Solid Waste Management:

Generation, Characteristics, & Quantities

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General

- *Solid wastes* are the wastes arising from human activities and are normally solid as opposed to liquid or gaseous and are discarded as useless or unwanted. Focused on urban waste (MSW) as opposed to agricultural, mining and industrial wastes.

- Integrated waste management (IWM) can be defined as the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals.

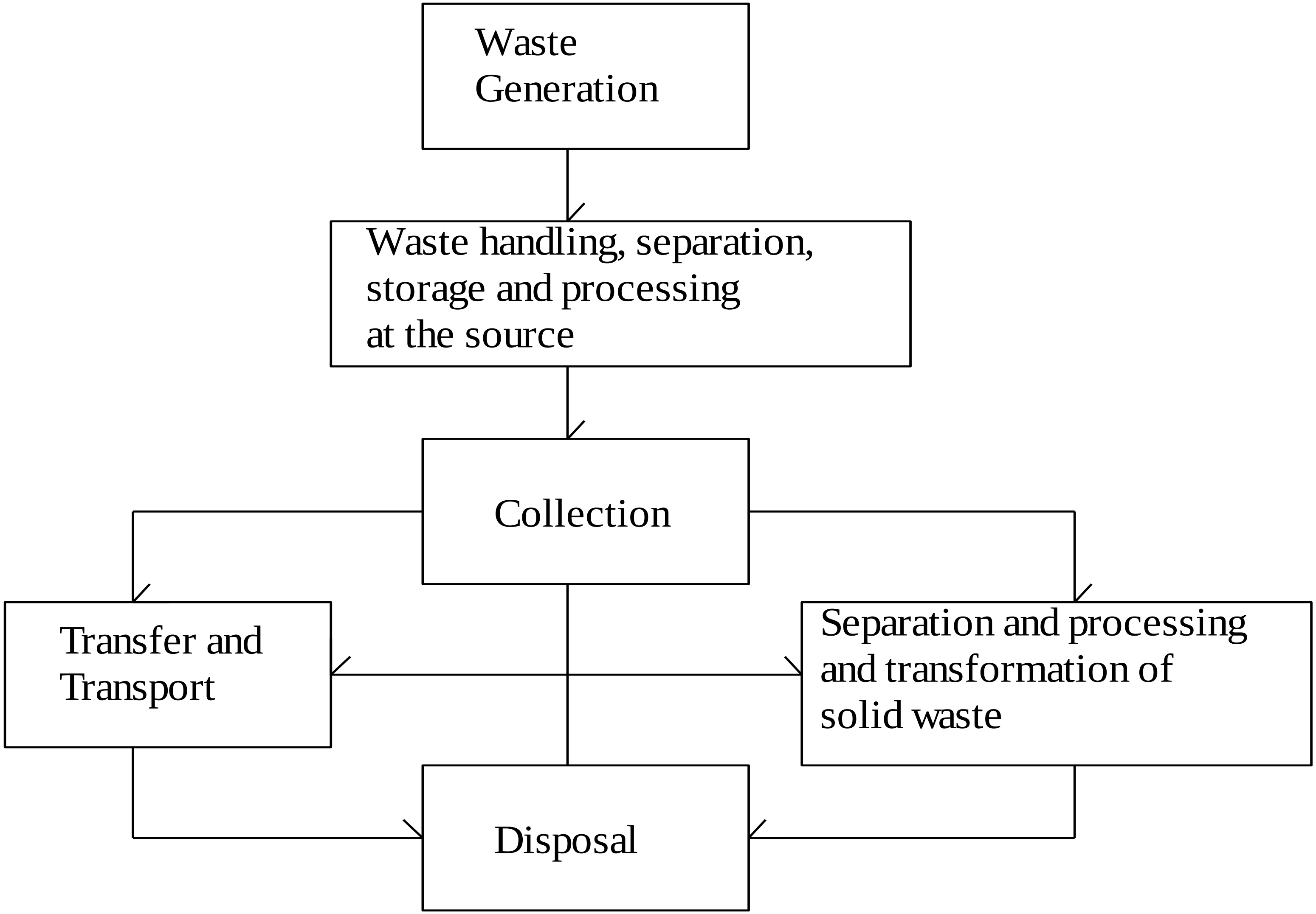
- Integrated Solid Waste Management (ISWM) is the term applied to all the activities associated with the management of society's wastes.

- The U.S. Environmental Protection Agency (EPA) has identified four basic management options (strategies) for IWM: (1) source reduction, (2) recycling and composting, (3) combustion (waste-to-energy facilities), and (4) landfills

Solid Waste Management

Solid waste management is the control of :

- generation, materials are identified as no longer being of value
- storage, management of wastes until they are put into a container
- collection, gathering of solid wastes and recyclable materials and the transport of these materials where the collection vehicle is emptied. 50% or higher of the total cost.
- processing, source separated (at the home) vs. mixed (everything together) is a big issue. Includes: physical processes such as shredding and screening, removal of bulky material, and chemical and biological processes such as incineration and composting.
- transfer and transport, small trucks to the biggest trucks allowable
- disposal of solid waste, landfilling with or without attempting to recover resources.


