Solid Waste Management

PDH: 3.0 Hours
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1. Introduction

The course titled "Fundamentals of Solid Waste Management", outlines definition and types of solid waste from technical and regulatory points of view, characteristics of solid waste, generation rate of solid waste in different regions and climate, processes for storage, collection, treatment, disposal procedures, and perspectives. This course is suggested for civil engineers, environmental engineers, chemical engineers, and solid waste landfill managers and operators.

In this course we will define several terms related to solid waste management, discuss the characteristics of solid waste, generation rate and effect of climate and other pertinent factors in generation of solid waste. We will also discuss the process for storage, collection, treatment, if any, disposal procedure and perspectives as well. We will also solve a few problems related to moisture content, density, and energy content determination for mixed solid waste.

2. Learning Outcomes

At the conclusion of this course, the students will be able to:

- define, classify, and characterize solid waste.
- know the generation rate of solid waste in different regions and climate.
- describe the process for storage, collection, treatment, and disposal.
- illustrate the waste management hierarchy.
- discuss the ultimate disposal options for solid waste.

3. Fundamentals and Definitions

Any discarded as useless or unwanted materials are waste. Waste can broadly be classified into two groups: **solid waste** and **liquid waste**. **Solid wastes** are all the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted. Solid wastes are managed into the landfill and **liquid wastes** are treated in wastewater treatment facilities and ultimately discharged to the natural water bodies. Figure 1 shows the flowchart of solid waste and the associated categories.

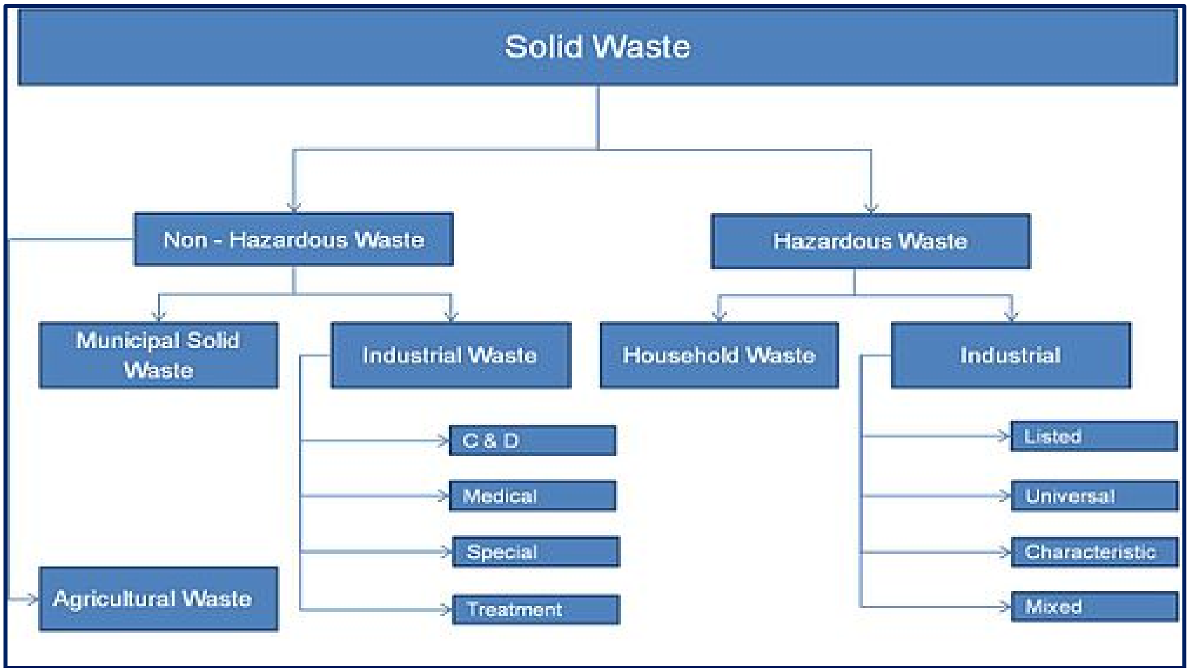


Figure 1: Flowchart of solid waste and the associated categories.

Regulatory definition of solid waste: Materials are solid wastes if they are used, reused, or reclaimed, or accumulated, stored or treated before such use, reuse, or reclamation, when they are:

1. Regulated as hazardous wastes under the Hazardous Waste Management Regulations; or
2. Used in a manner constituting disposal by being:
    a. Applied to or placed on the land; or
    b. Used to produce products that are applied to or placed on the land or are otherwise contained in products that are applied to or placed on the land. In the latter case, the product so containing remains a solid waste; or
3. Burned to recover energy, used to produce fuel, or are contained in fuels. In this case, the fuel so containing remains a solid waste; or
4. Reclaimed; or
5. Accumulated speculatively.

Speculatively accumulated material *means any material that is accumulated before being used, reused, or reclaimed or in anticipation of potential use, reuse, or reclamation. Materials are not being accumulated speculatively when they can be used, reused or reclaimed, have a feasible means of use, reuse, or reclamation available and 75% of the materials accumulated are being removed from the facility annually.*

4. An Overview of Solid Waste Management

The overall objective of solid waste management is to minimize the adverse environmental effects caused by the indiscriminate disposal of solid wastes, especially hazardous wastes. To assess the management possibilities it is important to consider (1) materials flow in the society, (2) reduction in raw material usage, (3) reduction in solid waste quantities, (4) reuse of waste materials, (5) materials recovery, (6) energy recovery, and (7) day-to-day solid waste management. Figure 2 depicts the overview of solid waste management activities.

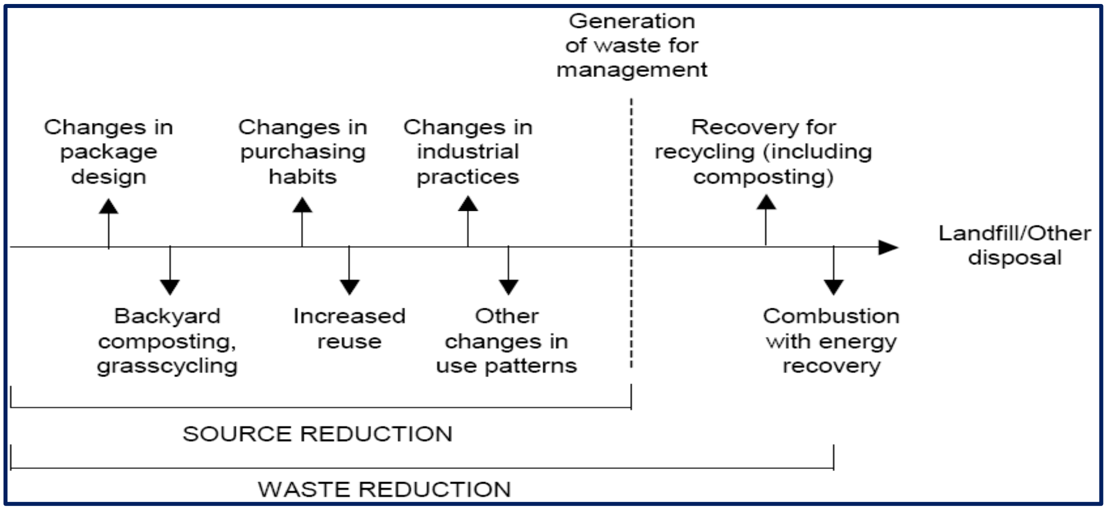


Figure 2: A pictorial overview of solid waste management activities

(1) Materials flow in the society: An indication of how and where solid wastes are generated in a technological society is shown in Figure 3. Solid wastes are generated at the start of the process, beginning with the mining of raw material. Thereafter, solid wastes are generated at every step in the process as raw materials are converted to goods for consumers. It is clear from Figure 1 that one of the best ways to reduce the amount of solid wastes to be disposed is to reduce the consumption of raw materials and to increase the rate of recovery and reuse of waste materials.

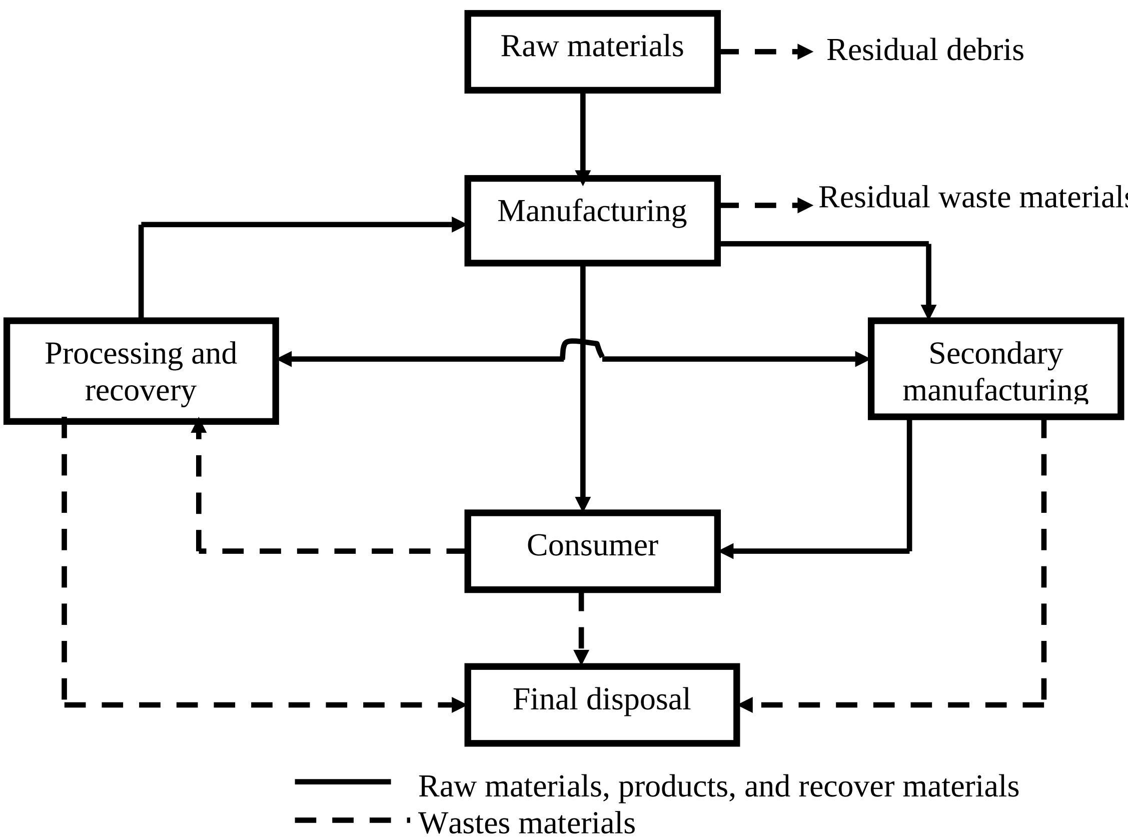


Figure 3: Generalized flow of materials and the generation of solid wastes in society[4]

(2) Reduction in raw materials usage: If a reduction in the usage of raw materials is to occur either an input or output must be reduced. Reduced raw materials usage can effectively reduce the quantity of municipal and industrial wastes generated.

(3) Reduction in solid waste quantities: Reduction in the quantities of solid waste can occur in several ways: (a) the amount of material used in the manufacture of a product can be reduced, (b) the useful life of a product can be increased, and (c) the amount of materials used for packaging and marketing consumer goods can be reduced.

(4) Reuse of solid waste materials: Reuse (or recycling) of waste materials now occurs most commonly in those situations where a product has utility in more than one application. For example, the paper bags used to bring home groceries are used to store household waste prior to placing them in the containers used for the storage and collection. Soup and vegetable containers are used to store cooking grease. Newspapers are used to start fire in the fireplaces. The impact of the above actions on the generation of solid wastes is minimal.

(5) Materials recovery: A number of materials present in the municipal solid wastes are suitable for recovery and reuse. The materials those are most commonly recovered from solid wastes are listed in Table 1(a). The most recent recovery upto 2012 is shown in Table 1(b).

