Chapter 2

Municipal solid waste characteristics and quantities

1. Municipal solid waste

- *Municipal solid waste (MSW)*
  - Solid wastes produced by communities
  - Components of MSW
    - Mixed household waste
    - Recyclables
      - Newspapers
      - Aluminum cans
      - Milk cartons
      - Plastic soft drink bottles
      - Steel cans
      - Corrugated cardboard
      - Other material collected by the community

What is the Nature of Municipal Solid Wastes?

- Organic
- Inorganic
- Putrescible
- Combustible
- Recyclable
- Hazardous
- Infectious

– Household hazardous waste
– Commercial waste
– Yard (or green) waste
– Litter and waste from community trash cans
– Bulky items (refrigerators, rugs, etc.)
– Construction and demolition waste

- ***Refuse defined* as**
  - Solid waste generated by households, including mixed non-sorted waste
  - Recyclables (whether or not they are collected separately)
  - Household hazardous wastes if these are not collected separately
  - Yard (or green) waste originating with individual households
  - Litter and community trash, because the material is produced by individuals
  - Commercial waste, because it often contains many of the same items as household waste

- Non – refuse solid wastes
  - Construction and demolition debris
  - Water and wastewater treatment plant sludge
  - Leaves and other green waste collected from community streets and parks in the fall
  - Bulky items such as large appliances, hulks of old cars, tree limbs, and other large objects that often require special handling

- MSW = refuse + C & D waste + leaves + bulky items
- Generated refuse = Collected refuse + diverted refuse
- Note:
  - Diversion is defined in most cased on the basis of MSW instead of refuse.
  - Refuse base diversion is good to encourage recycling, reuse and recovery, and to see honest performance

Example

A community produces the following on an annual basis:

Fraction	Tons per year
Mixed household waste	210
Recyclables	23
Commercial waste	45
Construction and demolition debris	120
Leaves and miscellaneous	36

The recyclables are collected separately and processed at a materials recovery facility. The mixed household waste and the commercial waste go to the landfill. The leaves are composted, and the C & D wastes are processed and used on the next project. Calculate the diversion on the basis of refuse and MSW.

Solution:

- If the calculation is on the basis of MSW:

  MSW = 434 tons/year

- If everything not going to the landfill is counted as having been diverted,

$$\text{Diversion} = \frac{23 + 120 + 36}{434} \times 100 = 41\%$$

It seems impressive performance

- If the diversion is calculated as that fraction of the *refuse:*

$$\text{Diversion} = \frac{23}{210 + 23 + 45} \times 100 = 8.3\%$$

Not impressive but honest performance

2. Municipal solid waste generation

➢ Importance of Generation Rates

- Compliance with government diversion requirements
- Design of management system
- Facilities design and equipment selection
- Collection and management decisions
- Methodology
  - Materials Flow
  - Load Count

Factors Affecting Generation Rates

- Generally, changes in MSW generation can be attributed to demographics and can be broken down into two basic factors:
  - Changes in population
  - Changes in per-capita generation

Per-capita generation depends:

- Degree of urbanization
  - Population density household size
- Size of households
- Geographic location
- Season
- Socio-economic status
  - Income
  - Legislation
  - Public attitudes
- Management practices
  - Source reduction/recycling
  - Pay-As-You Throw Programs
  - Collection Frequency

➢ Strongest Correlation

- Generation increases with:
  - Population
  - Age distribution (fraction in 15-39, employment)
  - The rate of increase in GDP
- Generation decreases with average household size
- Low income areas had low amounts of plastics, paper and cardboard, but not organics

