CE 433 : SOLID & HAZARDOUS WASTE MANAGEMENT

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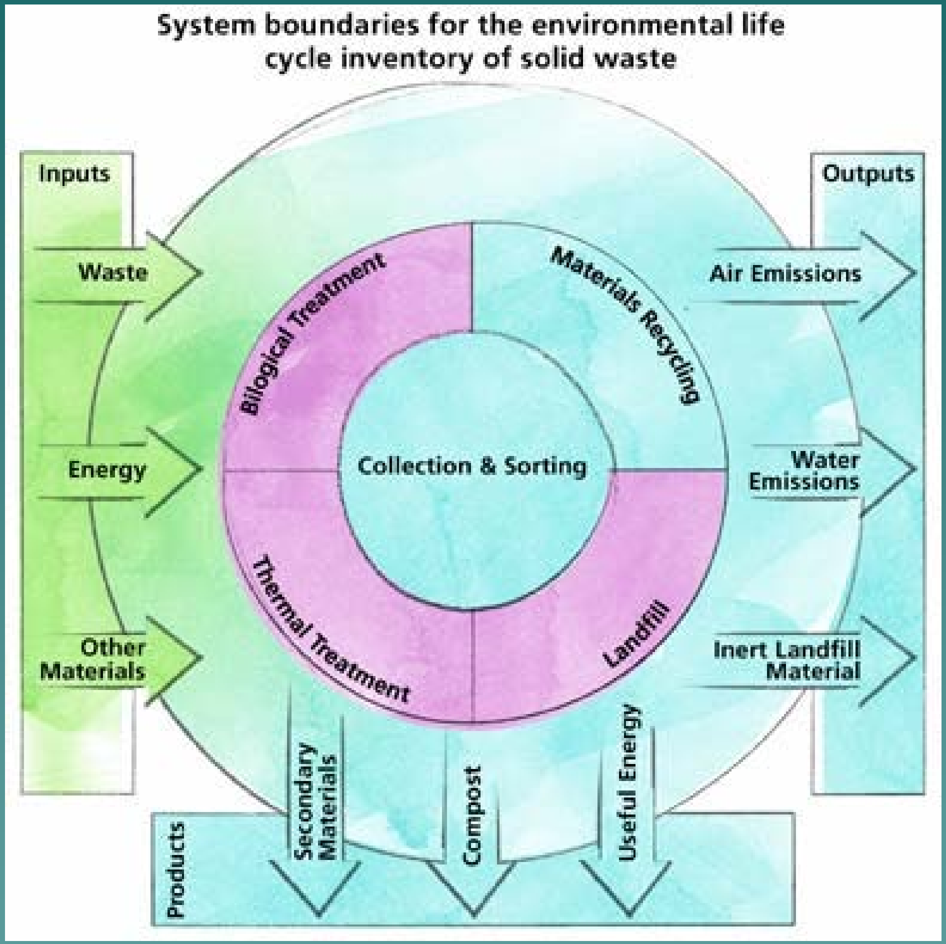
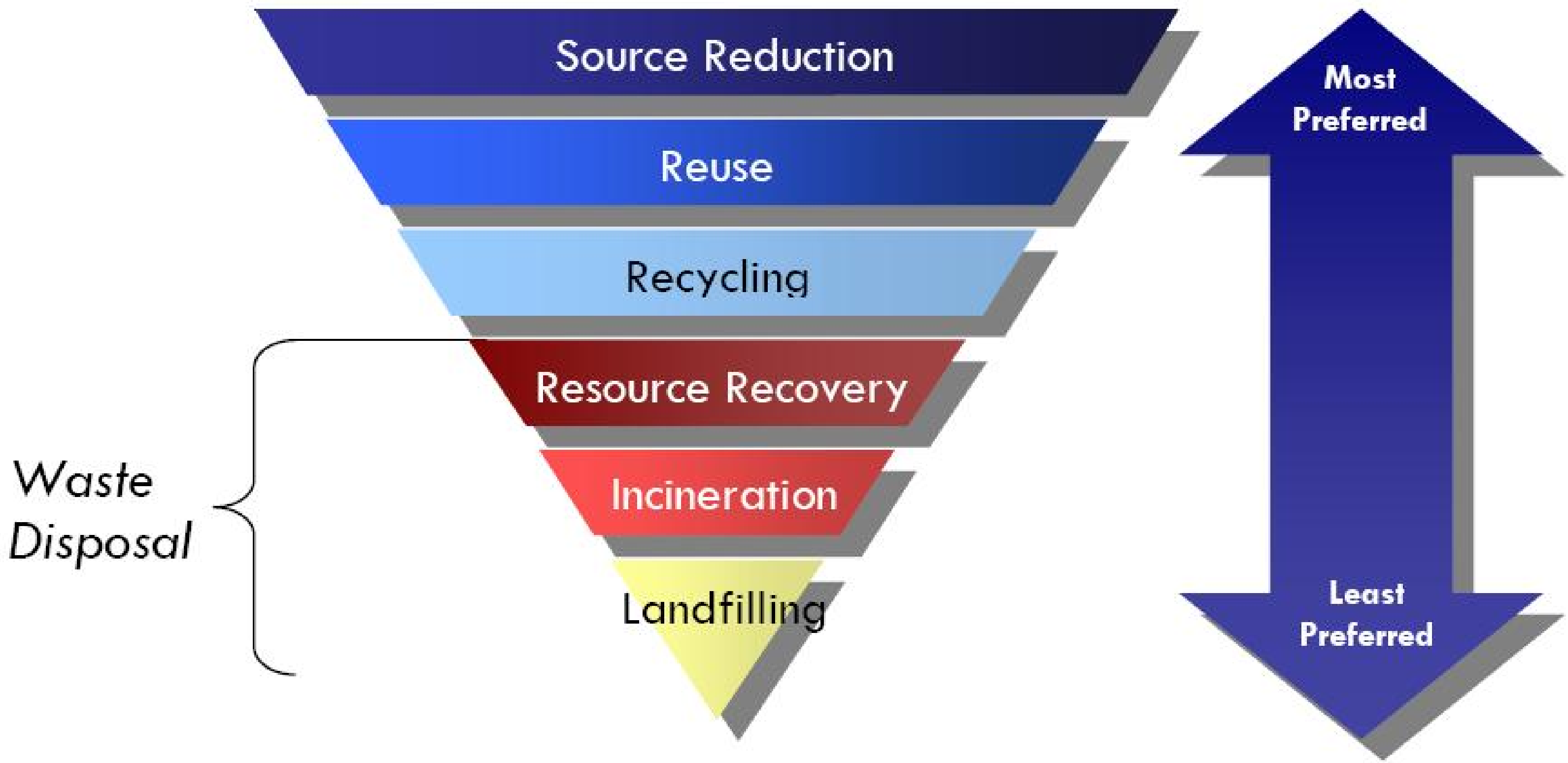
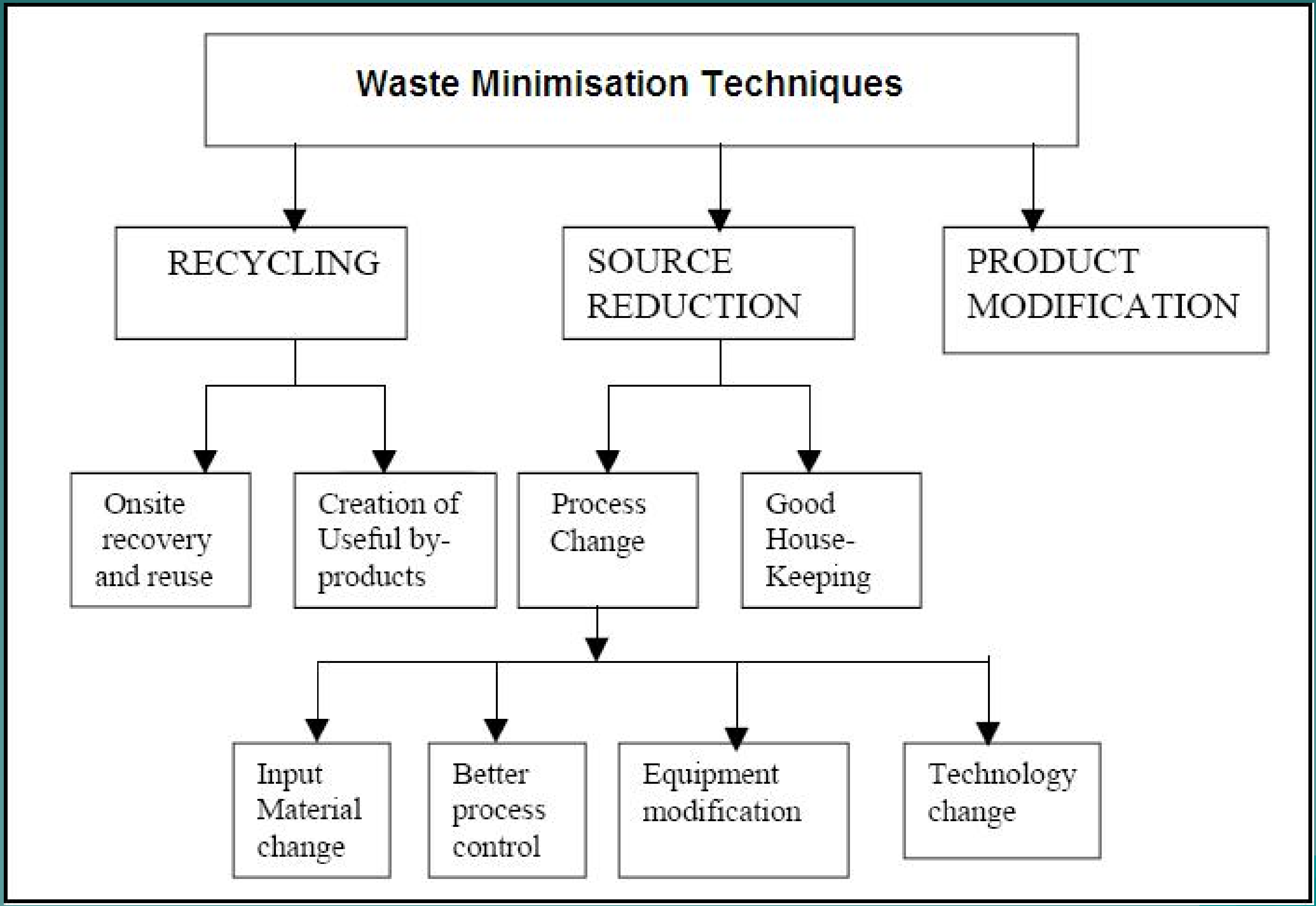