Table 1(a): Materials recovery in the USA in 1975, 2000, and 2001 by category[3]

Materials Category	Gross Discards*			Materials Recycled					
				Quantity*			Percent		
	1975	2000	2001	1975	2000	2001	1975	2000	2001
Paper	44.1	86.7	81.9	6.8	39.4	36.7	15.4	45.4	44.9
Glass	13.7	12.8	12.6	0.4	2.9	2.4	2.9	23.0	19.1
Metals	12.7	18.0	18.1	0.6	6.4	6.3	4.7	35.4	34.5
Ferrous	(11.3)	(13.5)	(13.5)	(0.5)	(4.6)	(4.6)	(4.4)	(34.0)	(33.8)
Aluminum	(1.0)	(3.2)	(3.2)	(0.1)	(0.9)	(0.8)	(10.0)	(27.4)	(24.5)
Other nonferrous**	(0.4)	(1.4)	(1.4)	(0.0)	(0.9)	(0.9)	(0.0)	(66.9)	(64.8)
Plastics	4.4	24.7	25.4	0.0	1.3	1.4	0.0	5.4	5.5
Rubber and Leather	3.5	6.4	6.5	0.2	0.8	1.1	7.1	12.2	17.4
Textiles	2.1	9.4	9.8	0.0	1.3	1.4	0.0	13.5	14.6
Wood	4.8	12.7	13.2	0.0	0.5	1.3	0.0	3.8	9.5
Other	0.1	4.0	4.2	0.0	0.9	0.9	0.0	21.3	20.7
Total nonfood product waste	**85.4**	**174.7**	**171.5**	**8.0**	**53.4**	**51.4**	**9.3**	**30.6**	**30.0**
Food waste	22.8	25.9	26.2	0.0	0.7	0.7	0.0	2.6	2.8
Yard waste	26.0	27.7	28.0	0.0	15.8	15.8	0.0	56.9	56.5
Miscellaneous organic wastes	1.9	3.5	3.5	0.0	0.0	Neg.	0.0	0.0	Neg.
Total MSW	**136.1**	**231.9**	**229.2**	**8.0**	**69.9**	**68.0**	**5.9**	**30.1**	**29.7**

* Million tons per year

** Includes lead from lead-acid batteries.

Table 1(b): Materials recovery in the USA from 1960-2012 by category[3]

	Thousands of Tons									
Materials	**1960**	**1970**	**1980**	**1990**	**2000**	**2005**	**2008**	**2010**	**2011**	**2012**
Paper and Paperboard	5,080	6,770	11,740	20,230	37,560	41,960	42,940	44,570	45,900	44,360
Glass	100	160	750	2,630	2,880	2,590	2,810	3,130	3,170	3,200
Metals										
Ferrous	50	150	370	2,230	4,680	5,020	5,330	5,770	5,460	5,550
Aluminum	Neg.	10	310	1,010	860	690	720	680	720	710
Other Nonferrous	Neg.	320	540	730	1,060	1,280	1,340	1,400	1,370	1,360
Total Metals	*50*	*480*	*1,220*	*3,970*	*6,600*	*6,990*	*7,390*	*7,850*	*7,550*	*7,620*
Plastics	Neg.	Neg.	20	370	1,480	1,780	2,140	2,500	2,660	2,800
Rubber and Leather	330	250	130	370	820	1,050	1,270	1,320	1,350	1,350
Textiles	50	60	160	660	1,320	1,830	1,950	2,010	2,020	2,250
Wood	Neg.	Neg.	Neg.	130	1,370	1,830	2,120	2,280	2,350	2,410
Other **	Neg.	300	500	680	980	1,210	1,280	1,330	1,310	1,300
Total Materials in Products	5,610	8,020	14,520	29,040	53,010	59,240	61,900	64,990	66,310	65,290
Other Wastes										
Food Waste	Neg.	Neg.	Neg.	Neg.	680	690	800	970	1,270	1,740
Yard Trimmings	Neg.	Neg.	Neg.	4,200	15,770	19,860	21,300	19,200	19,300	19,590
Miscellaneous Inorganic Wastes	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.	Neg.
Total Other Wastes	Neg.	Neg.	Neg.	4,200	16,450	20,550	22,100	20,170	20,570	21,330
Total MSW Recovered - Weight	5,610	8,020	14,520	33,240	69,460	79,790	84,000	85,160	86,880	86,620

(6) Energy recovery: Since about 70% of the components that comprise solid waste are organic, the potential for the recovery of energy is high. The energy contained in the organic matter must be converted to a form that can be used more easily. Recovery of heat by burning the organic materials in solid waste is a good example of energy recovery.

(7) Day-to-day solid waste management: Day-to-day management of solid waste is a complex and costly undertaking. The direct activities that must be considered and coordinated on a daily basis include waste generation rates, on-site storage, collection, transfer and transport, processing and recovery, and final disposal. The indirect activities that are associated directly with the management of solid waste include: financing, operations, equipment, personal, cost accounting and budgeting, contract administration, ordinances and guidelines, and public communications. The relationship between the direct activities is shown in Figure 4. The solid waste management hierarchy is shown in Figure 5.

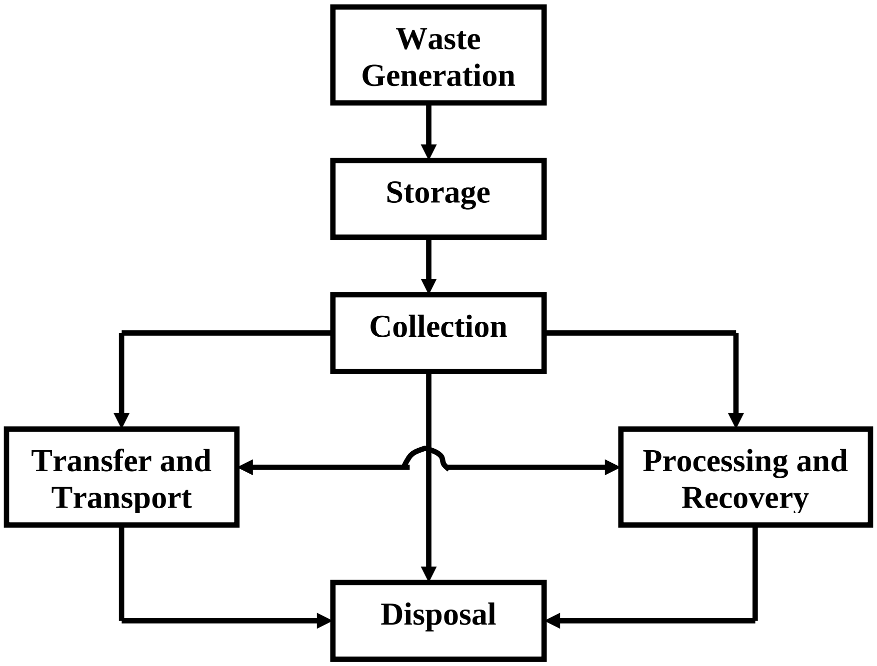


Figure 4: Interrelationship between the direct activities of solid waste management system[4]

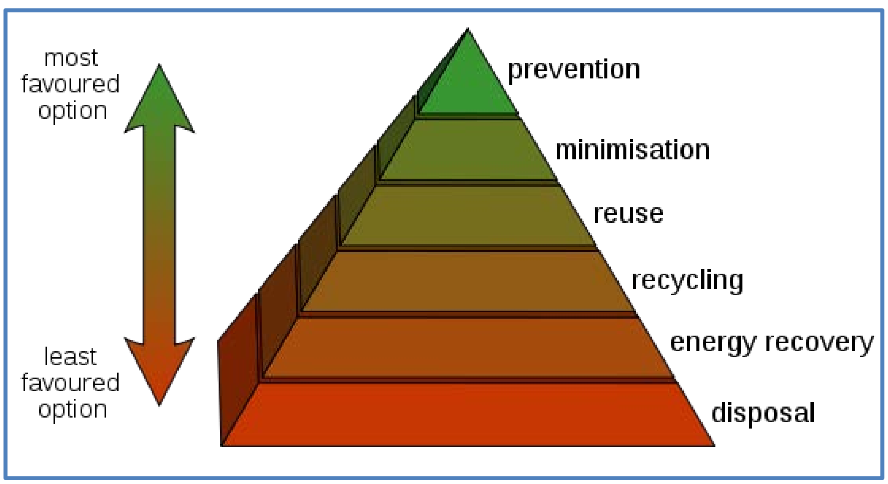


Figure 5(a): Waste management hierarchy[3]

Recent changes in EPA shows the following hierarchy[3] (USEPA, 2017):

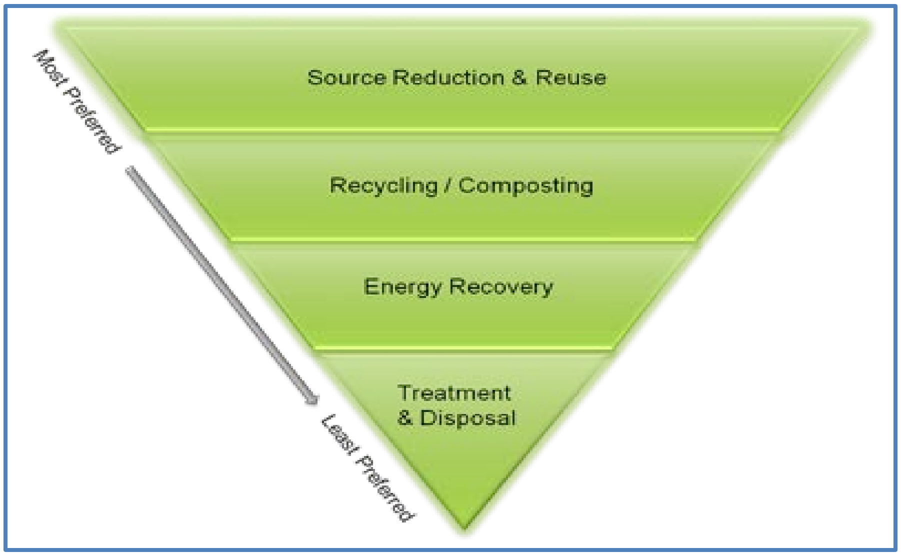


Figure 5(b): Waste management hierarchy based on recent changes[3]

5. Solid Waste Category

Three general categories of solid waste are considered: (1) Municipal Solid Waste (MSW), (2) Industrial Waste, and (3) Hazardous Waste.

MSW may be categorized as:

- Garbage = food waste (e.g., milk cartons and coffee grounds),
- Rubbish = combustible with some inert
- Refuse = 50/50 mix of Garbage & Rubbish (e.g., metal scrap, wall board, and empty containers),
- Trash = 100% combustible

Wastes can also be designated by generator type, i.e., the source or industry that generates the waste stream as follows:

(1) Municipal waste,
(2) Industrial waste,
(3) Hazardous waste,
(4) Medical waste,
(5) Universal waste,
(6) Construction and Demolition Debris (CDD) waste
(7) Radioactive waste,
(8) Mining waste, and
(9) Agricultural waste.

In the United States, most of the waste groupings listed above are indeed managed separately, as most are regulated under separate sets of federal and state regulations.

(1) **Municipal Solid Waste (MSW):** Municipal solid waste is normally composed of residential, commercial, and institutional wastes and residues derived from combustion of these wastes.

(a) **Residential Solid Waste:** Wastes generated from household activities that include but not limited to garbage (food waste), trash and refuse.
Garbage: Wastes that are readily putrescible materials composed of animal, fruit, vegetable residues resulting from the handling, preparation, cooking, and eating of foods or other organic matter.
Trash: Wastes that are combustible and noncombustible and is used interchangeably with the term rubbish.
Refuse: All solid waste products having the character of solids rather than liquids and which are composed of wholly or partially of materials such as garbage, trash, rubbish litter, residues from clean up of spills or contamination, or other discarded materials.
Rubbish: All wastes that are combustible or slowly putrescible discarded materials which include but are not limited to trees, wood, leaves, trimmings from shrubs or trees, printed matter, plastic and paper products, grass, rags and other combustible or slowly putrescible materials not included under the term "garbage".
Putrescible Waste: Solid wastes that contain organic materials capable of being decomposed by microorganisms and cause odor.