Generation and management of SW in US from 1960 to 2008

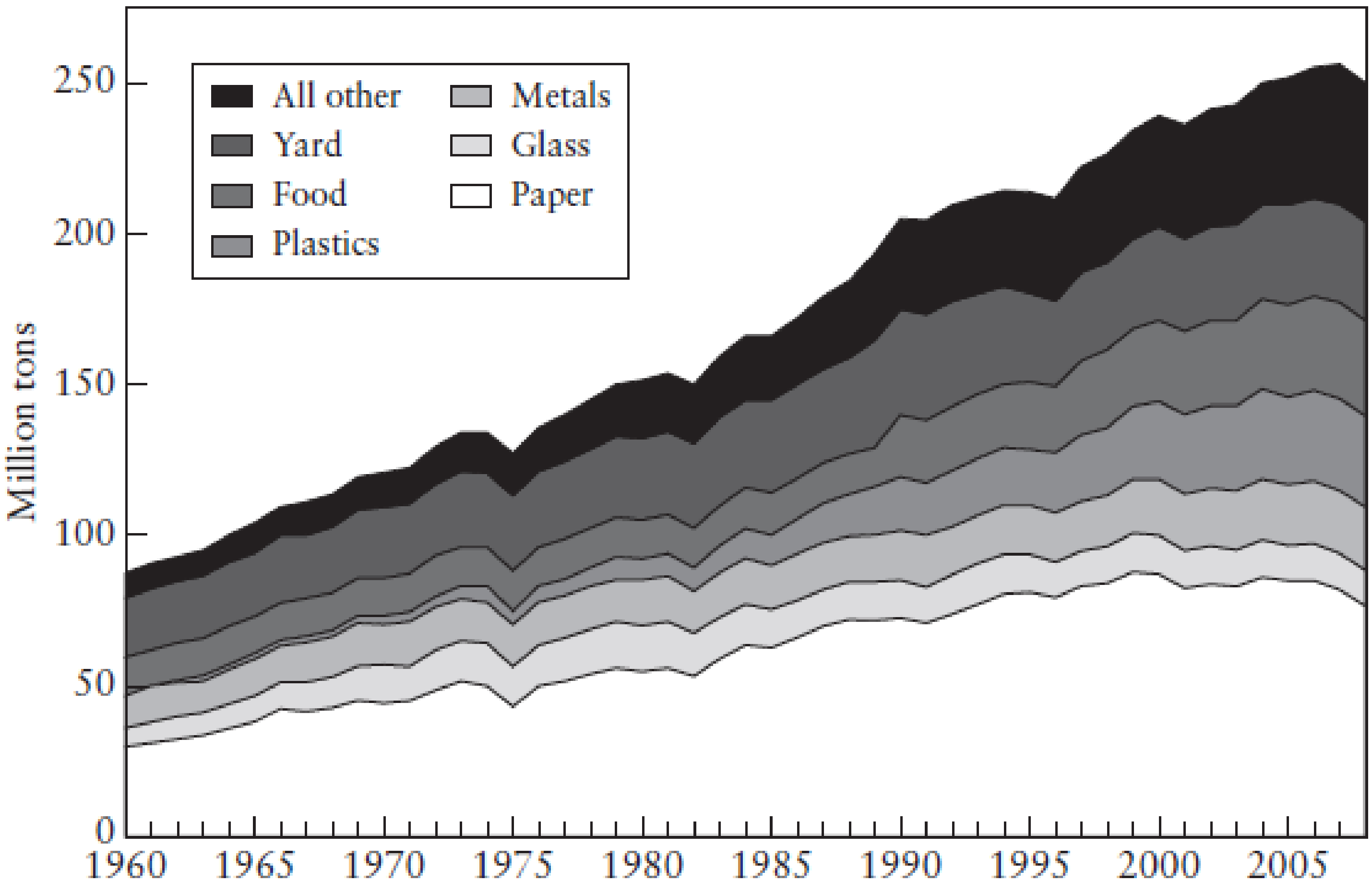
Activity	1960	1970	1980	1990	2000	2003	2005	2007	2008
Generation	88.1	121.1	151.6	205.2	239.1	242.2	249.7	254.6	249.6
Recovery for recyling	5.6	8.0	14.5	29.0	52.9	55.6	58.6	62.5	60.8
Recovery for composting*	Negligible	Negligible	Negligible	4.2	16.5	19.1	20.6	21.7	22.1
Total materials recovery	5.6	8.0	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.

Sources: [1]



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

Figure 2-2 Historical trends in municipal solid waste generation and composition in the United States.

The generation of refuse varies throughout the year.