System boundaries for the environmental life cycle inventory of solid waste
Inputs
Waste
Energy
Other Materials
Outputs
Air Emissions
Water Emissions
Inert Landfill Material
Bilogical Treatment
Materials Recycling
Collection & Sorting
Thermal Treatment
Landfill
Products
Secondary Materials
Compost
Useful Energy

Figure 3-1. The Solid Waste Management Hierarchy




Waste Minimisation Techniques
RECYCLING
SOURCE REDUCTION
PRODUCT MODIFICATION
Onsite recovery and reuse
Creation of Useful by-products
Process Change
Good House-Keeping
Input Material change
Better process control
Equipment modification
Technology change

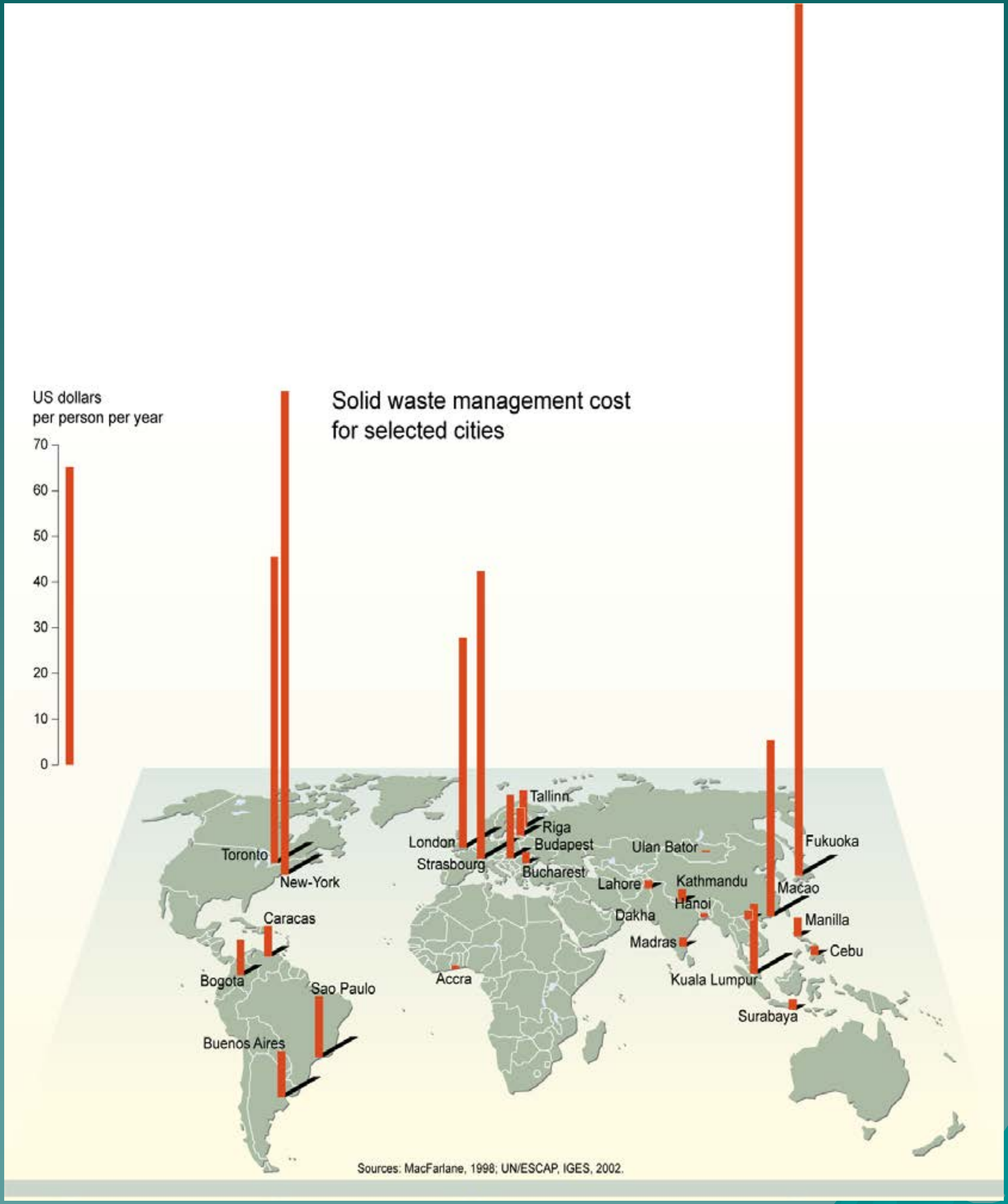

US dollars
per person per year
70
60
50
40
30
20
10
0
Solid waste management cost
for selected cities
Toronto
New-York
Caracas
Bogota
Sao Paulo
Buenos Aires
London
Strasbourg
Tallinn
Riga
Budapest
Bucharest
Accra
Ulan Bator
Lahore
Kathmandu
Hanoi
Dakha
Madras
Kuala Lumpur
Surabaya
Fukuoka
Macao
Manilla
Cebu
Sources: MacFarlane, 1998; UN/ESCAP, IGES, 2002.

TABLE 3-1

Sources of solid wastes within a community[a]

Source	Typical facilities, activities, or locations where wastes are generated	Types of solid wastes
Residential	Single family and multifamily detached dwellings, low-, medium-, and high-rise apartments, etc.	Food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, tin cans, aluminum, other metals, ashes, street leaves, special wastes (including bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires), household hazardous wastes