(b) **Commercial Solid Waste:** All solid waste generated by establishments engaged in business operations other than manufacturing or construction. This category includes but is not limited to, solid waste resulting from the operation of stores, markets, office buildings, restaurants, and shopping centers.

(c) **Institutional Solid Waste:** All solid wastes emanating from institutions, such as, but not limited to, hospitals, nursing homes, orphanages, and public and private schools. It can include regulated medical waste from healthcare facilities and research facilities that must be managed as a regulated medical waste.

Sources of MSW: Typical sources and the types of solid wastes are listed in Table 2.

Table 2: Typical sources of municipal solid wastes.

Source	Typical facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single family and multifamily dwellings, low-, medium-, and high-rise apartments, etc.	Food wastes, rubbish, ashes, special wastes
Commercial	Stores, markets, office buildings, restaurants, hotels, motels, print shops, auto repair shops, medical facilities, institutions, shopping centers, etc.	Food wastes, rubbish, ashes, special wastes, construction and demolition wastes, occasionally hazardous wastes.
Open area	Streets, alleys, parks, vacant lots, playgrounds, beaches, highways, recreation areas, etc.	Special wastes and rubbish
Treatment plant sites	Water, wastewater, and industrial treatment processes, etc.	Treatment plant wastes, primarily composed of residual sludges.

6. Characteristics of MSW

MSW is characterized by the combination of physical and chemical composition of waste.

Physical Composition: Physical composition includes (a) identification of the individual components that make up the MSW, (b) analysis of particle size, (c) moisture content, and (d) density.

(a) **Individual Components of MSW:** Typical individual components of MSW and organic composition of residential wastes are listed in Tables 3 and 4 and shown in Figures 6 and 7.

Table 3: Typical composition of municipal solid waste[2]

Component	Percent by mass (Range, typical, and perspective)			
	Range	Typical	Davis, California[(a)]	Merida, Venezuela[(b)]
Food waste	6 - 26	14	8.3	27.4
Paper	15 - 45	34	35.8	15.5
Cardboard	3 -15	7	10.9	13.0
Plastics	2 - 8	5	6.9	4.6
Textiles	0 - 4	2	2.5	2.3
Rubber	0 - 2	0.5	2.5	0.4
Leather	0 - 2	0.5	0.7	1.3
Garden trimmings	0 - 20	12	10.8	5.8
Wood	1 - 4	2	1.9	3.6
Miscellaneous organics	0 - 5	2	2.0	0.6
Glass	4 - 16	8	7.5	10.3
Tin cans	2 - 8	6	5.1	8.3
Non-ferrous metals	0 - 1	1	1.6	0.1
Ferrous metals	1 - 4	2	2.2	1.2
Dirt, ashes, brick etc.	0 - 10	4	1.3	5.6

(a) Based on measurements made during the month of October over a 5-year period (1978-1982)
(b) Based on measurements made during the month of July over a 3-year period (1978-1980)

Table 4: Typical organic composition of residential refuse (% dry weight).

Year / Composition	1989	1995	1997	1998	2000	2001
Cellulose	51.2	38.5	28.5	48.2	36.7	43.9
Hemicellulose	11.9	8.7	9.0	10.6	6.7	10.0
Lignin	15.2	28.0	23.1	14.5	13.6	25.1
CH:L ratio	4.15	1.68	1.64	4.06	3.19	2.15

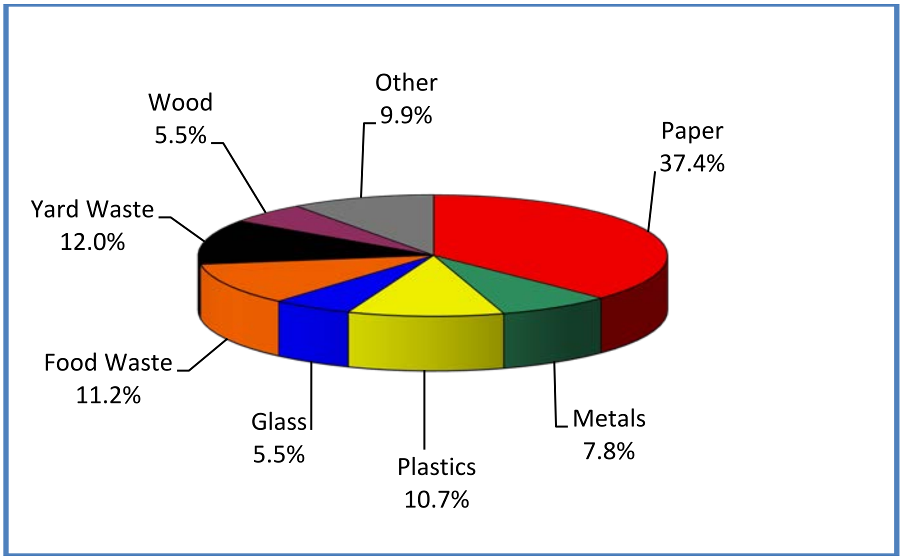


Figure 6: Composition of typical MSW.

Source: Lecture slides of EPA Bioreactor Landfill Seminar in Arlington, VA, February 27-28, 2003. Paper, yard waste and food wastes are comprised of cellulose and hemicellulose. These two components are converted to CH_4 and CO_2 by bacteria under anaerobic condition.

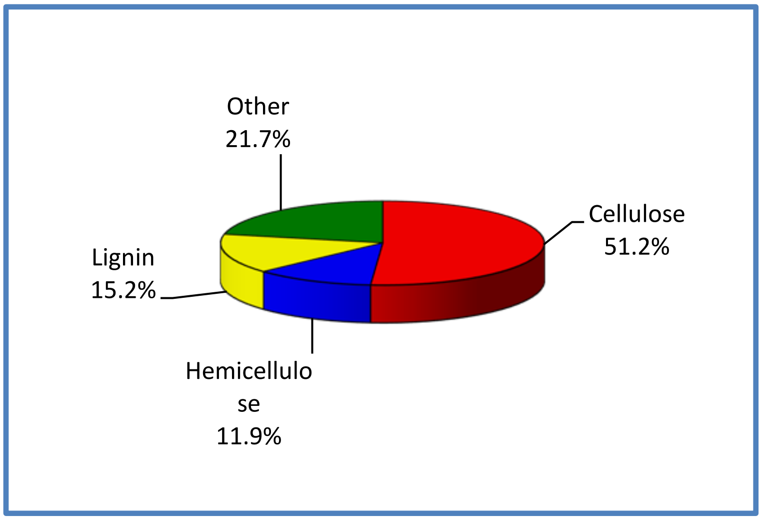


Figure 7: Typical organic composition of residential refuse.

(b) Particle Size: The size of the component materials in solid wastes is of importance in the recovery of materials, especially with mechanical means such as trommel screens and magnetic separators. A general indicator of the particle size distribution, by longest dimension and ability to pass a sieve, may be obtained from the data presented in Figures 8 and 9.

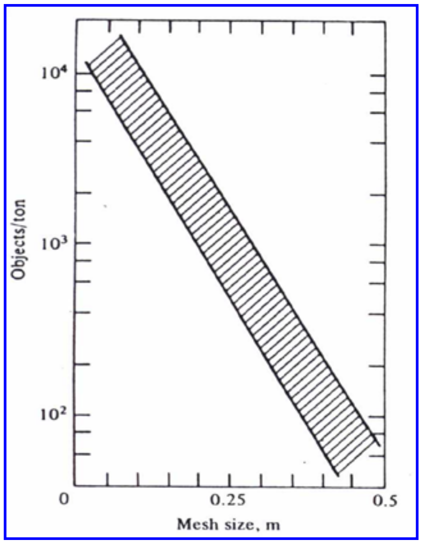


Figure 8: Typical size of individual components comprising solid wastes[2]

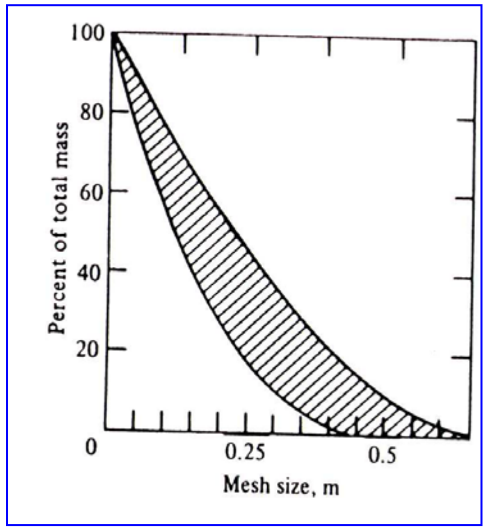


Figure 9: Number of individual component of a given size per ton of MSW[2]

The size of the component materials in solid wastes is important for improving the rate of chemical reactions; in other words, smaller particle sizes provide greater surface area and thus more rapid reaction with microorganisms in a compost pile, or more rapid combustion in an incinerator. Size distribution is also an important consideration in the recovery of materials, for example, with the use of processing equipment such as a trommel screen or a magnetic separator. MSW tends to stratify vertically when mixed, with smaller and denser components migrating to the bottom of a pile and lighter, bulkier objects migrating to the top. Such stratification has implications for efficient combustion on a traveling grate in a boiler or for materials separation in a MRF.

The size (i.e., "diameter") of a waste component may be calculated by any of the following equations:

$$D = l;\quad D=(l+w+h)/;\quad D = (l + w)/2;\quad D = (lw)^{1/2};\ \text{and}\quad D = (lwh)^{1/3}$$

where, D is the diameter, l the length, w the width and h the height. Typical particle size distributions of MSW are shown below*.

Component	Size Range (mm)	Typical (mm)
Food	0 – 200	100
Paper and cardboard	100 – 500	350
Plastics	0 – 400	200
Glass	0 – 200	100
Metals	0 – 200	100
Clothing and textiles	0 – 300	150
Ashes, dust	0 – 100	25

* MSW contains particles having a wide range of individual sizes.

(c) Moisture Content: The moisture content of solid wastes usually is expressed as the mass of moisture per unit mass of wet or dry material. To obtain the dry mass, the solid-waste material is dried in an oven at 77°C (170°F) for 24 hours. If a = initial mass of sample as delivered and b = mass of sample after drying, the wet-mass moisture content (MC) is expressed as follows:

$$MC = \left(\frac{a-b}{a}\right)x100\% \quad (1)$$

and the dry-mass moisture content is expressed as follows:

$$MC = \left(\frac{a-b}{b}\right)x100\% \quad (2)$$

Typical moisture content of municipal solid waste components is listed in Table 5.

Table 5: Typical moisture content of municipal solid waste components[2]

Component	Percent Moisture	
	Range	Typical
Food waste	50 - 80	70
Paper	4 - 10	6
Cardboard	4 - 8	5
Plastics	1 - 4	2
Textiles	6 - 15	10
Rubber	1 - 4	2
Leather	8 - 12	10
Garden trimmings	30 - 80	60
Wood	15 - 40	20
Miscellaneous organics	10 - 60	25
Glass	1 - 4	2
Tin cans	2 - 4	3
Non-ferrous metals	2 - 4	2
Ferrous metals	2 - 6	3
Dirt, ashes, brick etc.	6 - 12	8
Municipal solid waste	15 - 40	20

Example 1: Estimate the moisture content (both dry and wet basis) of a solid-waste sample with the following composition.

Composition	% by mass	Moisture content (%)	% by dry mass
Food wastes	15	70	
Paper	45	6	
Cardboard	10	5	
Plastics	10	2	
Garden trimmings	10	60	
Wood	5	20	
Tin cans	5	3	

Solutions:

Considering 100 kg of wet waste

Composition	Wet mass (kg)	Moisture content (%)	Dry mass (kg)	
Food wastes	15	70	15 x (1 - 0.70) =	4.50
Paper	45	6	45 x (1 - 0.06) =	42.30
Cardboard	10	5	10 x (1 - 0.05) =	9.50
Plastics	10	2	10 x (1 - 0.02) =	9.80
Garden trmmings	10	60	10 x (1 - 0.60) =	4.00
Wood	5	20	5 x (1 - 0.20) =	4.00
Tin cans	5	3	5 x (1 - 0.03) =	4.85
Σ	100			78.95

wet mass of the waste, a = **100** kg

dry mass of the waste, b = **78.95** kg

Moisture content in dry basis = $\left(\frac{a-b}{b}\right)\times 100\%$

= {(100-78.95)/78.95} x 100

= 26.66% Ans.