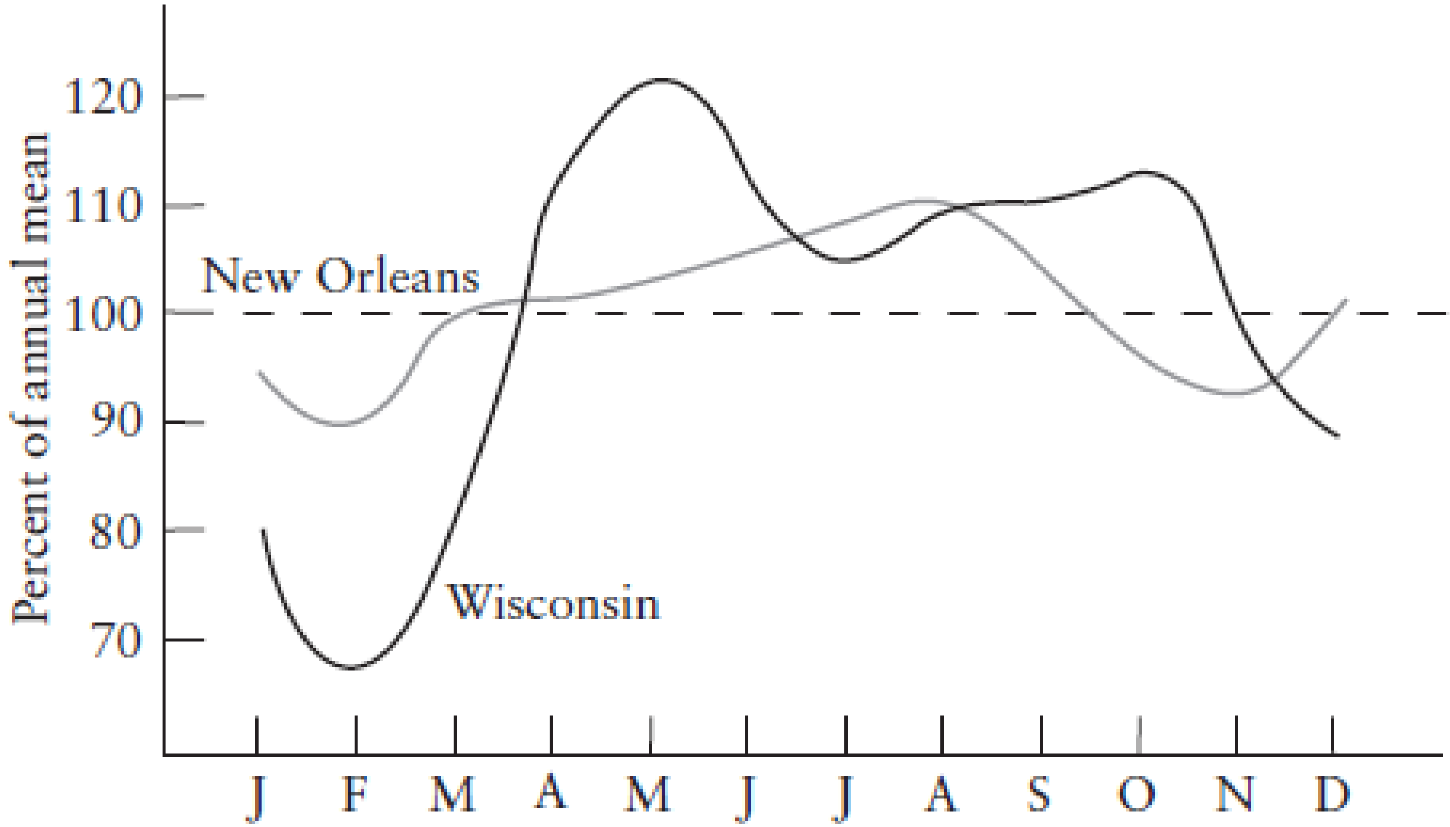


Figure 2-3 Monthly variation in the generation of municipal refuse in Wisconsin and New Orleans. Source: [2, 3]

