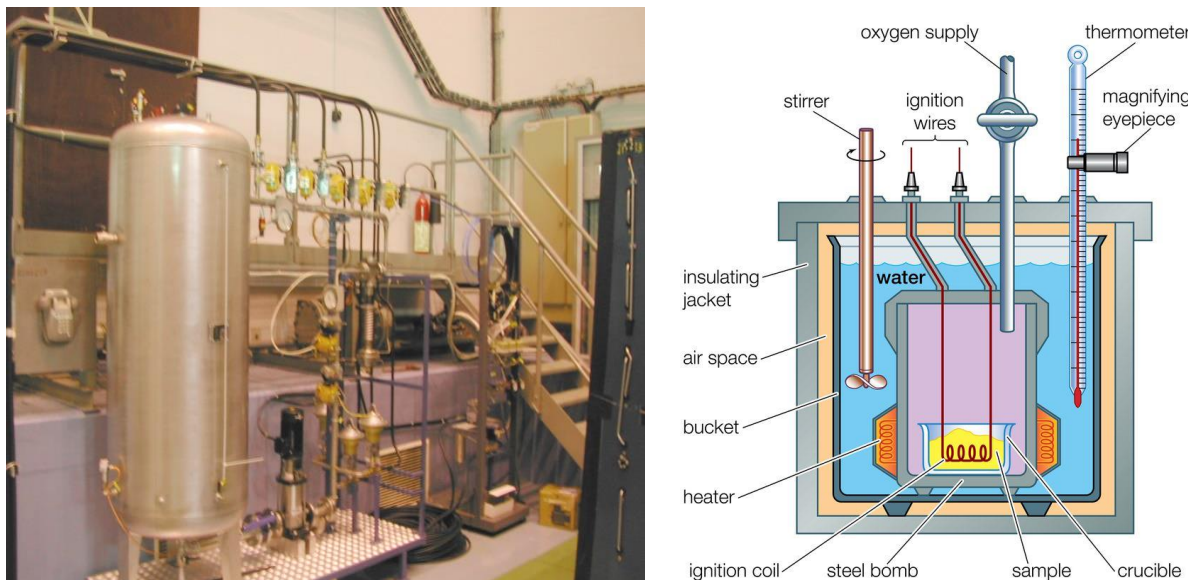
The fusing point ash is defined as that temperature at which the ash resulting from the burning of waste will form a solid (clinker) by fusion and agglomeration. Typical fusing temperature for the formation of clinker from solid waste range from 2000 to 2200°F (1100 to 1200°C).

## Ultimate Analysis of Solid Waste Components

The ultimate analysis of a waste component typically involves the determination of the percent C (carbon), H (hydrogen), O (oxygen), N (nitrogen), S (sulphur), and ash. Because of the concern over the emission of chlorinated compounds during combustion, the determination of halogens is often included in an ultimate analysis. The results of the ultimate analysis are used to characterize the chemical composition of the organic matter in MSW. They are also used to define the proper mix of waste materials to achieve suitable C/N ratios for biological conversion processes.

## Heat Value (Energy Content of Solid Waste Components)

Heat value of refuse is of paramount importance in resource recovery. Heat value is expressed as British thermal unit per pound, Btu<sup>3</sup>/lb, of refuse, or kJ/kg in the SI system. Heat value of refuse and other heterogeneous materials may be measured with a calorimeter. A calorimeter is a device in which a sample is combusted and the temperature rise is recorded. Knowing the mass of the sample and the heat generated by the combustion, the Btu/lb is calculated.



**Figure 3.** Calorimeter

The most popular method using ultimate analysis is the DuLong equation, which originally was developed for estimating the heat value of coal.

Energy values of solid waste and garbage can be estimated by using DuLong equation as shown in equation (1)

$$\frac{KJ}{kg} = 337C + 1428\left(H - \frac{O}{8}\right) + 9S \quad (1)$$

Where:

C = Carbon, (%).

H = Hydrogen, (%).

O = Oxygen, (%).

S = Sulfur, (%).

The DuLong formula is cumbersome to use in practice, and it does not give acceptable estimates of heat value for materials other than coal. Total energy content may be determined using the modified DuLong formula as presented in equation 2.

$$\frac{BTU}{lb} = 145C + 610\left(H_2 - \frac{O_2}{8}\right) + 40S + 10N \quad (2)$$

Where:

Btu/lb = Total energy.

C = Carbon, percent by weight.

H<sub>2</sub> = Hydrogen, percent by weight.

O<sub>2</sub> = Oxygen, percent by weight.

S = Sulfur, percent by weight.

N = Nitrogen, percent by weight.

Formulas based on compositional analyses are an improvement over formulas based on ultimate analyses. One such formula is indicated in equation 3.

$$Btu/lb = 49R + 22.5(G + P) - 3.3W \quad (3)$$

Where

R = Plastics, percent by weight of total MSW, on dry basis.

G = Food waste, percent by weight of total MSW, on dry basis.