Moisture content in wet basis = $\left(\frac{a-b}{a}\right)\times 100\%$

= {(100-78.95)/100} x 100

= 21.05% Ans.

(d) **Density**

Typical densities for of municipal solid waste components are listed in Table 6.

Table 6: Typical density of municipal solid waste components[2]

Component	Density, kg/m³ Range	Typical
Food waste	120 -480	290
Paper	30 - 130	85
Cardboard	30 - 80	50
Plastics	30 - 130	65
Textiles	30 - 100	65
Rubber	90 - 200	130
Leather	90 - 260	160
Garden trimmings	60 - 225	105
Wood	120 - 320	240
Miscellaneous organics	90 - 360	240
Glass	160 - 480	195
Tin cans	45 - 160	90
Non-ferrous metals	60 - 240	160
Ferrous metals	120 - 1200	320
Dirt, ashes, brick etc.	320 - 960	480
Municipal solid waste		
• Uncompacted	90 - 180	130
• Compacted	180 - 450	300
• In Landfill		
◦ Normally compacted	350 - 550	475
	600 - 750	600

Component	Density, kg/m³ Range	Typical
• Well-compacted		

Example 2: Estimate the "as-discarded" density of a solid waste sample with the composition given below:

Composition	% by mass	Typical density (kg/m^3)	Volume (m^3)
Food wastes	15	290	
Paper	45	85	
Cardboard	10	50	
Plastics	10	65	
Garden trimmings	10	105	
Wood	5	240	
Tin cans	5	90	

Solutions:

Considering 100 kg of waste

Composition	Mass (kg)	Typical Density (kg/m^3)	Volume (m^3)	
Food wastes	15	290	15/290 =	0.0517
Paper	45	85	45/85 =	0.5294
Cardboard	10	50	10/50 =	0.2000
Plastics	10	65	10/65 =	0.1538
Garden trmmings	10	105	10/105 =	0.0952
Wood	5	240	5/240 =	0.0208
Tin cans	5	90	5/90 =	0.0556
Σ	100			1.1066

Density of the "as-discraded" solid waste = 100 kg/1.1066 m^3

= 90.3662 kg/m^3 **Ans.**

Chemical Composition: Information on the chemical composition of solid wastes is important in evaluating alternative processing and energy recovery options. If solid wastes are to be used as fuel, the following four important properties are to be known:

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

Typical proximate and ultimate chemical analysis data for the components in municipal solid wastes are listed in Table 7.

Table 7: Proximate and ultimate chemical analysis of municipal solid wastes[2]

	Value, Percent by mass	
Proximate Analysis	**Range**	**Typical**
Moisture	14 - 40	20
Volatile matter	40 - 60	53
Fixed carbon	5 - 12	7
Noncombustibles	15 - 30	20
Ultimate Analysis (Combustible components)		
Carbon	40 - 60	47.0
Hydrogen	4 - 8	6.0
Oxygen	30 - 50	40.0
Nitrogen	0.2 - 1.0	0.8
Sulfur	0.05 - 0.3	0.2
Ash	1 - 10	6.0
Heating value as discarded basis		
Organic fraction, kJ/kg	12,000 - 16,000	14,000
Total, kJ/kg	8,000 - 12,000	10,500

Energy Content: Typical data on energy content and inert residue for solid wastes are reported in Table 8. Energy values may be converted to a dry basis by using the following equation.

$$kJ/kg(dry) = kJ/kg(discarded) \times \frac{100}{100 - \%moisture}$$

The corresponding equation on an ash-free dry basis is:

$$kJ/kg(dry) = kJ/kg(discarded) \times \frac{100}{100 - \%moisture - \%ash}$$

Example 3: Estimate the energy content of a solid-waste sample with the composition given below. What is the energy content on a dry basis and on an ash-free basis?

Composition	% by mass	Energy Content (kJ/kg)	Total Energy (kJ)
Food wastes	15	4,650	
Paper	45	16,750	
Cardboard	10	16,300	
Plastics	10	32,600	
Garden trimmings	10	6,500	
Wood	5	18,600	
Tin cans	5	700	

Solutions:

Considering 100 kg of solid waste

Composition	Waste mass (kg)	Energy Content (kJ/kg)	Total Energy (kJ)	
Food wastes	15	4,650	15x4,650 =	69,750
Paper	45	16,750	45x16,750 =	753,750
Cardboard	10	16,300	10x16,300 =	163,000
Plastics	10	32,600	10x32,600 =	326,000
Garden trmmings	10	6,500	10x6,500 =	65,000
Wood	5	18,600	5x18,600 =	93,000
Tin cans	5	700	5x700 =	3,500
Σ	100			**1,474,000**

Energy content as discarded = kJ/ 100 kg = 14,740 kJ/kg

Based on the problem 1, the dry-basis moisture content = 21.05 %

The energy content on a dry basis = $kJ/kg\,(\text{discarded}) \times \frac{100}{100 - \%\text{moisture}}$

= 14740 kJ/kg x 100/(100 - 21.05)

= 18,670 kJ/kg **Ans.**

Assuming ash content = **5.00** %

The energy content on an ash-free dry basis = $kJ/kg\,(\text{discarded}) \times \frac{100}{100 - \%\text{moisture} - \%\text{ash}}$

= 14740 kJ/kg x 100/(100 - 21.05 - 5)

= 19,932 kJ/kg **Ans.**

Table 8: Typical data on inert residue and energy content of municipal solid wastes[2]

Component	Inert residue, percent (After combustion)		Energy as discarded, kJ/kg	
	Range	Typical	Range	Typical
Food waste	2 - 8	5	3,500 - 7,000	4,650
Paper	4 - 8	6	11,600 - 18,600	16,750
Cardboard	3 - 6	5	13,950 - 17,450	16,300
Plastics	6 - 20	10	27,900 - 37,200	32,600
Textiles	2 - 4	2.5	15,100 - 18,600	17,450
Rubber	8 - 20	10	20,900 - 27,900	23,250
Leather	8 - 20	10	15,100 - 19,800	17,450
Garden trimmings	2 - 6	4.5	2,300 - 18,600	6,500
Wood	0.6 - 2	1.5	17,450 - 19,800	18,600
Miscellaneous organics	2 - 8	6	11,000 - 26,000	18,000
Glass	96 - 99	98	100 - 250	150
Tin cans	96 - 99	98	250 - 1,200	700
Non-ferrous metals	90 - 99	96	---	---
Ferrous metals	94 - 99	98	250 - 1,200	700
Dirt, ashes, brick etc.	60 - 80	70	23,00 - 11,650	7,000
Municipal solid waste			9,300 - 12,800	10,500

Chemical Content: Representative data on the ultimate analysis of typical municipal solid waste components are presented in Table 9. If energy values are not available, approximate values may be determined by using the following equation which is known as the modified Dulong formula and the data in the Table 9.

$$kJ/kg = 337C + 1428(H - \tfrac{O}{8}) + 9S$$

Where, C = Carbon content in % by mass, H = Hydrogen content in % by mass, O = Oxygen content in % by mass, and S = Sulfur content in % by mass.

Example 4: A mixed waste was analyzed and found the followings:
C = 28%; H = 8%; O = 35%; and S = 29%. Estimate the energy content of a mixed solid-waste sample using Dulong formula.

Solution:
We know that the content by Dulong formula is $kJ/kg = 337C + 1428(H - \tfrac{O}{8}) + 9S$

∴ **energy content in kJ/kg =** 337 x 28+1,428(8 - 35/8)+9 x 29 **= 14,873.5 kJ/kg Ans.**

Table 9: Typical data on ultimate analysis of the combustible components in municipal solid wastes.

Components	Percent by mass (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food waste	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
Plastics	60.0	7.2	22.8	--	--	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5

Components	Percent by mass (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
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
Miscellaneous organics	48.5	6.5	37.5	2.2	0.3	5.0
Dirt, ashes, brick etc.	26.3	3.0	2.0	0.5	0.2	68.0

(2) **Industrial Waste:** Industrial wastes are those wastes arising from industrial activities and typically include rubbish, ashes, construction, demolition, and debris (CDD), special wastes, hazardous wastes.

Construction Wastes: All solid wastes that are produced or generated during construction, remodeling, or repair of pavements, houses, commercial buildings, and other structures. Construction Wastes include, but are not limited to lumber, wire, sheetrock, broken bricks, shingles, glass, pipes, concrete, paving materials, and metal and plastics if the metal or plastics are a part of the materials of construction or empty container for such materials. Paints, coatings, solvents, asbestos, any liquid, compressed gases or semi-liquids and garbage are not construction wastes.

Ash or Bottom Ash: Ash or slag that has been discharged from the bottom of the combustion unit after combustion.

Special Wastes: Solid wastes that are difficult to handle due to its physical or chemical characteristics, require special precautions because of hazardous properties or the nature of the waste creates waste management problems in normal MSW operations. Special wastes include, but are not limited to ash, foundry sand, metal scrap, drums (non-RCRA empty), PCBs, leather straps (non-MSW, non-HW), street sweepings, roadside litter, catch-basin debris, dead animals, and abandoned vehicles.

(3) Hazardous Waste (HW): Wastes that pose a substantial danger immediately or over a period of time to human, plant, and animal life are classified as hazardous waste. The further definitions, generation, handling, transporting, treatment, disposal, and permitting requirements for hazardous waste will be discussed in the subsequent lecture.

7. Solid Waste Generation and Perspective

Solid Waste Generation

Those activities in which materials are identified as no longer being of value and are either thrown away or gathered together for disposal. Typical unit waste generation rates for municipal and selected commercial and industrial sources are reported in Tables 10 and 11. Where generation rate data are not available, the data presented in Table 10 can be used for purposes of estimation with reasonable confidence.

Table 10: Typical per capita solid waste generation rate in the United States[2]

Sources	Unit rate, kg/capita.day	
	Range	Typical
Municipal*	0.75 - 2.5	1.6
Industrial	0.4 - 1.60	0.9
Demolition	0.05 - 0.4	0.3
Other municipal	0.05 - 0.3	0.2

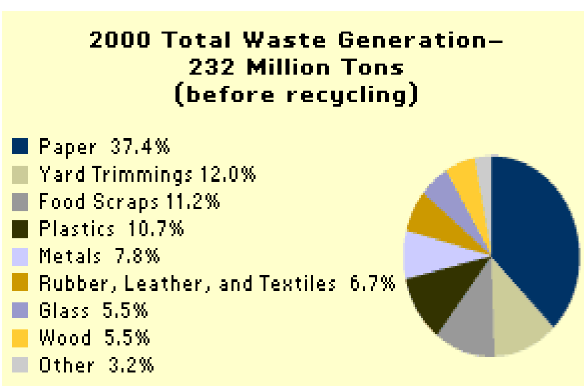
* Includes residential and commercial

Table 11: Typical commercial and industrial unit waste generation rate[2]

Source	Unit	Range
Office buildings	kg/employee.day	0.5 - 1.1
Restaurants	kg/customer.day	0.2 - 0.8
Canned and frozen foods	tonnes/tonne of raw product	0.04 - 0.06
Printing and publishing	tonnes/tonne of raw paper	0.08 - 0.10
Automotive	tonnes/vehicle produced	0.6 - 0.8
Petroleum refining	tonnes/employee.day	0.04 - 0.05
Rubber	tonnes/tonnes of raw rubber	0.01 - 0.3

Solid Waste Perspective

In 1999, U.S. residents, businesses, and institutions produced more than 230 million tons of MSW, which is approximately 4.6 pounds of waste per person per day, up from 2.7 pounds per person per day in 1960. Figure 10(a) shows the total waste generated in 2000 and 2013 before recycling. The trend of waste generation in the USA from 1960-2000 is presented in Figure 10(b).