➢ Effect of income and wealth

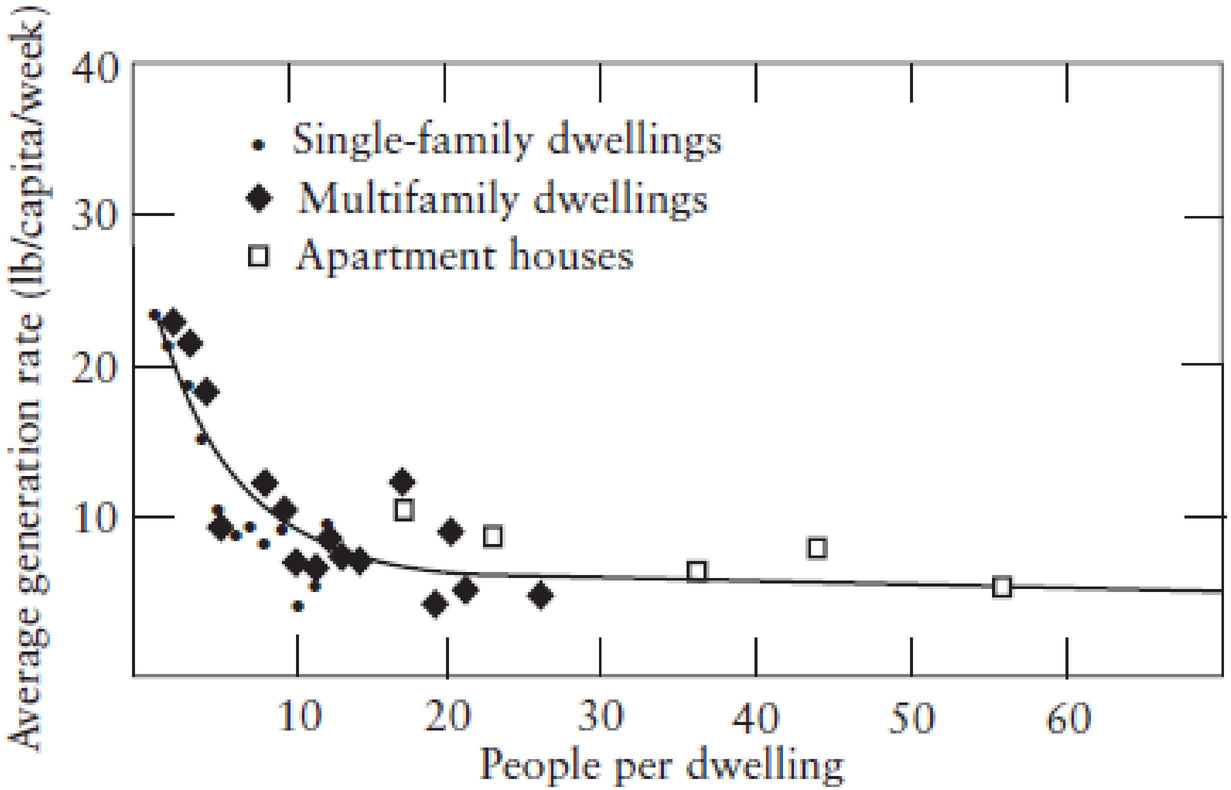


Figure 2-5 Solid waste generation as a function of number of people per dwelling in low-income areas. Source: [5]

- **Income and affluence tend to**
  - Have a positive effect on refuse generation with the logic that the more expendable income a household has, the more they tend to throw away.
  - Wealthier people tend to read more and have greater amounts of paper wastes.
  - there seems to be a positive correlation with more refuse generated by people who live in single-family residences than those who live in apartment houses

- On the other hand,
  - more affluent people eat less canned foods and purchase less wasteful packaging. Higher incomes also suggest that all adults work, and this results in the use of restaurants for meals.
  - Thus, it is possible to argue that the higher the income level, the lower will be waste generation