Waste Generation
Waste handling, separation, storage and processing at the source
Collection
Transfer and Transport
Separation and processing and transformation of solid waste
Disposal

MSW Generation

- Waste generation encompasses those activities in which materials are identified as no longer being of value and are either thrown away or gathered together disposal.

- Waste generation is, at present, an activity that is not very controllable.

- *Generation* refers to the amount of materials and products in MSW as they enter the waste stream before any materials recovery, composting, or combustion take place.

- *Recovery* refers to removal of materials from the waste stream for recycling or composting. Recovery does not automatically equal recycling.

- *Discards* refers to the MSW remaining after recovery. The discards are generally combusted or landfilled, but they could be littered, stored, or disposed on-site, particularly in rural areas.

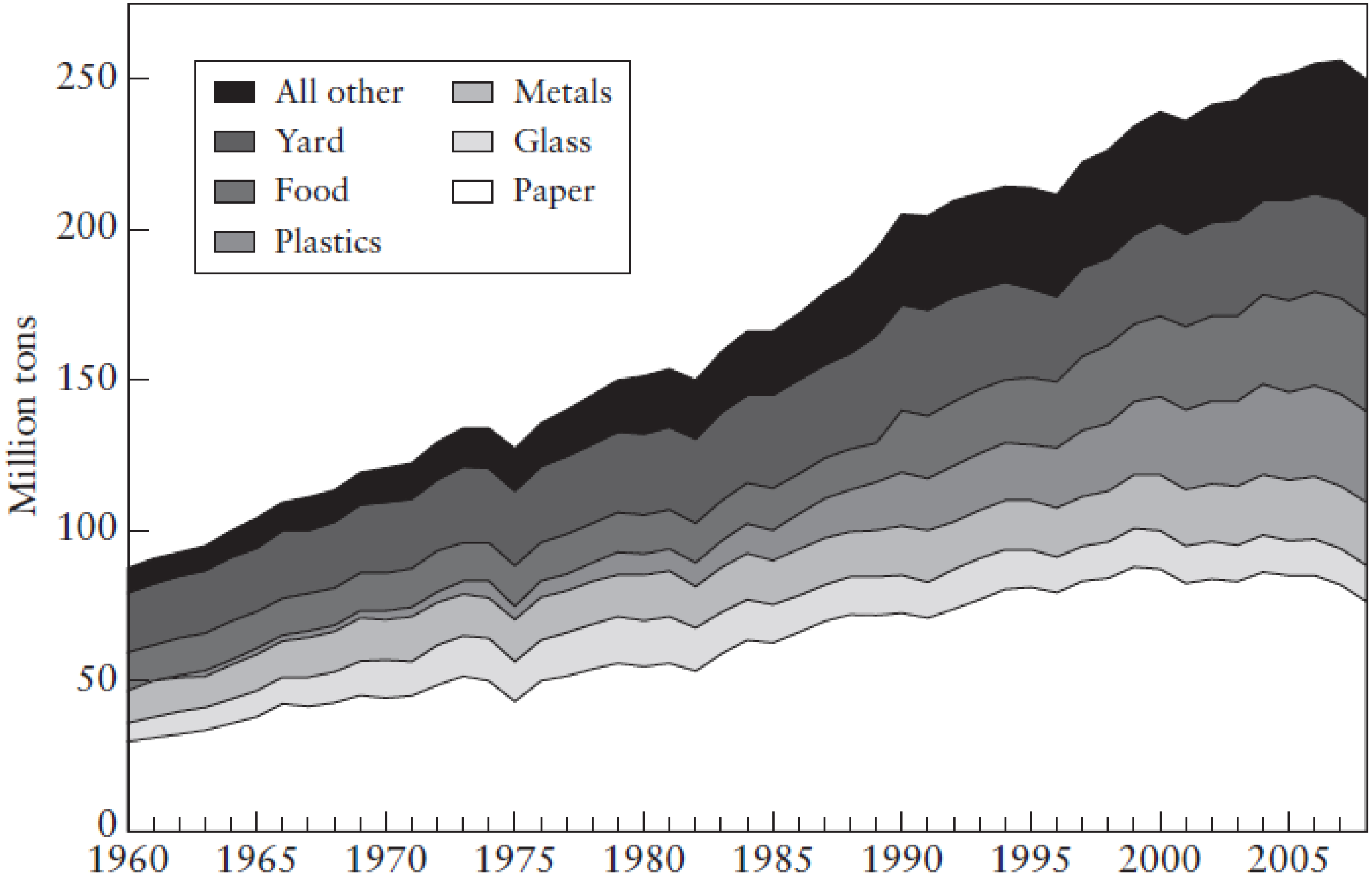
The generation of refuse in a community also varies throughout the year, seasonal variations, with the day of the week, income,

Table 2-1 Generation and Management of Solid Waste in the United States from 1960 to 2008 (in millions of tons)

Activity	1960	1970	1980	1990	2000	2003	2005	2007	2008
Generation	88.1	121.1	151.6	205.2	239.1	242.2	249.7	254.6	249.6
Recovery for recyling	5.6	8.0	14.5	29.0	52.9	55.6	58.6	62.5	60.8
Recovery for composting*	Negligible	Negligible	Negligible	4.2	16.5	19.1	20.6	21.7	22.1
Total materials recovery	5.6	8.0	14.5	33.2	69.4	74.7	79.2	84.2	82.9
Combustion with energy recovery†	0.0	0.4	2.7	29.7	33.7	33.1	31.6	32.0	31.6
Discards to landfill, other disposal‡	82.5	112.7	134.4	142.3	136.0	134.4	138.9	138.4	135.1

* Composing of yard trimmings, food scraps, and other MSW organic material. Does not include backyard composting.
† Includes combustion of MSW in mass burn or refuse-derived fuel form, and combustion with energy recovery os source separated materials in MSW (e.g., wood pallets, tire-derived fuel).
‡ Discards after recovery minus combustion whith energy recovery. Discards include combustion without energy recovery. Details might not add to totals due to rounding.