Commercial	Stores, restaurants, markets, office buildings, hotels, motels, print shops, service stations, auto repair shops, etc.	Paper, cardboard, plastics, wood, food waste, glass, metals, special wastes (see above), hazardous wastes, etc.
Institutional	Schools, hospitals, prisons, governmental centers	As above in commercial
Construction and demolition	New construction sites, road repair/renovation sites, razing of buildings, broken pavement	Wood, steel, concrete, dirt, etc.
Municipal services (excluding treatment facilities)	Street cleaning, landscaping, catch basin cleaning, parks and beaches, other recreational areas	Special wastes, rubbish, street sweepings, landscape and tree trimmings, catch basin debris, general wastes from parks, beaches, and recreational areas
Treatment plant sites; municipal incinerators	Water, wastewater, and industrial treatment processes, etc.	Treatment plant wastes, principally composed of residual sludges
Municipal solid waste[b]	All of the above	All of the above
Industrial	Construction, fabrication, light and heavy manufacturing, refineries, chemical plants, power plants, demolition, etc.	Industrial process wastes, scrap materials, etc. Non-industrial wastes including food wastes, rubbish, ashes, demolition and construction wastes, special wastes, hazardous wastes
Agricultural	Field and row crops, orchards, vineyards, dairies, feedlots, farms, etc.	Spoiled food wastes, agricultural wastes, rubbish, hazardous wastes

[a] For comparison, the sources of waste and waste classifications used in the early 1900s are given in Table 3-12.