➢ The effect of population density

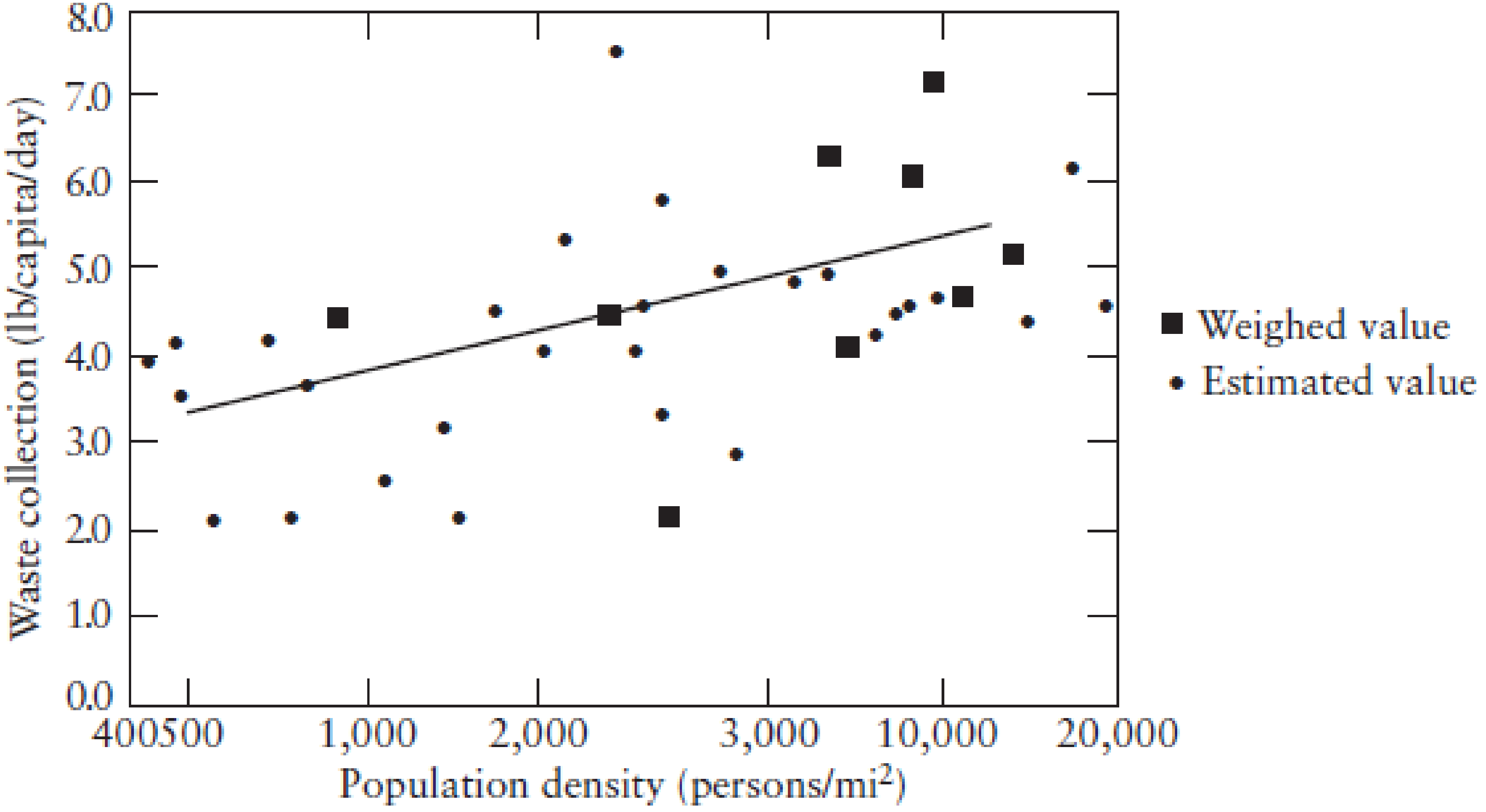


Figure 2-6 Solid waste generation as a function of population density. Source: [9]

- **The effect of population density**
  - for all communities with populations less than about 2000 people per square mile, the solid waste production is fairly constant
  - Higher population densities (beyond 2000 people per square mile) can be correlated with higher refuse generation.

➢ **Collection frequency**

- ➢ Affects the production of refuse.
  - – Generally, the more frequent the collection, the more MSW is produced.
  - – If the frequency of service is not sufficient, citizens will find
    - other, perhaps less desirable, means of solid waste disposal.
    - this might indicate that more waste diversion activities occur

3. Estimation of Waste Quantities

- **Load-count analysis**
  - A landfill without scales may estimate the vehicular capacity and the number of vehicles of that capacity
  - Weighing exercise at all waste facilities throughout the year.