Source: Ch.2 WW PV



*"All Other" includes primarily wood, rubber and leather, and textiles.

Source: Ch.2 Figure 2.2 WW PV

MSW Characteristics

- As long as the MSW is to be disposed of by landfill, there is little need to analyze the waste much further than to establish the tons of waste generated and perhaps consider the problems of special (hazardous) materials.

- If, however, the intent is to collect gas from a landfill and put it to some beneficial use, the amount of organic material is important. When recycling is planned, or if materials or energy recovery by combustion is the objective, it becomes necessary to have a better picture of the solid waste.

Some of the characteristics of interest are:

- ✓ Composition by identifiable items (steel cans, office paper, etc.)
- ✓ Moisture content
- ✓ Particle size
- ✓ Chemical composition (carbon, hydrogen, etc.)
- ✓ Heat value
- ✓ Density
- ✓ Mechanical properties
- ✓ Biodegradability

Composition by identifiable items

- ***Input method*** of estimating solid waste production on national level. The input method of estimating solid waste generation is applicable where the input data can be obtained from specialized agencies that routinely collect and publish industry-wide data.

  - Since the data collected by the same institutions include future projections, it is possible to estimate future solid waste generation.

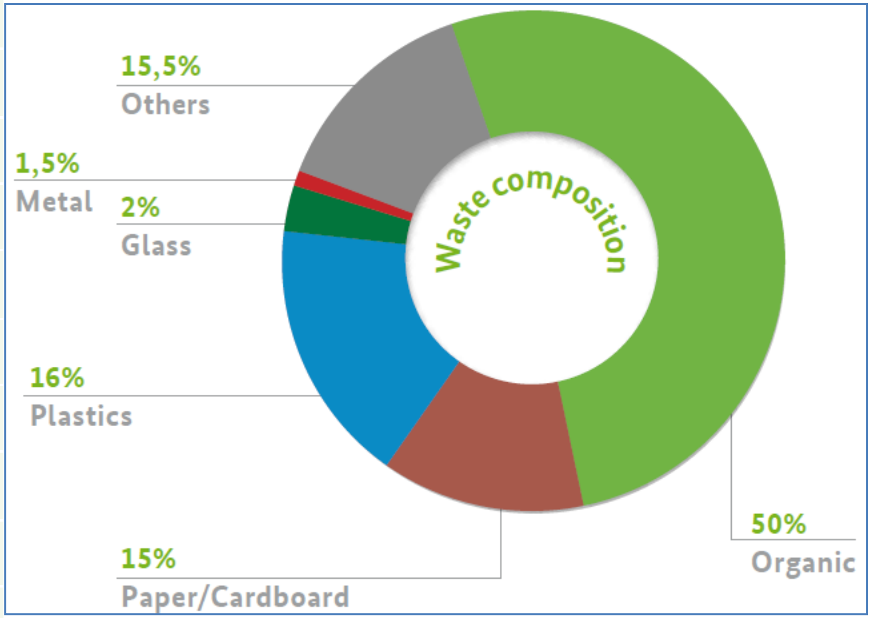
Table 2-3 Generation of Municipal Solid Waste Components in the United States, 2008

Ref: Ch.2 Section 2-3-1 WW PV

Item	Weight Generated (millions of tons)	Percent
Paper and paperboard	77.42	31.0
Glass	12.15	4.9
Ferrous metals	15.68	6.3
Aluminum	3.41	1.4
Other nonferrous metals	1.76	0.7
Plastics	30.05	12.0
Rubber and leather	7.41	3.0
Textiles	12.37	5.0
Wood	16.39	6.6
Other materials	4.50	1.8
Food waste	31.79	12.7
Yard trimmings	32.90	13.2
Miscellaneous inorganic	3.78	1.5
Total	249.61	100

Solid Waste Indicators in Jordan

Population:	6,388,000
Municipal Solid Waste (Msw) Generation:	2,077,215 tons/year
Per Capita Msw Generation:	
- Urban Areas	0.9 kg/day
- Rural Areas	0.6 kg/day
Msw Generation Growth:	3 %
Medical Waste Generation:	4,000 tons/year
Industrial Waste:	45,000 tons/year
Agricultural Waste:	> 4 million tons/year
C&D Waste:	2.6 million m^3/year
Waste Tyres:	2.5 million no./year
E-Waste:	30,000 piece/year
Packaging Waste:	700,000 tons/year



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- ***Output method:*** On the local level, the only reliable method of estimating refuse composition and production is to use an output method of analysis and to perform sampling studies.

- Sampling studies for characterizing refuse must be designed so as to produce the most useful and accurate data for the least cost and effort. The two variables of importance in designing such a study are **sample size** and the **method of characterizing the refuse**.