[b] The term *municipal solid waste* (MSW) normally is assumed to include all of the wastes generated in a community with the exception of industrial process wastes and agricultural solid wastes.

TABLE 3-3
Estimated distribution of all components of MSW generated in a typical community excluding industrial and agricultural wastes[a]

Waste category[b]	Percent by weight: Range	Percent by weight: Typical
Residential and commercial, excluding special and hazardous wastes	50–75	62.0
Special (bulky items, consumer electronics, white goods, yard wastes collected separately, batteries, oil, and tires)	3–12	5.0
Hazardous[c]	0.01–1.0	0.1
Institutional	3–5	3.4
Construction and demolition	8–20	14.0
Municipal services		
Street and alley cleanings	2–5	3.8
Tree and landscaping	2–5	3.0
Parks and recreational areas	1.5–3	2.0
Catch basin	0.5–1.2	0.7
Treatment plant sludges	3–8	6.0
Total		100.0

[a] Adapted in part from Refs. 9, 14–16.

[b] See Table 6-3 for estimated quantities of waste generated.

[c] Range of reported values varies widely depending on method used to identify and classify hazardous wastes found in MSW.

Properties of Solid Waste

- Physical composition of solid wastes includes:
  1. Identification of individual components that make up municipal solid wastes
  2. Analysis of particle size
  3. Moisture content
  4. Specific weight of solids
  5. Permeability of compacted waste

TABLE 3-4
Typical physical composition of residential MSW excluding recycled materials and food wastes discharged with wastewater (1990)

	Percent by weight			
	United States[a]			
Component	Range	Typical[b]	Packaging materials[c]	Davis, California[d]
Organic				
Food wastes	6–18	9.0	—	6.0
Paper	25–40	34.0	50–60	33.1
Cardboard	3–10	6.0		7.9
Plastics	4–10	7.0	12–16	10.7
Textiles	0–4	2.0	—	2.4
Rubber	0–2	0.5	—	2.5
Leather	0–2	0.5	—	0.1
Yard wastes	5–20	18.5	—	17.7
Wood	1–4	2.0	4–8	5.0
Misc. organics	—	—	—	0.4
Inorganic				
Glass	4–12	8.0	20–30	5.8
Tin cans	2–8	6.0	6–8	3.9
Aluminum	0–1	0.5	2–4	0.4
Other metal	1–4	3.0	—	3.6
Dirt, ash, etc.	0–6	3.0	—	0.5
Total		100.0		100.0

[a] Adapted in part from Refs. 2, 3, 9, and 14–16. Reported percentage distributions are exclusive of special and hazardous wastes.

[b] Twenty percent of the households in the United States are assumed to have food waste grinders. Additionally, it is assumed that the percentage of food waste ground up and discharged with wastewater is 25 percent. Current (1990) recycling rate for the United States assumed to be 11 percent.

[c] Adapted in part from Ref. 10.

[d] Based on measurements made over a five-year period (1985 to 1990) during the first two weeks of October (see Table 3-9).

TABLE 3-5

Typical distribution of components in residential MSW for low-, middle-, and upper-income countries excluding recycled materials[a,b]

Component	Low-income countries	Middle-income countries	Upper-income countries[c]
Organic			
Food wastes	40–85[d]	20–65	6–30
Paper	1–10	8–30	20–45
Cardboard			5–15
Plastics	1–5	2–6	2–8
Textiles	1–5	2–10	2–6
Rubber	1–5	1–4	0–2
Leather			0–2
Yard wastes	1–5	1–10	10–20
Wood			1–4
Misc. organics	—	—	—
Inorganic			
Glass	1–10	1–10	4–12
Tin cans	1–5	1–5	2–8
Aluminum			0–1
Other metal			1–4
Dirt, ash, etc.	1–40	1–30	0–10

[a] Adapted in part from Refs. 1 and 17.

[b] Low-income countries: per capita income of less than U.S. $750 in 1990.
Middle-income countries: per capita income of more than U.S. $750 and less than U.S. $5000 in 1990.
Upper-income countries: per capita income of more than U.S. $5000 in 1990.

[c] Upper-income countries are more highly industrialized.