- The data was collected throughout the year as under :
  - Waste intake records from landfill weighbridge and refuse transfer stations;
  - Results of quarterly exercise; and
  - Quantities of special waste and other solid waste from relevant specialist groups.

i. Compute the total weight

Item	Number of loads	Avg. Volume yd3	Specifica Weight lb/yd3	Total Weight lb col.2x3x4
Compactor truck	10	16	500	80,000
Pickup trucks with leaves loose and dry	18	3	100	5,400
private cars	56	1	220	12,320
broken concrete	2	45	2595	233,550
Total lb/day				331,270

- Determine the number of homes or population covered by the vehicles

  Say: **9,475 people**

- Determine per capita waste generation
  - Use refuse to calculate (avoid broken concrete)
  - **Then, SW per capita/day = 3.28 lb/cap.day**

ii. Household based waste generation and characterization

- A representative sample is collected directly from selected households
- Factors to be considered:
  - Number of households in the area (i.e. local authority catchment);
  - type of housing;
  - social background; and
  - type of collection system used.

- Recommended procedure for selecting and collecting a representative sample
  - A breakdown of social class groups in the local authority catchment is obtained from the Census
    - suggested that social classes be combined into three categories

- The number of households to be surveyed is determined
  - The minimum number of households = 50.
  - This will result in a sample of approximately 1,000 kg, assuming a waste generation rate of 20 kg /household/ week.
  - For practical purposes, the weight of the sample for a single survey should be kept below about 5,000 kg, which is roughly equivalent to the waste collected from about 250 households3.

- The recommended range for a survey therefore, is, roughly, 50 – 250 households.
- In larger areas, where the sample size will be greater than 250 households, it is recommended that a survey be split into several sub-surveys.
- The actual houses to be sampled are then selected from local knowledge of the sampling area.

➢ Manual Sorting Methodology

- Study Planning
- Sample Plan
- Sampling Procedure
- Data Interpretation

a. Sample Plan

- Load Selection
- Number of Samples

b. Sampling Procedure

- Vehicle Unloading
- Sample Selection and Retrieval
- Container Preparation
- Sample Placement
- Sorting