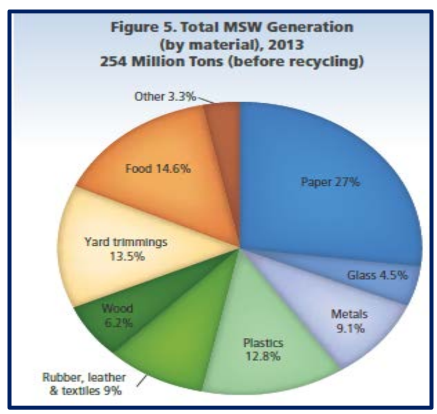


Figure 10(a): Total waste generation in the USA in 2000[3] and 2013

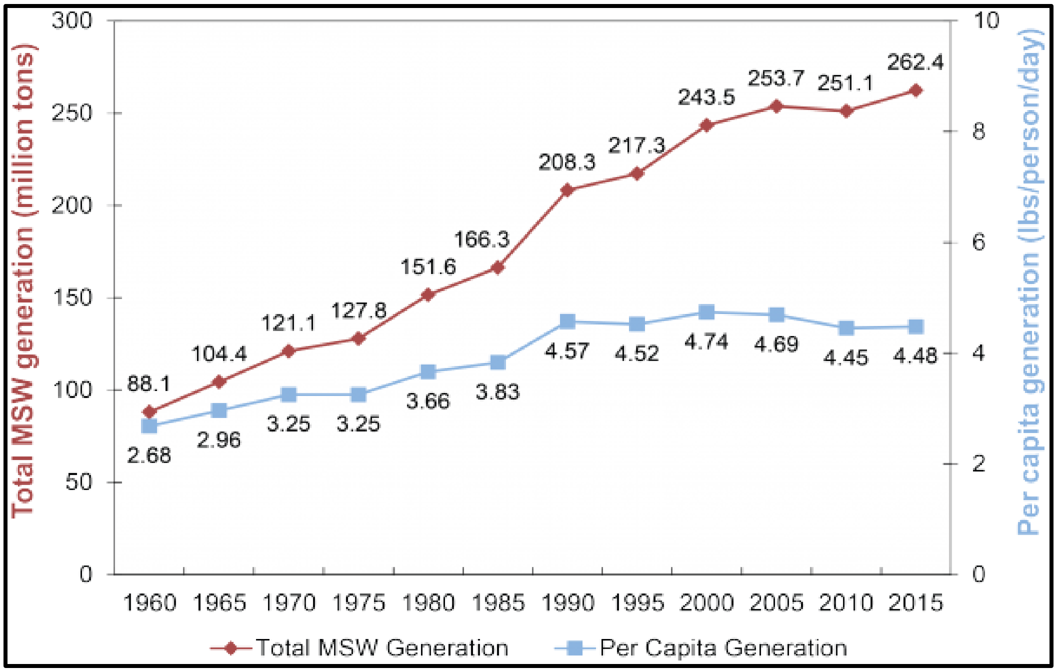


Figure 10(b): The trend of waste generation in the USA from 1960-2015[3]

Several MSW management practices, such as source reduction, recycling, and composting, prevent or divert materials from the wastestream. Source reduction involves altering the design, manufacture, or use of products and materials to reduce the amount and toxicity of what gets thrown away. Recycling diverts items, such as paper, glass, plastic, and metals, from the wastestream. These materials are sorted, collected, and processed and then manufactured, sold, and bought as new products. Composting decomposes organic waste, such as food scraps and yard trimmings, with microorganisms (mainly bacteria and fungi), producing a humus-like substance. Per person per day generation, materials recovery, composting, and discards of municipal solid wastes from 1960 to 2001 are shown in Table 12.

Table 12: Generation, materials recovery, composting, and discards of municipal solid wastes from 1960 to 2001 in the USA[3]

	Pounds per person per day								
	1960	**1970**	**1980**	**1990**	**1995**	**1998**	**1999**	**2000**	**2001**
Generation	2.68	3.25	3.66	4.50	4.40	4.52	4.64	4.52	4.41
Recovery for recycling	0.17	0.22	0.35	0.64	0.94	0.97	1.01	1.04	0.99
Recovery for composting*	Negl.	Negl.	Negl.	0.09	0.20	0.27	0.30	0.32	0.32
Total materials Recovery	0.17	0.22	0.35	0.73	1.14	1.24	1.31	1.36	1.31
Discards after recovery	2.51	3.03	3.31	3.77	3.26	3.28	3.33	3.15	3.10
Population (millions)	**179.979**	**203.984**	**227.255**	**249.907**	**263.168**	**270.561**	**272.691**	**281.422**	**284.797**

*Composting of yard trimmings and food wastes.

The generation of MSW in the USA was approximately 229.2 million tons in 2001 - a decrease of 2.8 million tons from 2000. This is a decrease of 1.2% from 2000 to 2001. Excluding composting, the amount of MSW recovered for recycling increased to 51.1 million tons, an increase of 0.2 million tons from 2000. This is a 0.4% increase in the tons recycled. The tons recovered for composting rose slightly to 16.6 million tons in 2001, up from 16.5 million tons in

2000. The recovery rate for recycling (including composting) was 29.7% in 2001, up from 29.2% in 2000 (Table 1 and Figure 11(a)). MSW generation in 2001 declined to 4.4 pounds per person per day. This is a decrease of 2.2% from 2000 to 2001. The recycling rate in 2001 is 1.3 pounds per person per day. Discards after recycling declined to 3.1 pounds per person per day in 2001. (Table 12 and Figure 11(b)).

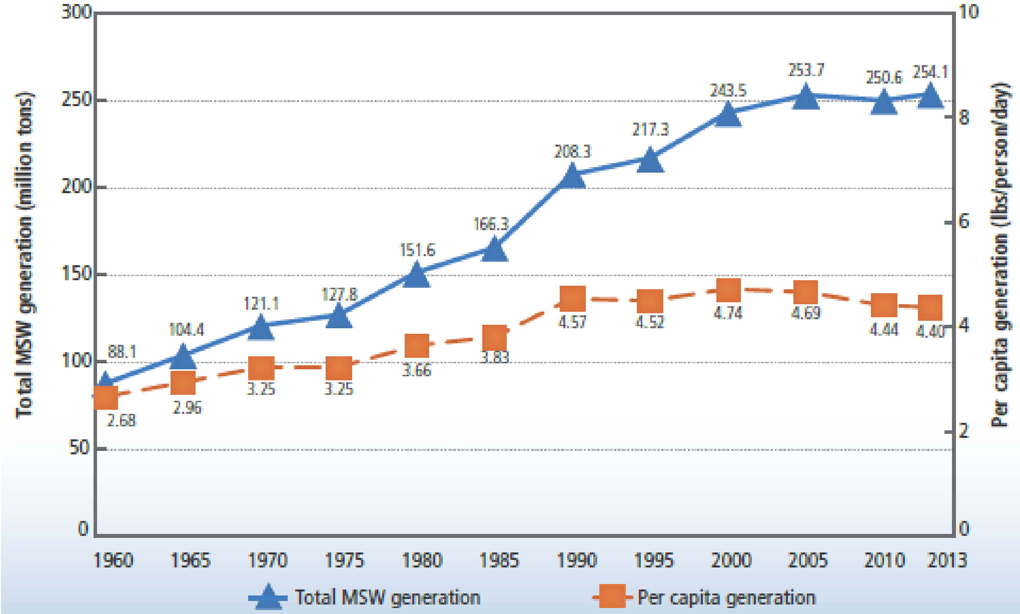


Figure 11(a): Trend of MSW generation rates in the USA from 1960 to 2013[3]

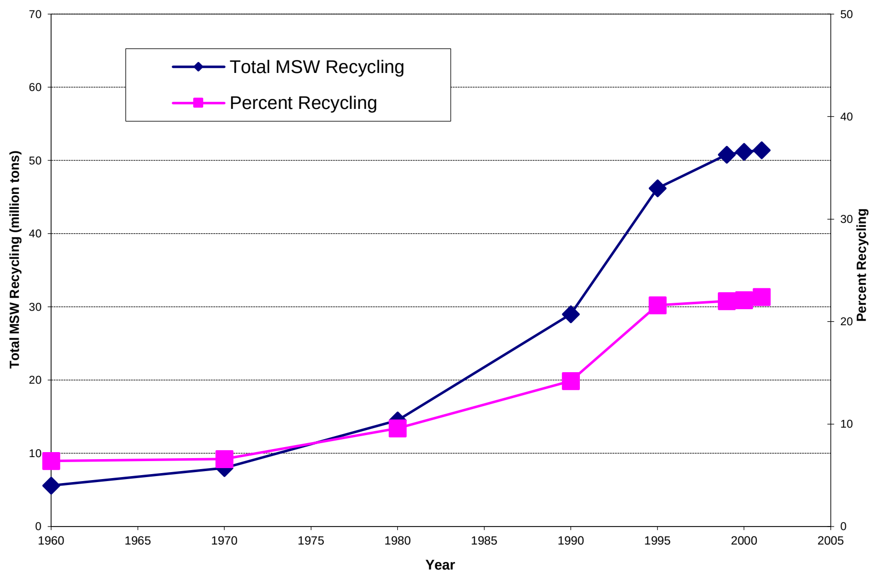


Figure 11(b): Trend of MSW recycling rates from 1960 to 2001[4]

The following graph (Figure 11(c)) compares the trend of MSW generated, recycled, combusted, and landfilled in the USA from 1960-2001.

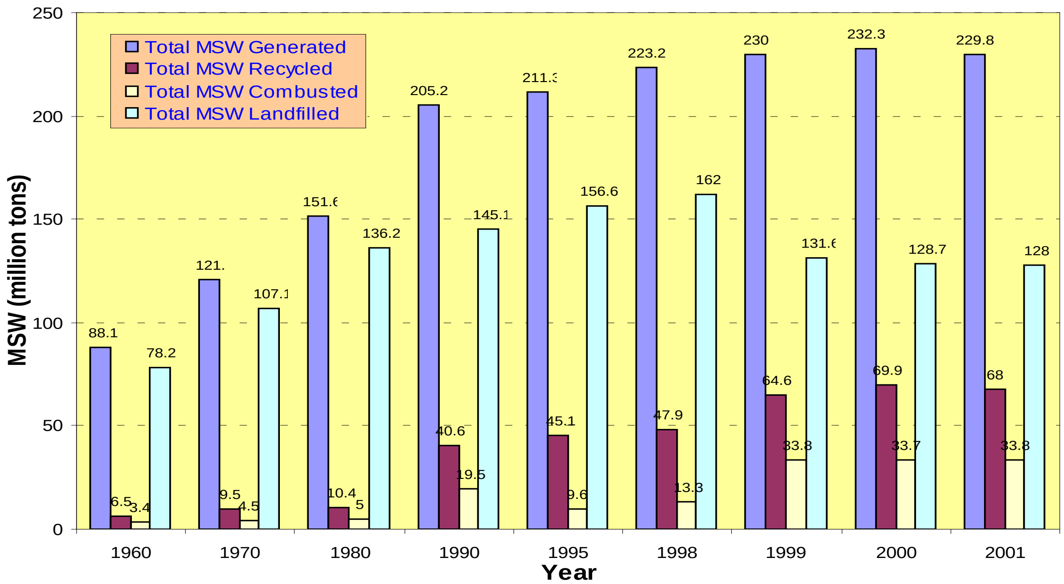


Figure 11(c): The trend of MSW generated, recycled, combusted, and landfilled in the USA from 1960-2001[4]

The following graph (Figure 11(d)) shows the trend of population change, total and per capita MSW generated in the USA from 1960-2001.