- Although manual sampling is still the only truly reliable way of estimating composition, other techniques—such as photogrammetry—hold promise for the future.

- Composition studies should be used where accurate data are absolutely required for estimating the economics of future solid waste management alternatives.

Ref: Ch.2 Section 2-3-1 WW PV

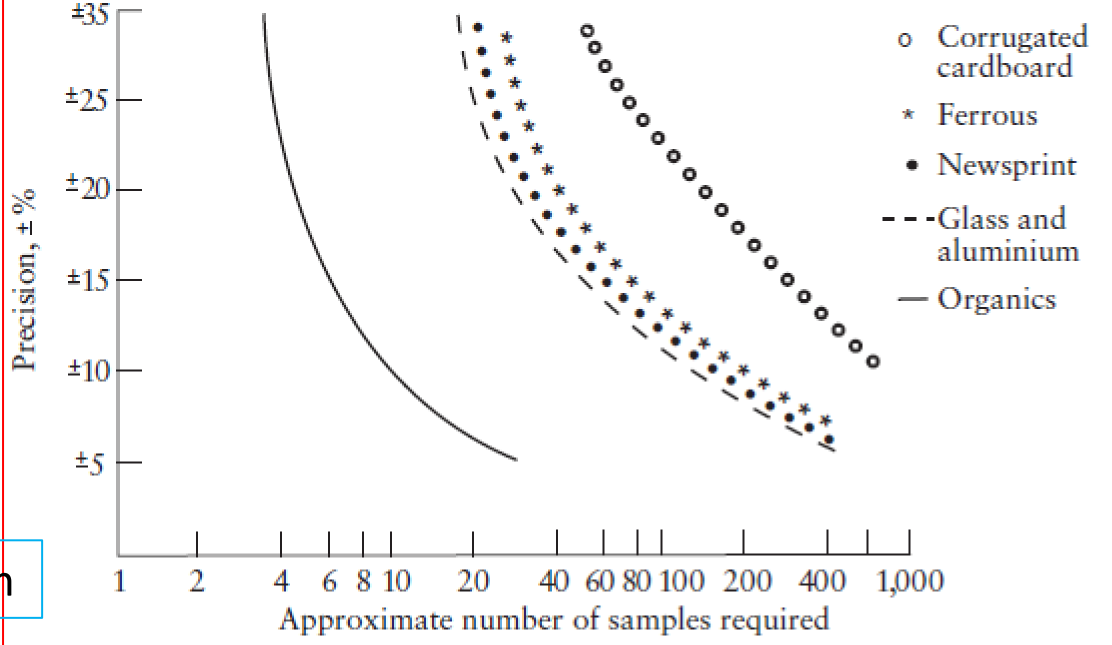
TABLE 5.1 Materials Generated* in the Municipal Waste Stream, 1960 to 2005
(In millions of tons)

Materials	1960	1965	1970	1975	1980	1985	1990	1995	1998	2005†
Paper and paperboard	30.0	38.1	44.3	43.2	55.2	62.8	72.7	81.7	84.1	94.8
Glass	6.7	8.7	12.7	13.6	15.1	13.2	13.1	12.8	12.5	11.2
Metals:										
Ferrous	10.3	11.1	12.4	12.3	12.6	11.4	12.6	11.6	12.4	13.6
Aluminum	0.3	0.5	0.8	1.1	1.7	2.2	2.8	3.0	3.1	3.8
Other nonferrous metals	0.2	0.6	0.7	0.9	1.2	1.1	1.1	1.3	1.4	1.3
Total metals	10.8	12.2	13.8	14.3	15.5	14.6	16.6	15.9	16.8	18.7
Plastics	0.4	1.5	2.9	4.3	6.8	11.1	17.1	18.9	22.4	26.7
Rubber and leather	1.8	2.4	3.0	3.8	4.2	4.6	5.8	6.0	6.9	7.7
Textiles	1.8	1.9	2.0	2.1	2.5	2.9	5.8	7.4	8.6	10.2
Wood	3.0	3.4	3.7	4.3	7.0	8.4	12.2	10.4	11.9	15.8
Other	0.1	0.4	0.8	1.7	2.5	3.0	3.2	3.7	3.9	4.3
Total materials in products	54.6	68.5	83.3	87.2	108.8	120.6	146.5	156.8	167.1	189.4
Other wastes:										
Food wastes	12.2	12.7	12.8	13.4	13.0	13.2	20.8	21.7	22.1	23.5
Yard trimmings	20.0	21.6	23.2	25.2	27.5	30.0	35.0	29.7	27.7	23.0
Miscellaneous inorganic wastes	1.3	1.6	1.8	2.0	2.3	2.5	2.9	3.2	3.3	3.7
Total other wastes	33.5	35.9	37.8	40.6	42.8	45.7	58.7	54.6	53.2	50.1
Total MSW generated	88.1	104.4	121.1	127.8	151.6	166.3	205.2	211.4	220.2	239.5

* Generation before materials recovery or combustion. Details may not add to totals due to rounding.
† Projected data.
Source: Adapted from U.S. EPA (1999) and unpublished data developed for the U.S. EPA.