P = Paper, percent by weight of total MSW, on dry basis.

W = Water, percent by weight, on dry basis.

Using regression analysis and comparing the results to actual measurements of heat value, an improved form of a compositional model is suggested by equation 4.

$$Btu/lb = 1238 + 15.6R + 4.4P + 2.7G - 20.7W \quad (4)$$

Where

R = Plastics, percent by weight, on dry basis.

P = Paper, percent by weight, on dry basis.

G = Food wastes, percent by weight, on dry basis.

W = Water, percent by weight, on dry basis.

Representative data on the ultimate analysis of typical municipal waste components are presented in Table 5.

Typical data on the inert residue and calorific values for municipal wastes are reported in Table 6. As shown, (the calorific values on an as-discarded basis). The Btu values in Table 6 may be converted to a dry basis by using Eq. 5

$$\text{Btu/lb (dry basis)} = \text{Btu/lb (as discarded)} * (100/100 - \% \text{ moisture}) \dots \dots \dots (5)$$

The corresponding equation for the Btu per pound on an ash-free dry basis is

$$\text{Btu/lb (ash-free dry basis)} = \text{Btu/lb (as discarded)} * (100/100 - \% \text{ ash} - \% \text{ moisture}) \dots \dots \dots (6)$$

The use of the data in Table 6 in computing the energy content of a municipal solid waste is illustrated in example 3.

Table 5: Typical Data on Ultimate Analysis of the Combustible

Components in Municipal Solid Wastes

Component	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastic	60.0	7.2	22.8	-	-	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	-	2.0	-	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Garden trimmings	47.8	6.0	38.0	3.4	0.3	4.5
Wood	49.5	6.0	42.7	0.2	0.1	1.5
Dirt, ashes, brick etc.	26.3	3.0	2.0	0.5	0.2	68.0



Table 6. Typical data on energy contents of municipal solid waste

Components	Energy BTU/lb	Typical
Food wastes	1,500- 3,000	2,000
Paper	5,000- 8000	7,200
Cardboard	6,000- 7,500	7,000
Plastics	12,000-16,000	14,000
Textile	6,500- 8,000	7,500
Rubber	9,000-12,000	10,000
Leather	6,500- 8,500	7,500
Garden trimmings	1.000- 8,000	2,800
Wood	7,500- 8,500	8,000
Glass	50-100	60
Tin cans	100-500	300
Non ferrous	—	-.
Ferrous	100-500	300
Dirt, Ash, Brick	1,000- 5.000	3.000
Municipal solid wastes	4,000- 5,500	4,500

Note(1):  $\text{BTU/lb} \times 2.320 = \text{KJ/Kg}$

**Example 3:** Determine the energy Value of typical municipal solid wastes with the average composition shown in Table below

**Solution**

1. Assume the heating value will be computed on an as-discarded basis.
2. Determine the energy value using a computation table

Table 9 Computation of energy contents

Component	Solid Wastes % 1b.	Energy Btu/1b	Total energy Btu
Food waste	15	2,000	
Paper	40	7,200	
Cardboard	4	7,000	
Plastics	3	14,000	
Textile	2	7,500	
Rubber	0.5	10,000	
Leather	0.5	7,500	
Garden trimming	12	2,800	
Wood	2	8,000	
Glass	8	60	
Tin cans	6	300	
Non ferrous	1	—	
Ferrous	2	300	
Dirt, Ash, and brick	4	3,000	

Ans: 4762Btu/1b

### **Generation Rates**

The reason for measuring generation rates is to obtain data that can be used to determine the total amount of wastes to be managed. Therefore, in any solid waste management study extreme care must be exercised in allocating funds and deciding what actually needs to be known.

### **Measures of Quantities**

Both volume and weight are used for the measurement of solid waste quantities. Unfortunately, the use of volume as a measure of quantity can be extremely

misleading. For example, a cubic yard ( $0.764 \text{ m}^3$ ) of loose waste represents different quantity than a cubic yard of wastes that have been compacted in a packer truck, and each of these is different from a cubic yard of wastes that have been compacted further in a landfill. Accordingly, if volume measurements are to be used, the volume measured must be related to the degree of compaction of the wastes.

### **Methods Used to Determine Generation Rates**

Methods commonly used to assess the per capita generation of solid wastes are (1) load-count analysis, (2) weight –volume analysis and 3) materials-balance analysis.

**Load-count analysis:** The number of individual loads and corresponding vehicles characteristics are reported over a specified time period. If scales are available, weight data are also recorded. Unit generation rates are determined by using (the field data and, where necessary, published data. This method is illustrated in example (3) load-count analysis.

### **Example 4**

From the following data estimate the unit waste generation rate for a residential area consisting of approximately 1,000 homes. The observation location is a local transfer station, and the observation period is 1 wk.