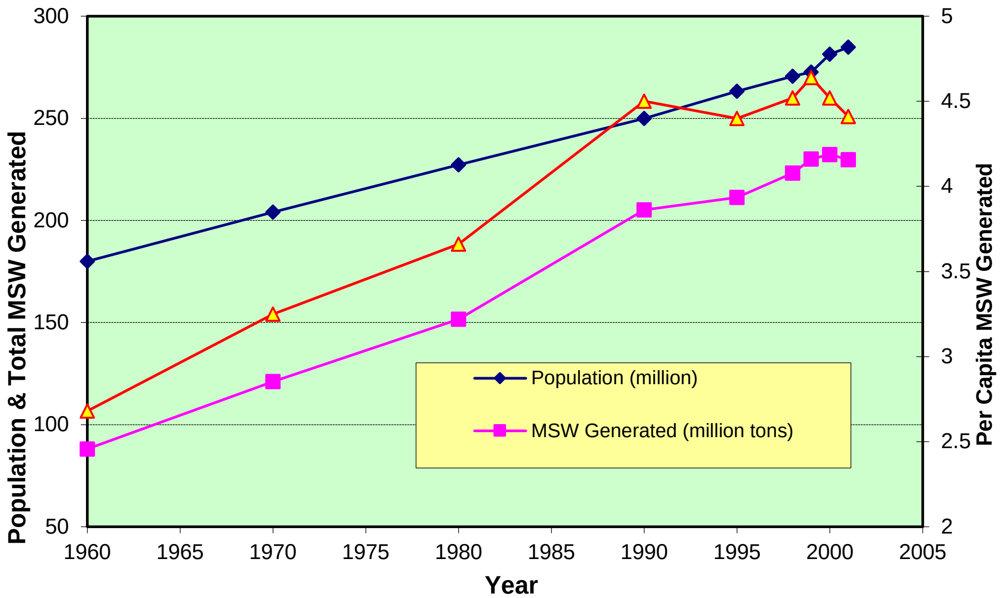


Figure 11(d): The trend of population change and total and per capita MSW generated in the USA from 1960-2001[4]

Example 5: How long will it take (in years) to fill the state of Georgia with a 25-ft depth of solid waste? The waste will come from all over the USA with a population of 312,745,538. Assume average solid waste generation rate as 4.5 lb/capita/day, bulk density of solid waste as 800 lb/cubic yard, and the area of Georgia as 59,425 square miles.

Solutions:

Given,	Population =	312,745,538		Waste Density =		800	lb/cy	= 800 lb/cy x 1cy /27 cft	
								=	**29.630** lb/cft
Generation rate =		4.5	lb/capita/day	Area of GA =		59,425	sq. mile	= 59425 sq. mile x 5280 ^2 sq. ft / 1 sq. mile	
								=	**1,656,673,920,000** sq. ft
Amount of solid waste generated =			312,745,538	x 4.5 =		1,407,354,921	lb/day x 365 day/ year =		513,684,546,165 lb/year
Volumer of solid waste generated =			513,684,546,165 / 29.630	lb/year / lb/cft	=	17,336,853,433	cft/year		
Area occupied by 25-ft depth of waste =			17,336,853,433 / 25	cft/year / ft	=	693,474,137	sq. ft/year		
Number of years to fill GA with 25-ft of waste =			1,656,673,920,000 / 693,474,137	sq. ft / sq. ft/year	=	**2,389**	years **ANS.**		

8. Estimation of Solid Waste Quantities

The quantity and general composition of the waste material that is generated is of critical importance in the design and operation of solid waste management systems. Unfortunately, reliable quantity and composition data are difficult to obtain as most measurements are of the quantities collected or disposed of at a landfill. The following methods are recommended, although any method of estimation is subject to limitations.

Load-Count Analysis: In this method, the quantity and composition of solid wastes are determined by recording the estimated volume and general composition of each load of waste delivered to a landfill or transfer station during a specified period of time. The total mass and mass distribution by composition is determined using average density data for each waste category.

Mass-Volume Analysis: This is similar to the above method with added feature that the mass of each load is also recorded. Unless the density of each waste category is determined separately, the mass distribution by composition must be derived using average density values.

Factors that affect the quantity of municipal solid wastes include:

(1) geographical location,
(2) season of the year,
(3) collection frequency (affects amount collected),
(4) use of kitchen grinders,
(5) characteristics of populace,
(6) extend of salvaging and recycling,
(7) public attitudes,
(8) per capita income,
(9) size of households,
(10) population density, and

(11) legislation.

9. Onsite Handling, Storage, and Processing

Those activities associated with the handling, storage, and processing of solid wastes at or near the point of generation. Depending on the type of collection service, handling may also be required to move loaded containers to the collection point and to return the empty containers to the point where they are stored between collections.

In high-rise apartment buildings wastes are:

(1) picked up by building maintenance personnel or porters from each floor and taken to the basement service area,
(2) taken to the basement by the tenants, or
(3) bagged and placed by the tenants in specially designed chutes with openings located at each floor.

In most office, commercial, and industrial buildings, solid waste that accumulates in the offices or work locations usually are collected in relatively large containers mounted on rollers. Once filled, these containers are removed by means of the service elevator and emptied into:

(1) large storage containers,
(2) compactors used in conjunction with storage containers,
(3) stationary containers, or
(4) other processing equipment such as incinerator.

The factors that must be considered in the on-site storage of solid wastes include:

(1) type of container to be used,
(2) the container location,
(3) public health and aesthetics, and
(4) the collection methods to be used.

10. Solid Waste Collection

Those activities associated with the gathering of solid wastes and the hauling of wastes after collection to the location where collection vehicle is emptied.

Municipal Collection Services: There are three most common collection methods. These are curb, alley, and backyard collection.

Commercial-Industrial Collection Services: The collection services provided to large apartment buildings, residential complexes, and commercial and industrial activities typically is centered around the use of large movable and stationary containers and large stationary compactors. Compactors are of the type that can be used to compress material directly into large containers or to form bales that are then placed in the large containers.

Types of Collection Systems: Based on their mode of operation, collection systems are classified into two categories: hauled-container system and stationary-container system.

Hauled-Container Systems (HSC): Collection systems in which the containers used for the storage of wastes are hauled to the processing, transfer, or disposal site, emptied, and returned to either their original location or some other location are defined as hauled-container systems. There are two main types of hauled-container systems: (1) tilt-frame container, and (2) trash container. The definition sketch for HCS is shown in Figure 12.

Systems that use tilt-frame-loaded vehicles and large containers, often called drop boxes, are ideally suited for the collection of all types of solid wastes and rubbish from locations where the generation rate warrants the use of large containers. Open top containers are used routinely at warehouse and construction sites.

The application of trash trailers is similar to that of tilt-frame container systems. Trash-trailers are better for the collection of especially heavy rubbish, such as sand, timber, and metal scrap, and often are used for the collection of demolition wastes at construction sites.

Stationary-Container Systems (SCS): Collection systems in which the containers used for the storage of wastes remain at the point of waste generation, except when moved for collection are defined as stationary-container systems. Labor requirements for mechanically loaded SCS are essentially the same as for HCS. There are two main types of SCS: (1) those in which self-loading compactors are used, and (2) those in which manually loaded vehicles are used. The definition sketch for SCS is shown in Figure 12.

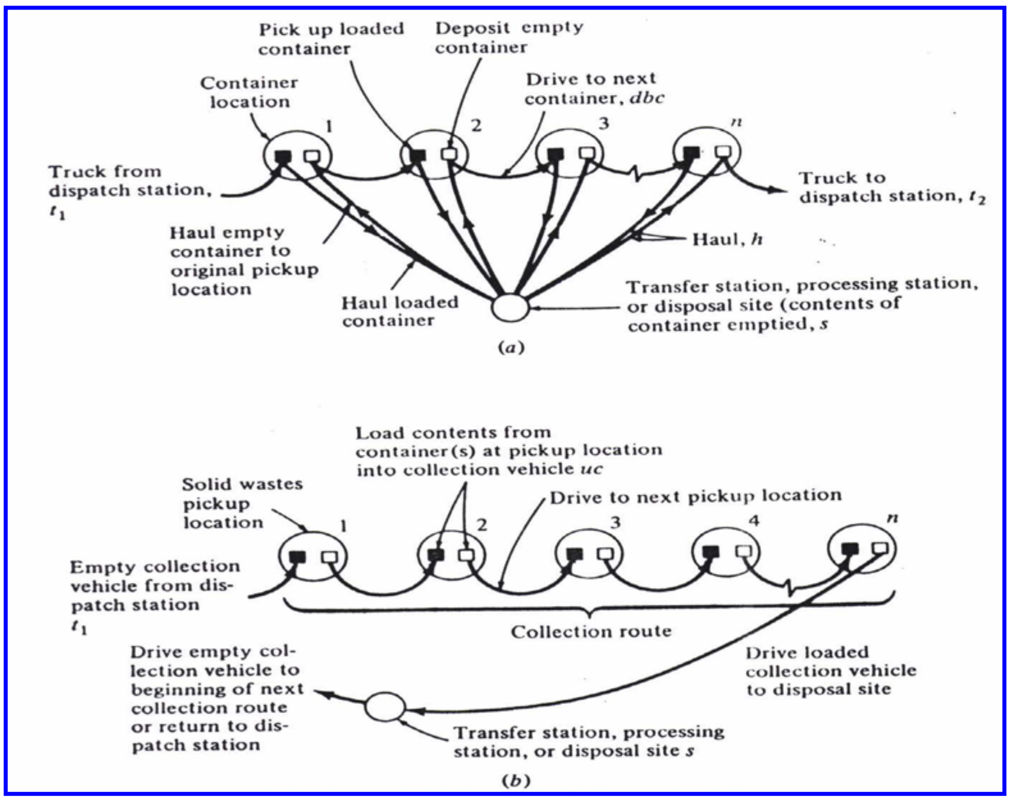


Figure 12: Definition sketch for waste collection system: (a) hauled-container and (b) stationary-container[1]

Vehicle and Labor Requirements: Vehicle and labor requirements are important parameters in waste collection systems. By separating the collection activities into unit operations, it is possible to develop design data and relationships that can be used to establish vehicle and labor requirements for the various collection systems. The activities involved in the collection of solid wastes can be resolved into four units operations: pickup, haul, at-site, and off-route. A typical collection vehicle is shown in Figure 13.

Pickup:

Hauled-container system (P_{hcs}): The time spent picking up the loaded container, the time required to redeposit the container after its contents have been emptied, and the time spent driving to the next container.

Stationary-container system (P_{scs}): The time spent loading the collection vehicle, beginning with the stopping of the vehicle prior to loading the contents of the first container first container, and ending when the contents of the last container to be emptied have been loaded.

Haul:

Hauled-container system (H_{hcs}): The time required to reach the disposal site, starting after a container whose contents are to be emptied has been loaded on the truck, plus the time after leaving the disposal site until the truck arrives at the location where the empty container is to be redeposited. Time spent at the disposal site is not included.

Stationary-container system (H_{scs}): The time required to reach the disposal site, starting after the last container on the route has been emptied or the collection vehicle is filled, plus the time after leaving the disposal site until the truck arrives at the location of the first container to be emptied on the next collection route. Time spent at the disposal site is not included.

At-site: The time spent at the disposal site, including the time spent waiting to unload as well as the time spent unloading.

Off-Route: All time spent on activities that are nonproductive from the point of view of the overall collection operation. Necessary off-route time includes:

(1) time spent checking in and out in the morning and at the end of the day,
(2) time lost due to unavoidable congestion, and
(3) time spent on equipment repairs and maintenance.

Unnecessary off-route time includes time spent for lunch in excess of the stated lunch period and time spent on taking unauthorized coffee breaks, talking to friends, etc.

Figure 13: Typical collection vehicle[1]

Collection Routes: Once the equipment and labor requirements have been determined, collection routes must be laid out so both the work force and equipment are used effectively. In general, the layout of collection routes is a trial-and-error process. However, some factors that should be taken into consideration when laying out routes are as follows:

(1) existing company policies and regulations related to such items as the point of collection and frequency of collection must be identified,
(2) existing system conditions such as crew size and vehicle types must be coordinated,
(3) wastes generated at traffic-congested locations should be collected as early in the day as possible,
(4) sources at which extremely large quantities are generated should be collected during the first part of the day, and
(5) scattered pickup points where small quantities of solid wastes are generated should, if possible, be serviced during one trip or on the same day, if they receive the same collection frequency.

Layout of Routes: The layout of collection routes is a four-step process:

(1) prepare location maps,
(2) prepare data summaries,
(3) lay out preliminary collection routes starting from the dispatch station or where the collection vehicles are parked. Routes should be laid out so that the last location is the nearest the disposal site, and
(4) develop a balanced route.