Measuring of Waste Composition

- **Manual Sampling**
  - the waste has to be accurately represented through proper load selection so as not to bias the final analysis. The truckload to be analyzed has to represent (as closely as possible) the average production of refuse in the community,
  - American Society for Testing and Materials (ASTM) Standard Test for Determination of the Composition of Unprocessed Municipal Solid Waste (ASTM designation D 5231-92):



Accuracy and precision - theory

http://conflict.lshtm.ac.uk/page_49.htm

- To obtain representative 200 lb (90 kg) samples, ASTM recommends quartering and coning. Quartering is the separation of a truckload of waste into successive quarters after thoroughly mixing the contents with a front-end loader. The samples are then coned again and quartered again until they are about 200 lb (90 kg). The greater the desired precision, the greater will be the number of 200 lb samples analyzed.

- The larger the articles, the more is required to achieve acceptable precision.

- Read through page 43.

Measuring of Waste Composition

- **Photogrammetry**

  - A good substitute for manual sampling which involves photographing a representative portion of refuse and analyzing the photograph.

  - The photograph should be taken directly of the refuse (90º angle) with a wide-angle lens. The picture is then projected onto a screen that has been divided into about 10 X 10 grid blocks. The components in each grid intersection are then identified and tabulated. Using predetermined bulk densities (which include interior space, e.g., in a beverage can), the fraction by weight is then calculated.

  - Photogrammetry also might be useful for wastes other than refuse. Construction and demolition wastes, for example, have a limited number of components, and taking pictures of large piles of C & D wastes may be far more effective (not to say safer) than sorting by hand.

  - Using this measuring technique the refuse need not be touched or smelled, and thus, there are no problems with disease transmission.

Table 2-4 Bulk Densities of Some Refuse Components

Components	Condition	Bulk density (lb/yd^3)*
Aluminum cans	Loose	50–74
	Flattened	250
Corrugated cardboard	Loose	350
Fines (dirt, etc.)	Loose	540–1600
Food waste	Loose	220–810
	Baled	1000–1200
Glass bottles	Whole bottles	500–700
	Crushed	1800–2700
Magazines	Loose	800
Newsprint	Loose	20–55
	Baled	720–1000
Office paper	Loose	400
	Baled	700–750
Plastics	Mixed	70–220
	PETE, whole	30–40
	Baled	400–500
	HDPE, loose	24
	Flattened	65
Plastic film and bags	Baled	500–800
	Granulated	700–750
Steel cans	Unflattened	150
	Baled	850
Textiles	Loose	70–170
Yard waste	Mixed, loose	250–500
	Leaves, loose	50–250
	Grass, loose	350–500

* To obtain kg/m^3, multiply by 0.59.

Moisture Content

- A transfer of moisture takes place in the garbage can and truck, and thus, the moisture content of various components changes with time.
- Moisture content becomes important when the refuse is processed into fuel or when it is fired directly.
- The usual expression for calculating moisture content is

Solve example 2-2 page 46 (Ref. WW PV)

$$M = \frac{w - d}{w} \times 100$$

where M = moisture content, wet basis, %
w = initial (wet) weight of sample
d = final (dry) weight of sample

Some engineers define moisture content on a dry weight basis as

$$M_d = \frac{w - d}{d} \times 100$$

where M_d = moisture content on a dry basis, %

In this text, moisture is always expressed on a **wet basis** unless otherwise indicated.

- Typically, the moisture content of loose refuse is about 20% if there have not been rainstorms before collection. During rainy weather, the moisture content can go as high as 40%.

- In a refuse truck, *moisture transfer* takes place, and the moisture of various components of refuse changes. Paper sops up much of the liquid waste, and its moisture increases substantially. The moisture content of refuse that has been compacted by a collection truck is therefore quite different from the moisture of various components as they are in the can ready for collection.

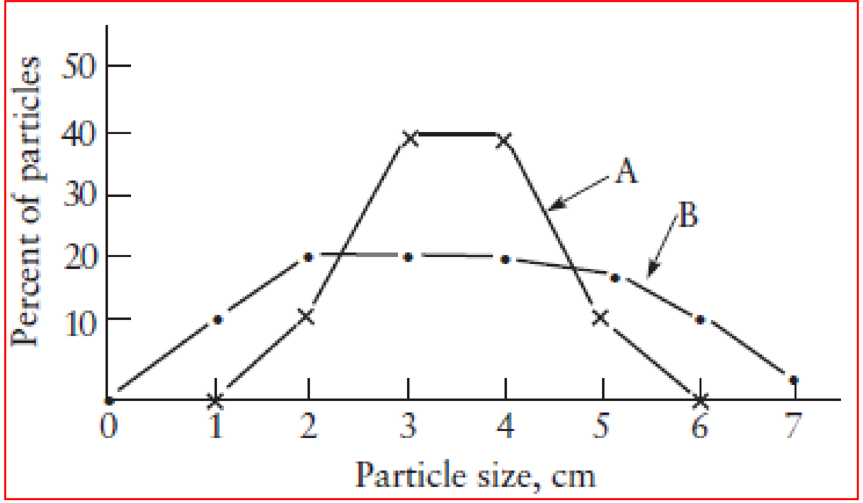
Particle size

- Any mixture of particles of various sizes is difficult to describe analytically. If these particles are irregularly shaped, the problem is compounded.