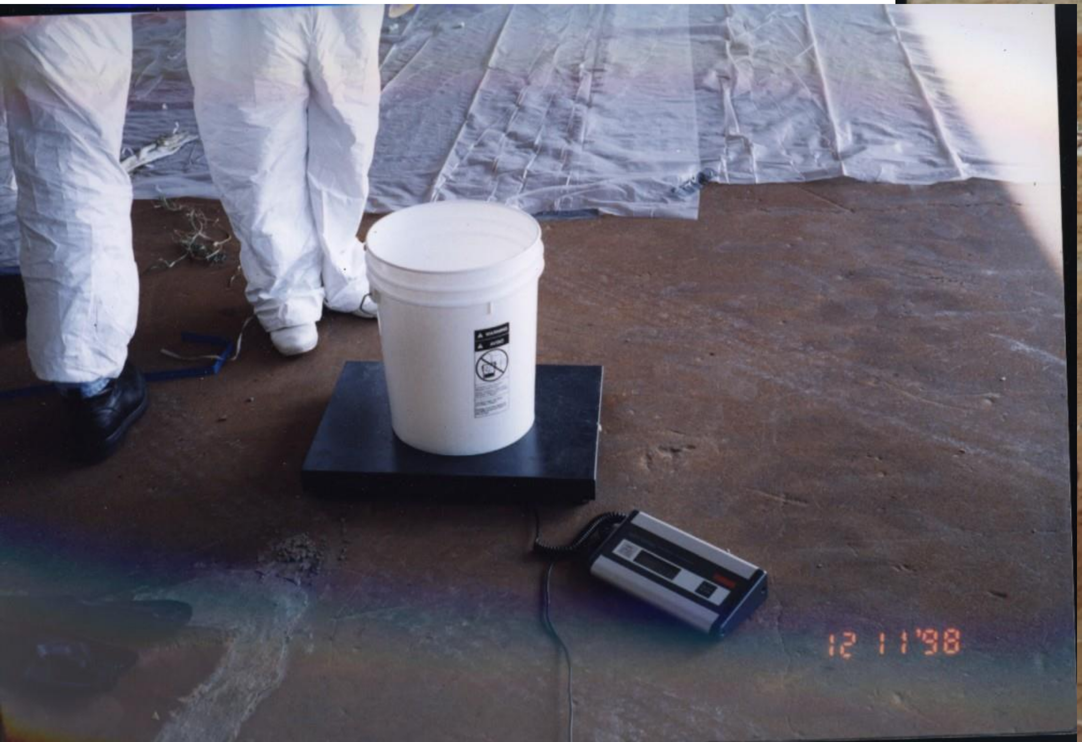
Waste contents are unloaded for sorting

Each load:

- separated manually by component
- example - Wood, concrete, plastic, metal, etc.

Each component:

- weighed and weights recorded



c. Data Interpretation

- Weighted Average based on Generator Source Composition/Distribution
- Contamination Adjustment

4. Municipal Solid Waste characteristics

- 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

- Paper
  - Newsprint
  - Magazines
  - Corrugated cardboard
  - Telephone books
  - Office/computer paper
  - Other mixed paper
- Plastics
  - PETE bottles
  - HDPE bottles
  - PVC containers
  - Polypropylene containers
  - Polystyrene
  - Other containers
  - Films/bags and other rigid plastics

- Organics
  - Food waste
  - Textiles/rubber/leather
  - Fines (unidentifiable small organic particles)
  - Other organics
- Ferrous materials
  - Ferrous/bimetal cans
  - Empty aerosols
  - Other ferrous metals

- Nonferrous metals
  - Aluminum cans
  - Other nonferrous metals
- Electronic components
  - Parts and materials from computers
  - Printers
  - Copy machines

- Glass
- Wood
- Inerts
- Yard waste

- • Hazardous materials
  - Lead acid batteries
  - Other batteries
  - Other hazardous wastes

Moisture content

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

where M = moisture content, wet basis, %

w = initial (wet) weight of sample

d = final (dry) weight of sample

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

where M_d = moisture content on a dry basis, %

Example

A residential waste has the following components:

Paper	50%
Glass	20%
Food	20%
Yard waste	10%

Estimate its moisture concentration using the typical values in Table 2-5.

Assume a wet sample weighing 100 lb. Set up the tabulation:

Solution

Component	Percent	Moisture	Dry weight (based on 100 lb)
Paper	50	6	47
Glass	20	2	19
Food	20	70	6
Yard waste	10	60	4
			Total: 76 lb dry