After the preliminary collection routes have been laid out, the haul distance for each route should be determined. Next, determine the labor requirements per day and check against the available work times per day. After the balanced routes have been established, they should be drawn on the master map. An example of a collection route lay out is illustrated in Figure 14.

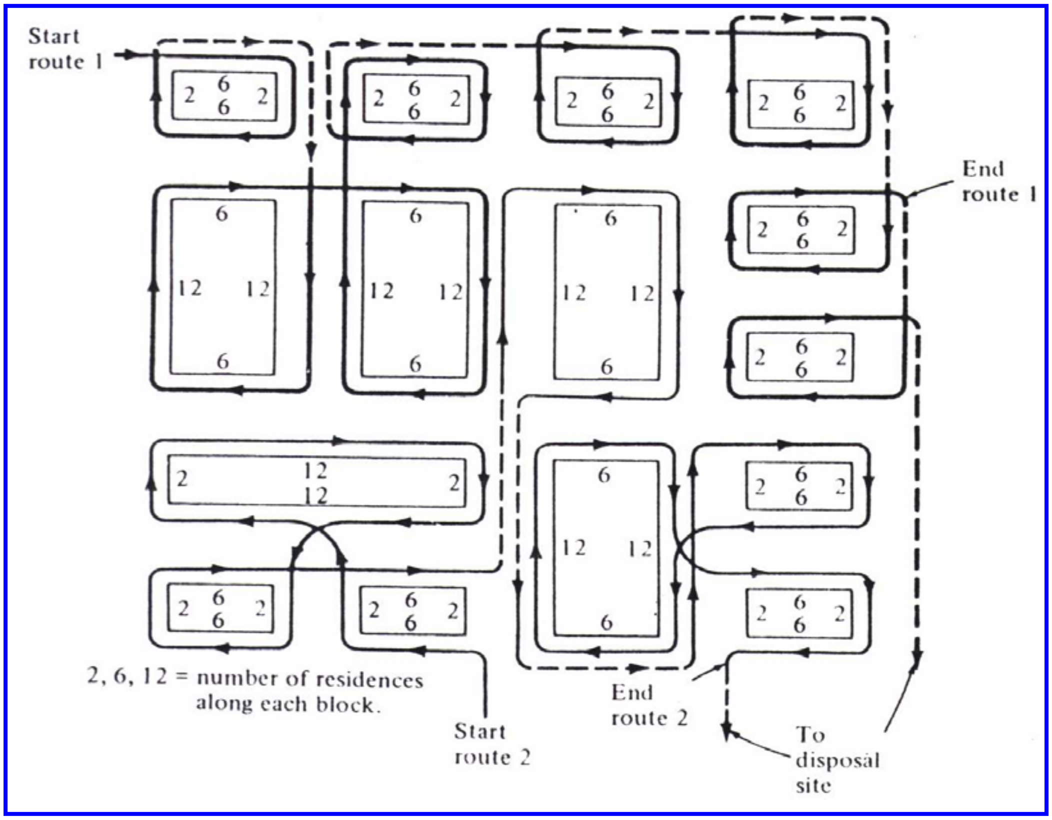


Figure 14: Example lay out of collection routes[1]

Example 6: The City of Atlanta (Population 420,003) has requested you for engineering services in evaluating its solid waste collection system. Determine the mean time per collection stop plus the mean time to reach the next stop, the number of pick up locations per load, and the minimum number of garbage trucks the city must own. The City of Atlanta collection data are as follows:
Average truck capacity = 15 $m^{3;}$ Average observed compaction ratio = 2.54
Crew size = 2; Number of pickups = 1/week (no rear-of-house service)
Average number of cans per stop = 2.65 /week at 0.0652 m^3/can
Average number of residents per stop = 6
Average uncompacted density = 122.0 kg/m^3
Average transport time to disposal site including delays and dumping = 1.5 hours/trip; Average number of trips to disposal site = 2 /day
Rest breaks = 2 at 25.0 minutes; Average maintenance down time = 45.0 minute/day; Average workday = 8.0 hours; Average percent trucks out of service for major repairs = 20%.

$$t_p = \frac{\forall_p}{\forall_T r}\left[\frac{H}{N_d} - \frac{2x}{s} - 2t_d - t_u - \frac{B}{N_d}\right] \qquad N_p = \frac{\frac{H}{N_d} - \frac{2x}{s} - 2t_d - t_u - \frac{B}{N_d}}{t_p} = \frac{V_T r}{V_p}$$

Example 6: Solutions

Average truck capacity =	15	m^3		V_T	15
Average observed compaction ratio =	2.54			r =	2.54
Crew size =	2				2
Number of pickups =	1	/week (no rear-of-house service)			1
Average number of cans per stop =	2.65	/week at	0.0652 m^3/can	2.65	0.065
Average number of residents per stop =	6				6
Average uncompacted density =	122	kg/m3			122
Average transport time to disposal site including delays and dumping =	1.5	hrs/trip			1.5
Average number of trips to disposal site =	2	/day		N_d =	2
Rest breaks =	2 at 25	minute each			50
Average maintenance down time =	45	minute/day			45
Average work day =	8	hours		**H =**	8
Average percent trucks out of service for major repairs =	20%				20%

(a) Volume per pickup

Vp = (2.65 cans/stop) x (0.0652 m^3/can) = **0.1728** m^3

Estimation of t_p (mean time per collection)

$$t_p = \frac{\forall_p}{\forall_T r}\left[\frac{H}{N_d} - \frac{2x}{s} - 2t_d - t_u - \frac{B}{N_d}\right]$$

Here, $\frac{2x}{s} + 2t_d + t_u =$ **1.50** hours

B = 2-25 min for breaks + 45 min for maintenance = (2 x 25 + 45)/60 = **1.58 hours**

$$t_p = \frac{\forall_p}{\forall_T r}\left[\frac{H}{N_d} - \frac{2x}{s} - 2t_d - t_u - \frac{B}{N_d}\right] = \frac{0.1728}{15 \times 2.54}[8/2-1.5-1.58/2]$$

= 0.0077 hour/stop = **0.465** min/stop **Ans.**

(b) Number of pick up locations per load

$$N_p = \frac{\frac{H}{N_d} - \frac{2x}{s} - 2t_d - t_u - \frac{B}{N_d}}{t_p} = \frac{8\text{ hr}/2 - 1.5\text{ hr} - 1.58\text{ hr}/2}{0.0077\text{ hr}} = 220.512 \approx 221 \text{ locations/load}$$ **Ans.**

or $$N_p = \frac{V_T r}{V_p} = \frac{15 \times 2.54\ \text{m}^3}{0.1728\ \text{m}^3/\text{stop}} = 220.51 \approx 221 \text{ locations/ load}$$

©	**Number of Trucks**							
	Population given =	420,003		Assuming no. of days/week =	5	days		
	No. of stops/week = 420,003/6 =	**70,001**	stops/week					
	Volume of waste to be collected per week =		70001 x 2.65 x 0.0652 m^3 =		**12095**	m^3/week		
	No. of loads/week =	12095 m^3/week	=	**317.45**	loads/week			
		15 m^3 x 2.54						
	No. of loads/week/truck =	No. days/week x No. of trip to landfill/day (Nd) =		5 x 2 =	**10**	loads/week/truck		
	No. of trucks =	No. of loads/week	=	317.45	=	**31.75**		
		No. of loads/week/truck		10				
	OR No. of trucks =	No. of stops/week						
		No. of day/week x No. of stops/load x N_d						
	=	70,001	=	**31.67**				
		5 x 221 x 2						
	No. of trucks with	20%	out of service = 31.67x(1 + 0.20) =	**38.01**	≈	38	**Ans.**	

(4) Transfer and Transport

Those activities associated with (1) the transfer of wastes from the smaller collection vehicle to the larger transport equipment and (2) the subsequent transport of the wastes, usually over long distance, to the disposal site. Transfer and transport operations become a necessity when haul distances to available disposal sites or processing centers increase to the point that direct hauling is no longer economically feasible.

Important factors that must be considered in the design of transfer stations include:

(1) type of transfer operation to be used,
(2) capacity requirements,
(3) equipment and accessory requirements, and
(4) environmental requirements.

Depending on the method used to load the transfer vehicles, transfer stations may be classified into three types:

(1) direct discharge,
(2) storage discharge, and
(3) combined direct and storage discharge.

A typical Transfer Station is shown in Figure 15.

Figure 15: A typical Transfer Station[4]

Direct Discharge: In a direct discharge transfer station, wastes from the collection vehicles usually are emptied directly into the vehicles to be used to transport them to a place of final disposal. To accomplish this, these transfer stations are usually constructed in a two-level arrangement. A typical direct discharge transfer station is illustrated in Figure 16.

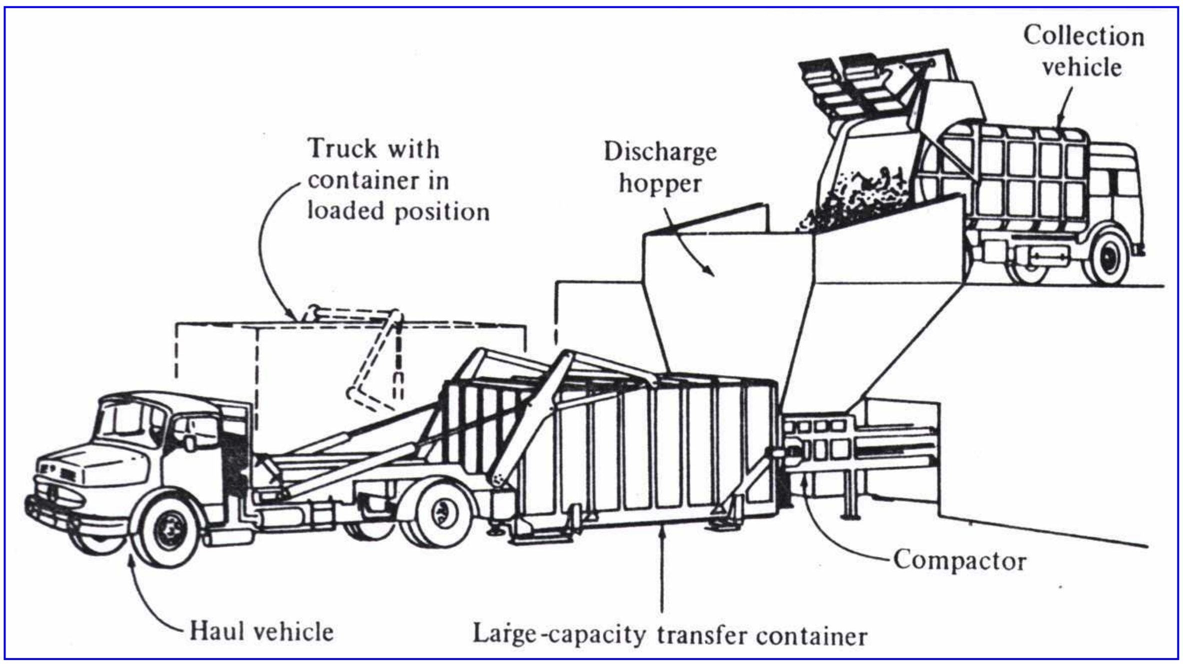


Figure 16: Typical direct-discharge transfer station[1]

Storage Discharge: In the storage discharge transfer stations, wastes are emptied either into a storage pit or onto a platform from which they are loaded into transport vehicles by various types of auxiliary equipment. A typical storage discharge transfer station is illustrated in Figure 17.