- Municipal refuse is possibly the worst imaginable material for particle size analysis, and yet much of the MSW processing technology depends on an accurate description of particle size.

- Probably the best effort in that direction is to describe the mixture by means of a curve showing percents of particles (by either number or weight) versus the particle size.

- average particle size (defined as that diameter where 50% of the particles (by weight) are smaller than—and 50% are larger than—this diameter.



Chemical composition

- The economic recovery of materials and/or energy often depends on the chemical composition of the refuse—the individual chemicals as well as the heat value.
- Two common means of defining the chemical composition of refuse are the proximate analysis and the ultimate analysis.
- The **proximate analysis** is an attempt to define the fraction of volatile organics and fixed carbon in the fuel, while the **ultimate analysis** is based on elemental compositions.

Table 2-6 Proximate and Ultimate Chemical Analyses of Refuse

Proximate Analysis (percent by weight)	
Moisture	15–35
Volatile matter	50–60
Fixed carbon	3–9
Noncombustibles	15–25
Higher heat value (HHV)	3000–6000

Ultimate Analysis (percent by weight)	
Moisture	15–35
Carbon	15–30
Hydrogen	2–5
Oxygen	12–24
Nitrogen	0.2–1.0
Sulfur	0.02–0.1
Total noncombustibles	15–25

Source: [24]

Heat Value

- The heat values of refuse are of some importance in resource recovery.

- Commonly, the heat values of refuse and other heterogeneous materials are measured with a calorimeter, 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 (recognizing, of course, that 1 Btu is the heat necessary to raise the temperature of 1 lb of water 1ºF).

- But sometimes, the heat value is expressed as moisture-free, and the water component is subtracted from the denominator. In case heat value is to also subtract the inorganics, so the Btu is moisture- and ash-free, the ash being defined as the inorganic upon combustion.

Check If: the heat value of coal is 10,000 Btu/lb and that of RDF is about 7000 Btu/lb, one might conclude (erroneously) that 10 tons of RDF represents the same energy value as 7 tons of coal **????**

Table 2-7 Heat Value of Fuels

Fuel	Heat Value		Composition (wt%)					
	(kJ/kg)	(Btu/lb)	S	H	C	N	O	Ash
Natural gas	54,750	23,170	nil	23.5	75.2	1.22	—	nil
Heating oil (no. 2)	45,000	19,400	0.3	12.5	87.2	0.02	nil	nil
Coal, anthracite	29,500	12,700	0.77	3.7	79.4	0.9	3.0	11.2
Coal, bituminous	26,200	11,340	3.22	4.6	40.0	1.0	6.5	9.0
Coal, lignite	19,200	8300	0.4	2.5	32.3	0.4	10.5	4.2
Wood, hardwood	7180*	3090*	—	—	—	—	—	—
Wood, softwood	7950*	18,400*	—	—	—	—	—	—
Shredded refuse[a]	10,846	4675	0.1	—	—	—	—	20.0
RDF[b]	15,962	6880	0.2	—	37.1	0.8	—	22.6
RDF[c]	18,223	7855	0.1	—	45.4	0.3	—	6.0
Unprocessed refuse	10,300	4450	0.1	2.65	25.6	0.64	21.2	20.8
Unprocessed refuse			0.13	4.80	35.6	0.9	29.5	28.9
Paper	24,900	7500	0.1	2.7	20.7	0.13	19.1	2.74

* Lower Heat Value (LHV); all other heat values are Higher Heat Value (HHV)

[a] Shredded, non-air-classified, ferrous removed, not dried; St. Louis RDF facility