The moisture content (wet basis) would then be

$$M = \frac{w - d}{w}(100) = \frac{100 - 76}{100}(100) = 24\%$$

➢ Particle size

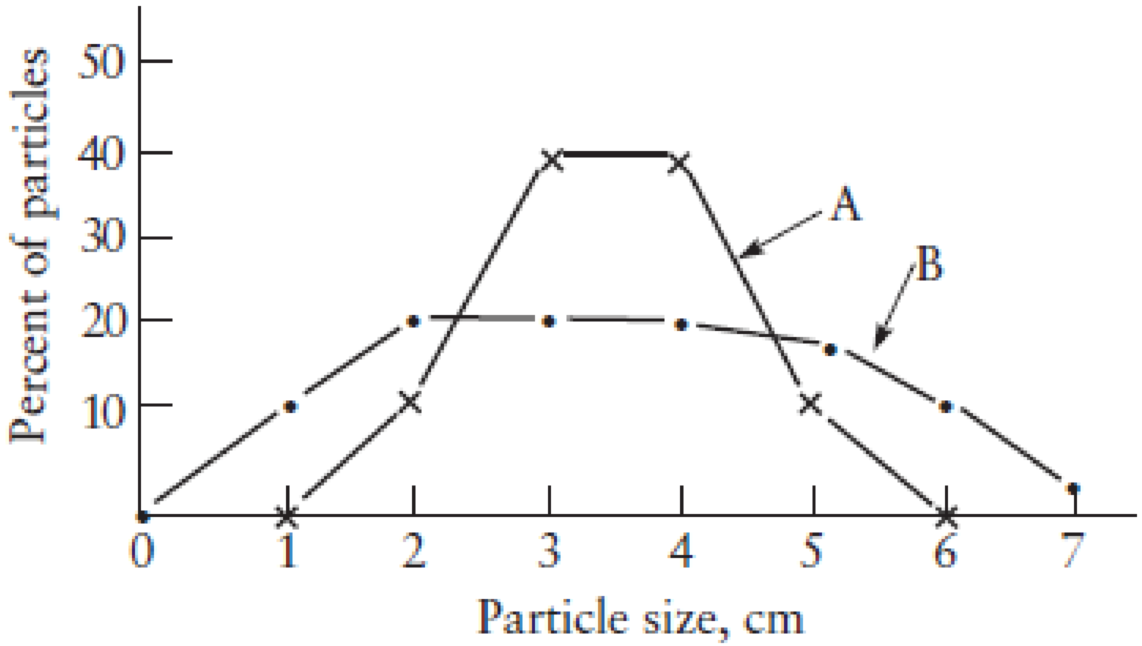


Figure 2-9 Particle-size distribution curves for two mixtures of particles.

- For non-spherical particles the diameter of a particle may be defined as any of the following:

$$D = \frac{h + w + l}{3}$$

$$D = \sqrt[3]{hwl}$$

$$D = \sqrt{lw}$$

$$D = \frac{w + l}{2}$$

where D = particle diameter
l = length
w = width
h = height

- Example

Consider non-spherical particles that are uniformly sized as length, *l* 2; width, *w* 0.5; and height, *h* 0.5. Calculate the particle diameter by the previous various definitions.

Solution:

$$D = l = 2;\ D = \frac{w + l}{2} = 1.25;\ D = \frac{h + w + l}{3} = 1.0$$
$$D = \sqrt{lw} = 1;\ D = \sqrt[3]{hwl} = 2.12$$

➢ Chemical Composition

- Used primarily for combustion and waste to energy (WTE) calculations but can also be used to estimate biological and chemical behaviors
- Waste consists of combustible (i.e. paper) and non-combustible materials (i.e. glass)

- **Proximate Analysis**
  - Loss of moisture (temp held at 105^o C)
  - Volatile Combustible Matter (VCM) (temp increased to 950^o C, closed crucible)
  - Fixed Carbon (residue from VCM)
  - Ash (temp = 950^o C, open crucible)

- Ultimate Analysis
  - Molecular composition (C, H, N, O, P, etc.)
  - Table in notes

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]

Typical Data on the Ultimate Analysis - Example

- Food Wastes
  - Carbon: 48%
  - Hydrogen: 6.5%
  - Oxygen: 37.6%
  - Nitrogen: 2.6%
  - Sulfur: 0.4%
  - Ash: 5%

2-3-5 Heat Value

Table 2-7 Heat Value of Fuels

	Heat Value		Composition (wt%)					
Fuel	(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

Energy Content

- Models are derived from physical composition and from ultimate analysis
- Determined through lab calculations using calorimeters
- Individual waste component energy contents

- Empirical Equations
  - Modified Dulong formula (wet basis):

    $$BTU/lb = 145C + 610(H2 - 02/8) + 40S + 10N$$

  - Model based on proximate analysis

    $$Kcal/kg = 45B - 6W$$

    B = Combustible volatile matter in MSW (%)

    W = Water, percent weight on dry basis

- **Bulk density solid wastes**

Table 2-9 Refuse Bulk Densities

Condition	Density (lb/yd^3
Loose refuse, no processing or compaction	150–250
In compaction truck	600–900
Baled refuse	1200–1400
Refuse in a compacted landfill (without cover)	750–1250

Table 2-10 Material Densities Commonly Found in Refuse

Material	Specific Gravity	lb/yd^3
Aluminum	2.70	4536
Steel	7.70	12,960
Glass	2.50	4212
Paper	0.70–1.15	1190–1940
Cardboard	0.69	1161
Wood	0.60	1000
Plastics		
HDPE	0.96	1590
Polypropylene	0.90	1510
Polystyrene	1.05	1755
PVC	1.25	2106

- **Biodegradability**

Table 2-11 Calculation of Biodegradable Fraction of MSW

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	

Source: [20, 28]