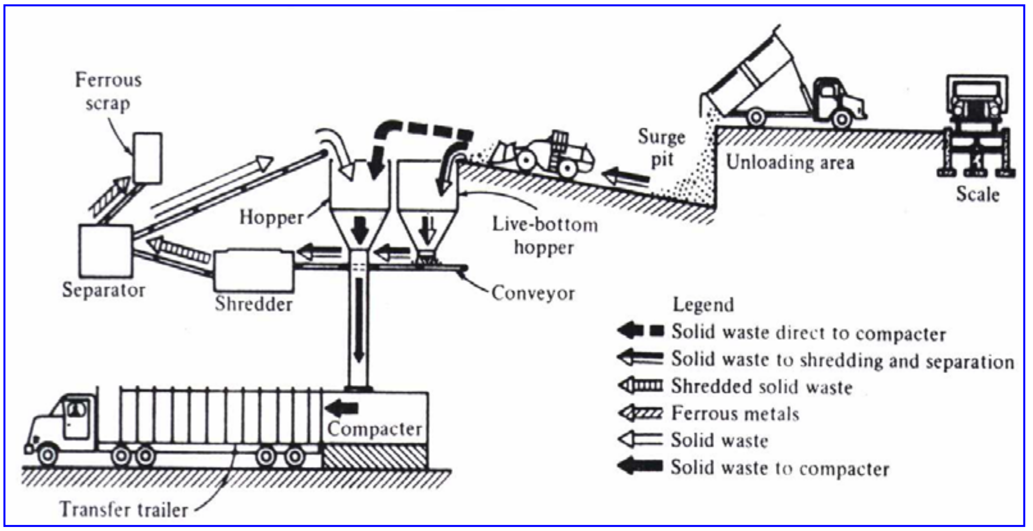


Figure 17: Typical storage-discharge transfer station[1]

Combined Direct and Storage Discharge: In some transfer stations, both direct-discharge and storage-discharge methods are used.

11. Solid Waste Processing and Recovery

Those techniques, equipment, and facilities used both to improve the efficacy of the other direct activities and to recover usable materials, conversion products, or energy from solid wastes. Processing and recovery of solid wastes will be discussed under a separate cover titled **Waste Processing, Minimization, and Separation** and it is beyond the scope of this course.

12. Solid Waste Disposal

Those activities associated with ultimate disposal of solid wastes, including those wastes collected and transported directly to a landfill site, semisolid waste (sludge) from wastewater treatment plants, incinerator residue (ash), compost, or other substances from the various solid waste processing plants that are of no further use.

There are 3 basic types of landfills:

- Sanitary (MSW) Landfill
- Construction/Demolition/Debris (CDD) Landfill, and
- Industrial Landfill

Number of landfills appears to be decreasing (Figure 18(a)) with time as the recycling and recovery of wastes is increasing. Figure 18(b) shows the number of landfills by region.

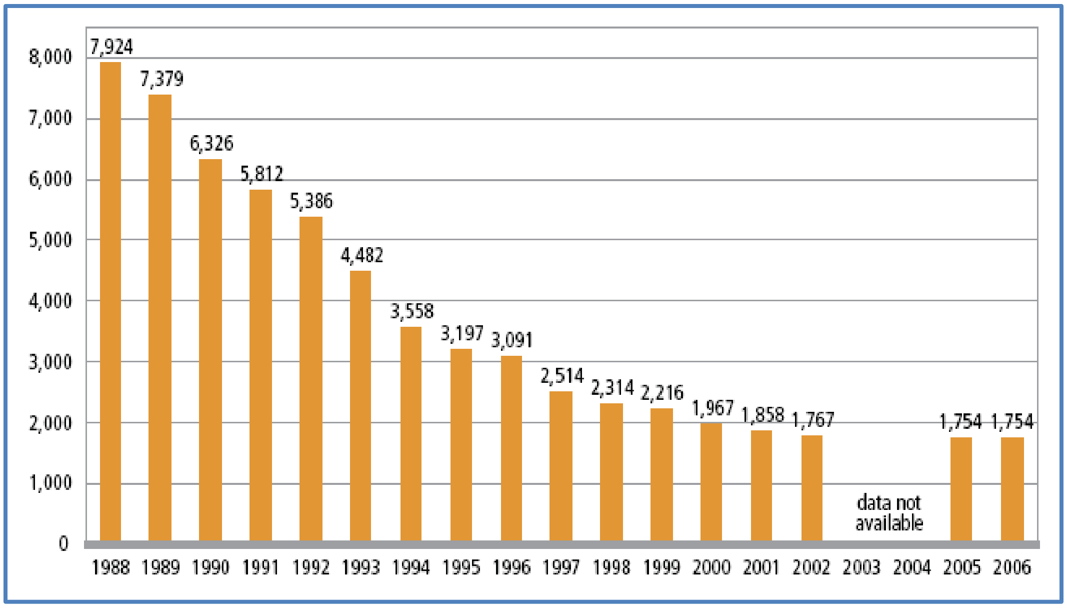


Figure 18(a): Number of Landfills in the USA 1987-2006[3]

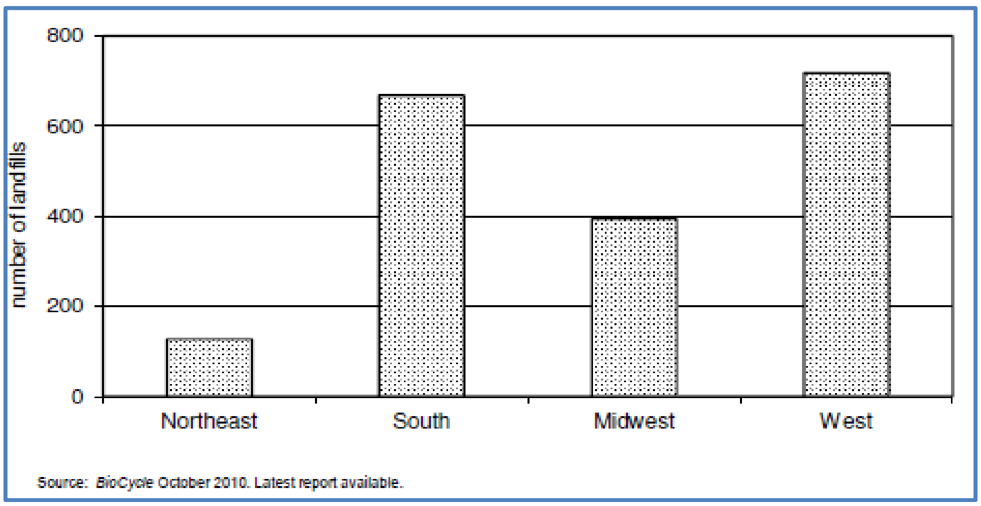


Figure 18(b): Number of Landfills in the USA by region in 2012[3]

13. Summary

In this course we defined several terms related to solid waste management, discussed the characteristics of solid waste, generation rate and other pertinent factors in generation of solid waste. We also discussed the process for storage, collection, treatment, if any, disposal procedure and perspectives as well. We solved several example problems related to moisture content, density, and energy content determination for mixed solid waste.

14. References

1. Introduction to Environmental Engineering by Mackenzie L. Davis and David A. Cornwell**,** McGraw-Hill Book Company.
2. Environmental Engineering by Howard S. Peavy, Donald R. Rowe, and George Tchobanoglous, McGraw-Hill Book Company.
3. United States Environmental Protection Agency (USEPA), 2017. Sustainable materials management: Non-hazardous material and waste management hierarchy. Retrieved April 7, 2019, from https://www.EPA.gov/smm/sustainable-materials-management-non-hazardous-materials-and-waste-management-hierarchy#Source_Reduction.
4. Personal experience working for Virginia Department of Environmental Quality as a Senior Environmental Engineer (Solid Waste Permit Writer).

+++++++++++++++ **The End** ++++++++++++++

Any questions please contact the instructor at makarim@juno.com

QUIZ for Solid Waste Management

1. The energy contained in the organic matter must be converted to a form that can be used more easily. Recovery of heat by burning the organic materials in solid waste is a good example of ______ _________.
a. energy recovery
b. materials recovery
c. material incineration
d. food recovery

2. The waste management hierarchy is:
a. prevention, minimization, reuse, recycling, energy recover, and disposal
b. prevention, minimization, reuse, recycling, and energy recover
c. prevention, minimization, reuse, and disposal
d. prevention, minimization, and reuse

3. The 3 general categories of solid waste are considered and these are _____________, ____________, and _____________.
a. (1) Municipal Solid Waste (MSW), (2) Industrial Waste, and (3) Hazardous Waste
b. (1) MSW, (2) Agricultural Waste, and (3) Hazardous Waste
c. (1) Radioactive, (2) Industrial Waste, and (3) Hazardous Waste
d. (1) MSW, (2) Industrial Waste, and (3) Nuclear Waste

4. Municipal solid waste (MSW) may be categorized as:
a. Garbage = food waste (e.g., milk cartons and coffee grounds)
b. Rubbish = combustible with some inert
c. Refuse = 50/50 mix of garbage & rubbish
d. Trash = 100% combustible
e. All of the above
f. None of the above

5. The physical composition of MSW includes _______________, _______________, _____________, and ___________________.
a. identification of the individual components that make up the MSW
b. analysis of particle size
c. moisture content and density
d. all of the above
e. none of the above

6. Fusing point of ash of burned MSW is a part of chemical composition of MSW.
a. True
b. False

7. Name the two methods of analysis that are used to estimate the quantity of solid waste.
a. Load-count analysis
b. mass-volume analysis
c. all of the above
d. none of the above

8. The factors that must be considered in the on-site storage of solid wastes include:
a. type of container to be used
b. the container location
c. public health and aesthetics
d. the collection methods to be used
e. all of the above
f. none of the above

9. There are three most common collection methods of municipal solid waste and these are:
a. Back Yard - convenient but expensive
b. Curbside - inconvenient but cheap
c. Set out/ Set back (Alley)
d. All of the above
e. None of the above.

10. Based on the mode of operation, the collection systems are:
a. hauled-container system
b. stationary-container system
c. tilt-frame container
d. trash container
e. a and b
f. c and d

11. There are two main types of hauled-container systems and these are:
a. hauled-container system
b. stationary-container system
c. tilt-frame container
d. trash container
e. a and b
f. c and d

12. Depending on the method of used to load the transfer vehicles, transfer stations may be classified into three types and these are.
a. direct discharge
b. storage discharge
c. combined direct and storage discharge
*d. all of the above
e. none of the above

13. There are 3 basic types of solid waste landfills and these are ____________, ______________, and ____________.
a. Sanitary (MSW) Landfill, Construction/Demolition/Debris (CDD) Landfill, and Industrial Landfill
b. MSW Landfill, CDD Landfill, and Subtitle C Landfill
c. MSW Landfill, Subtitle D Landfill, and Subtitle C Landfill
d. CDD Landfill, Nuclear Waste Landfill, and Subtitle C Landfill

14. Waste can broadly be classified into two groups such as ________________ and ____________________.
a. solid waste and liquid waste
b. radiative waste and agriculture waste
c. agriculture waste and construction waste
d. nuclear waste and hazardous waste

15. Proximate analysis is performed as a part of chemical composition analysis of MSW. The parameters that are analyzed in this analysis are:
a. Moisture loss at 105^{o}C for an hour, Volatile matter, Ash residue after burning, and Fixed carbon.
b. Flushing point, fusing point, and boiling point
c. Heating value
d. None of the above

16. The wet weight of a mixture of waste is 100 lbs and the dry weight is 78 lbs. The moisture content (dry basis) of the mixed waste is:
a. 22.0%
b. 28.2%
c. 30.5%
d. 32.5%

17. The wet weight of a mixture of waste is 100 lbs and the dry weight is 78 lbs. The moisture content (wet basis) of the mixed waste is:
a. 22.0%
b. 28.2%
c. 30.5%
d. 32.5%

18. The mixed waste was analyzed and found the weight of 89 lbs and the volume is 1.5 cubic ft. The density of the mixed waste is nearly:
a. 29 lb/ft^3
b. 47 lb/ft^3
c. 59 lb/ft^3
d. 63 lb/ft^3

19. A mixed waste was analyzed and found the followings:
C = 25%; H = 8%; O = 38%; and S = 29% by mass. The energy content of a mixed solid-waste sample using Dulong formula, kJ/kg = 337C + 1,428(H – O/8) + 9S, is nearly.
a. 10,500 kJ/kg
b. 11,333 kJ/kg
c. 12,320 kJ/kg
d. 13,330 kJ/kg

20. The factor that does not affect the quantity of municipal solid wastes is:
a. Moisture content
b. season of the year
c. collection frequency
d. characteristics of populace
e. None of the above