[b] Shredded, air-classified, not dried

[c] Same as above, but oversize from a 3/16-in. screen

Table 2-8 **Heat Values of Some Refuse Components**

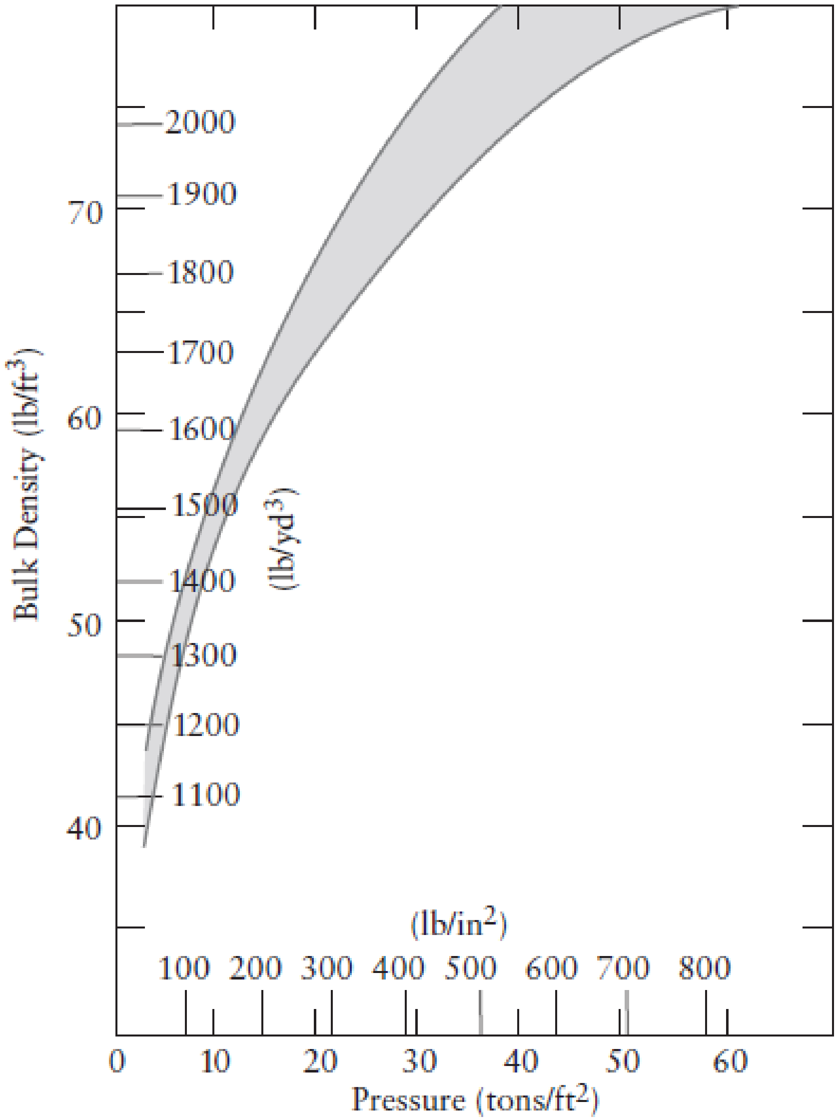
	Btu/lb		
Component	As Collected	Moisture-Free	Moisture- and Ash-Free
Cardboard	7040	7400	7840
Food waste	1800	6000	7180
Magazines	5250	5480	7160
Newspapers	7980	8480	8610
Paper (mixed)	6800	7570	8050
Plastics (mixed)	14,100	14,390	16,020
HDPE	18,700	18,700	18,900
PS	16,400	16,400	16,400
PVC	9750	9770	9980
Steel cans	0	0	0
Yard waste	2600	6500	6580

Source: Adapted from [20 from 21]

Density

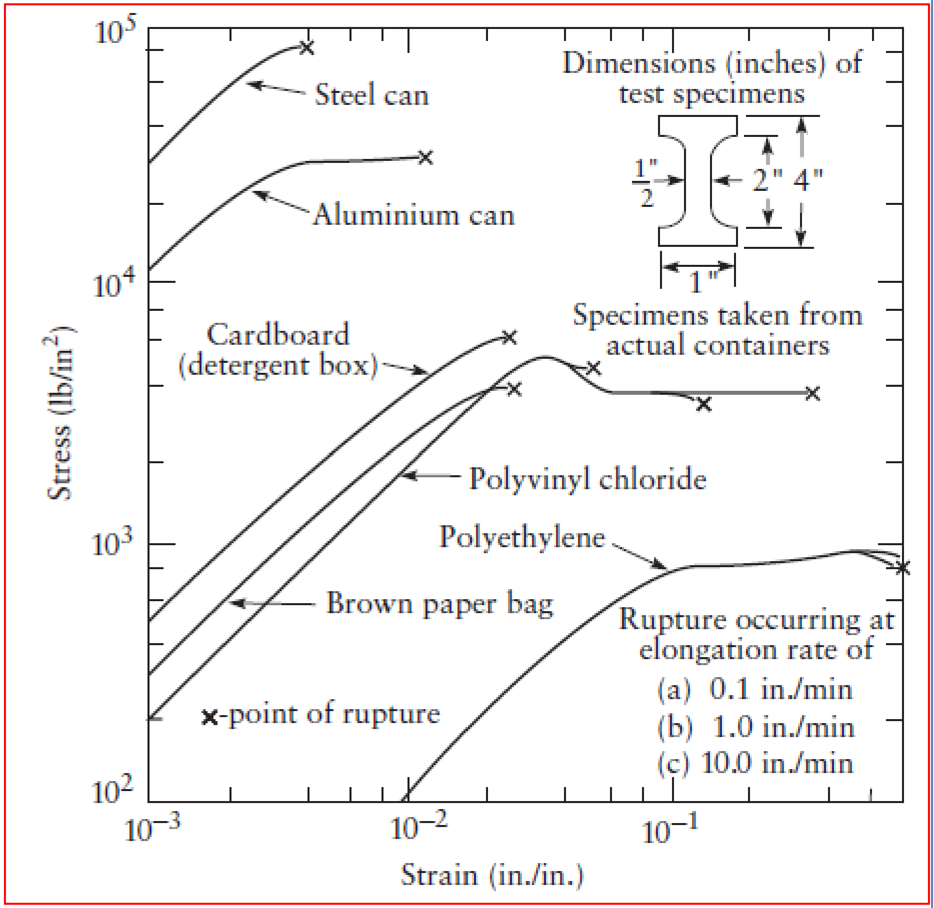
- Municipal solid waste has a highly variable bulk density, depending on the pressure exerted.