1. Number of compactor truck kinds = 10
2. Average size of compactor truck =  $20 \text{ yd}^3$

3. Number of flatbed loads = 10
4. Average flatbed volume = 1.5 yd<sup>3</sup>
5. Number of loads from individual resident private cars and trucks = 20
6. Estimated volume per domestic vehicle = 8 ft<sup>3</sup> (1 yd<sup>3</sup>= 27 ft<sup>3</sup>)

#### Solution

1. Set up the computation table (see Table 13 below).
2. Determine the unit waste generation based on the assumption that each household is comprised of 3.5 people.

#### Estimation of unit solid waste generation rates

Item	No. of loads	Ave. vol.	Unit wt. lb/yd <sup>3</sup>	Total wt lb
Compactor truck	10	20 yd <sup>3</sup>	350	
Flatbed truck	10	1.5yd <sup>3</sup>	150	
Individual private vehicle	20	0.30 yd <sup>3</sup>	100	

1b= 0.454 kg

Ans: 3.0 1b /capita/day

**Weight-volume Analysis** Although the use of detailed weight-volume data obtained by weighing and measuring each load will certainly provide better information on the density and generation rates at a given location.

#### Materials-Balance Analysis

The only way to determine the generation and movement of solid wastes with any degree of reliability is to perform a detailed material balance analysis for each generation source such as an individual home or a commercial or industrial activity. Because of the high expense and the large amount of work involved, however, this method of analysis should be used only in special situations. The approach to be followed in the preparation of a materials balance analysis is as follows:

**First:** draw a system boundary around the unit to be studied.

**Second:** Identify all the activities that cross or occur within the boundary and affect the generation of wastes.

**Third:** If possible, identify the rate of generation associated with these activities.

**Fourth:** using a material balance, determine the quantity of wastes generated, collected, and stored. A simplified materials-balance analysis is illustrated in example 5.

### **Example 5**

#### Material Balance Analysis

A cannery receives on a given day:

12 tons of raw produce,

5 tons of cans,

0.5 ton of cartons,

and 0.3 ton of miscellaneous materials.

Its output includes:

10 tons of processed product,

the remaining becoming part of waste,

four tons of the cans are stored for future use and the remainder are used to package the produce.

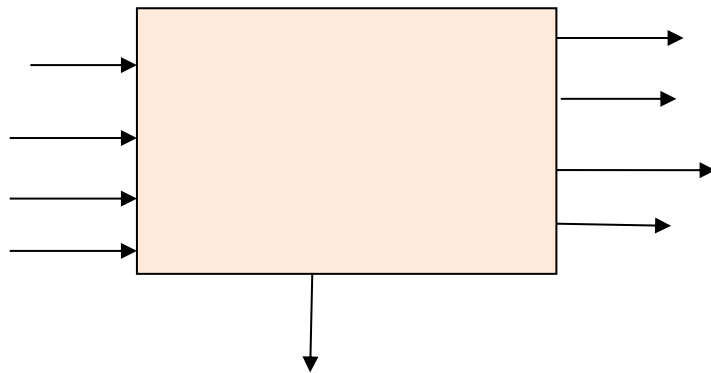
About 3 percent of the cans used are damaged and recycled.

The cartons are also used for packaging, except for 3 percent which become damaged and are incinerated with other paper wastes.

Of the miscellaneous materials, 75 percent become paper wastes that are incinerated, and the remainder are disposed of by the municipal collection agency.

Draw a materials flow diagram for this activity.

## Solution



## Factors that affect Generation rates

### **Geographic location**

In the warmer southern areas where the growing season is considerably longer than in the northern areas, yard wastes are collected not only in considerably greater amounts but also over a longer period of time.

### **Season of the year**

The quantities of certain types of solid wastes are also affected by the season of the year. For example, the quantities of food wastes are affected by the growing season for vegetables and fruits

### **Frequency of Collection**

In general, it has been observed that where unlimited service is provided, more wastes are collected. This observation should not be used as more waste is generated.

### **Use of home grinders**

While the use of home grinders definitely reduces the quantity of food wastes collected, it is not clear whether they affect quantities of wastes generated. Because the use of home grinders varies widely throughout the country, the effects of their use must be evaluated separately in each situation if such information is warranted.

## **Characteristics of population**

It has been observed that the characteristics of the population influence the quantity of solid wastes generated. For example, the quantities of yard wastes generated on a per capita basis are considerably greater in many of the wealthier neighborhoods than in other parts of town.

## **The Extent of Salvage and Recycling**

The existence of salvage and recycling operations within a community definitely affects the quantities of wastes collected. Whether such operations affect the quantities generated is another question. Until more information is available, no definite statement can be made on this issue.

## **Legislation**

Perhaps the most important factor affecting the generation of certain types of wastes is the existence of local, state, and world regulations concerning the use and disposal of specific materials. Legislation dealing with packaging and beverage container materials is an example.

## **Public attitudes**

Significant reductions in the quantities of solid wastes that are generated will occur, if people are willing to change—on their own volition—their habits and life style to conserve national resources.