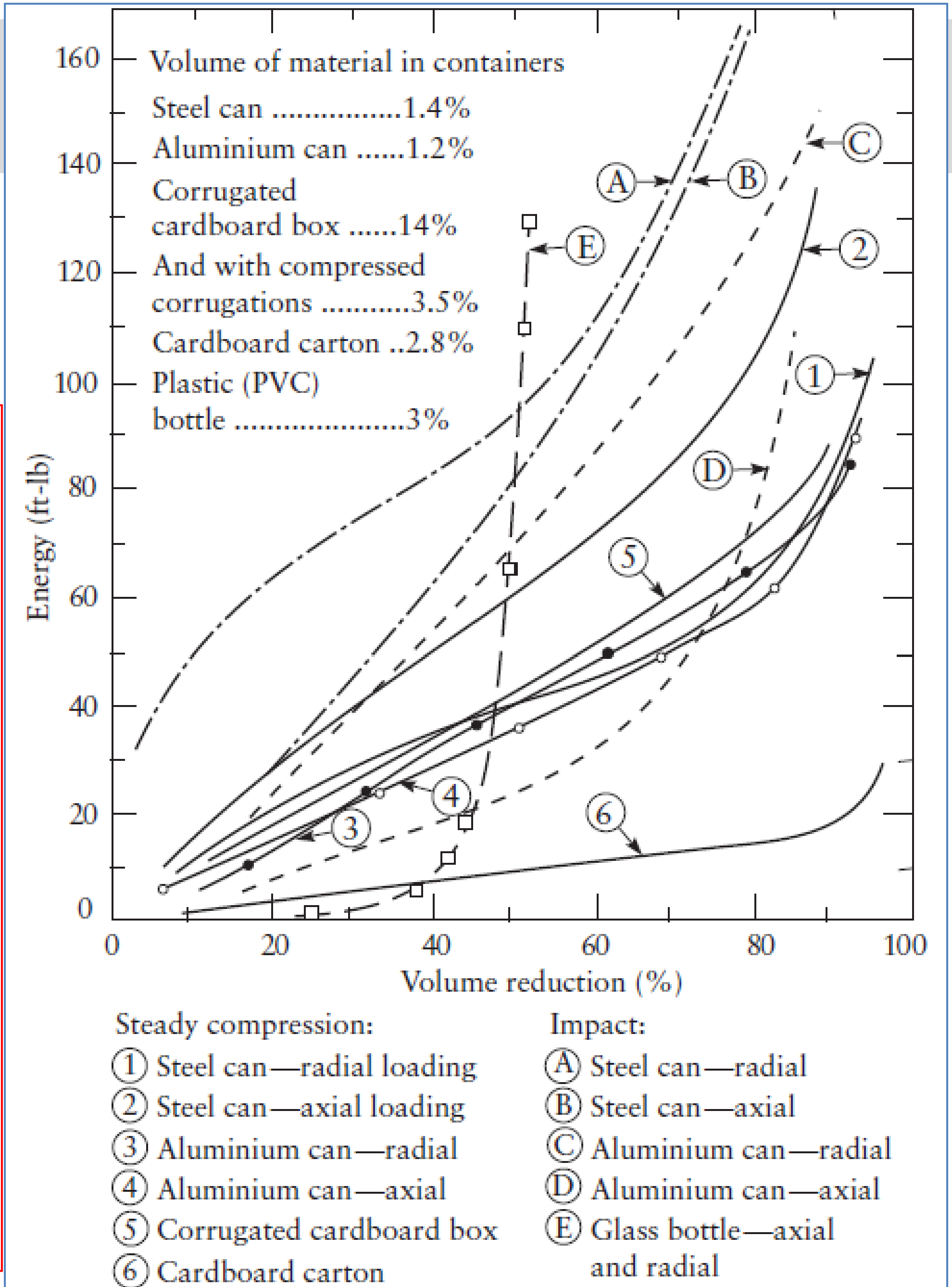
- Loose, as it might be placed into a garbage can by the homeowner, the bulk density of MSW might be between 150 and 250 lb/yd3 (90 and 150 kg/m3); pushed into the can, it might be at 300 lb/yd3 (180 kg/m3). In a collection truck that compacts the refuse, the bulk density is normally between 600 and 700 lb/yd3 (350 and 420 kg/m3). Once deposited in a landfill and compacted with machinery, it can achieve bulk densities of about 1200 lb/yd3 (700 kg/m3). If the covering soil in landfills is included, the total landfilled density can range from about 700 lb/yd3 for a poorly compacted landfill to as high as 1700 lb/yd3 (1000 kg/m3) for a landfill where thin layers of refuse are compacted.



Mechanical Properties

- A wide variation exists in the amount of energy necessary to obtain volume reduction.





Biodegradability

- 45% of MSW is potentially biodegradable,
- Treatment techniques (such as composting) must take into account that a large fraction of MSW is not biodegradable and that this material must be disposed of by means other than producing useful products using biodegradation.

Component	Percent of MSW	Percent of each component that is biodegradable
Paper and paperboard	37.6	0.50
Glass	5.5	0
Ferrous metals	5.7	0
Aluminum	1.3	0
Other nonferrous metals	0.6	0
Plastics	9.9	0
Rubber and leather	3.0	0.5
Textiles	3.8	0.5
Wood	5.3	0.7
Other materials	1.8	0.5
Food waste	10.1	0.82
Yard trimmings	12.8	0.72
Miscellaneous inorganic	1.5	0.8
Total	100	

HWs

Solid Waste Engineering Textbook:

2-2	**2-4**
2-10	**2-15**
2-17	**2-19**