[d] Food wastes composed predominantly of waste from the preparation of food (corn husks, melon rinds, banana leaves, etc.).

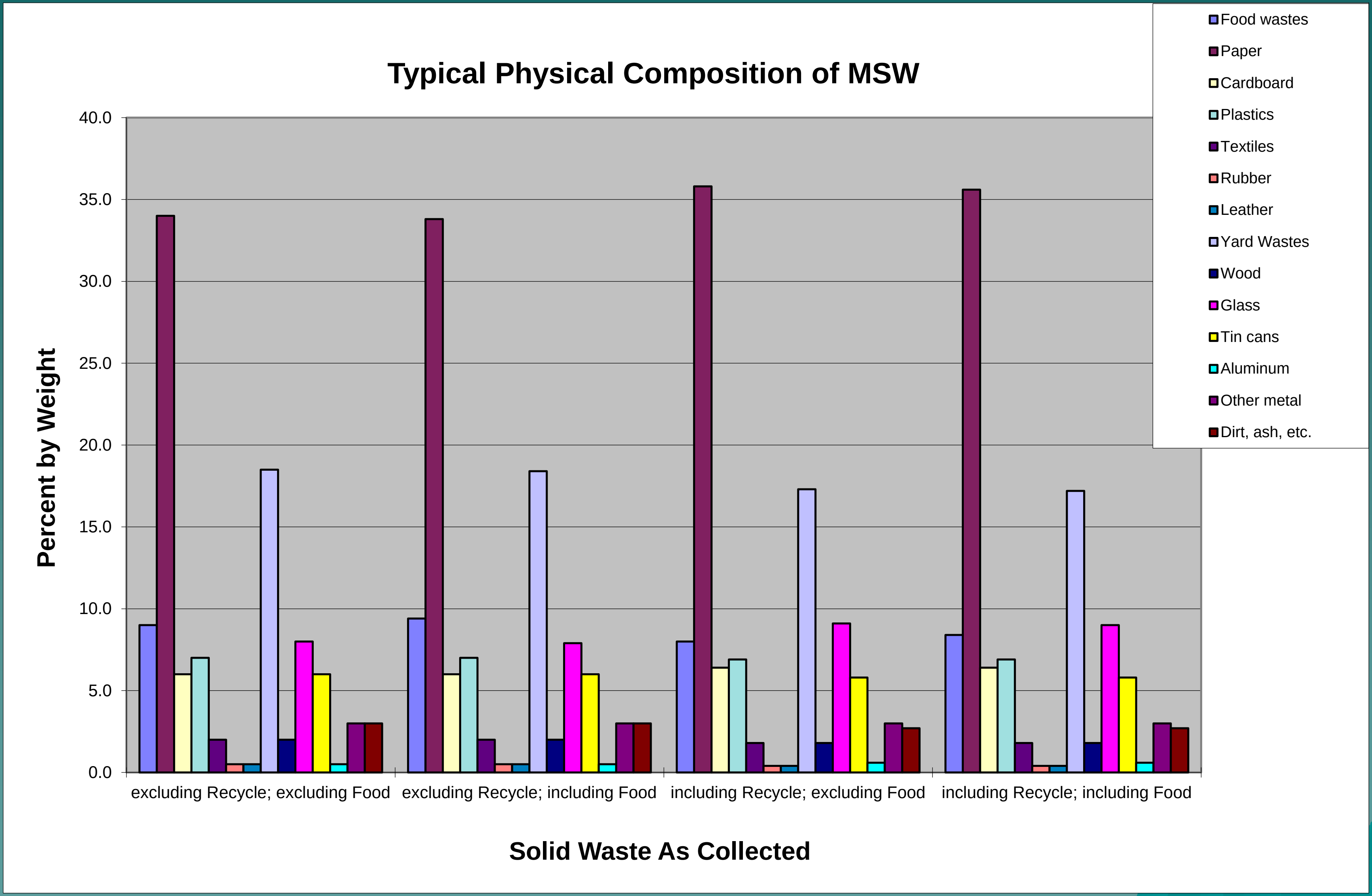
TABLE 3-6
Typical data on the distribution of solid wastes generated by major industries excluding recycled materials and industrial process wastes[a]

SIC Code		Percent by weight									
		Food wastes[b]	Paper	Wood	Leather	Rubber	Plastics	Metals	Glass	Textiles	Misc.
20	Food and kindred products	15–20	50–60	5–10	0–2	0–2	0–5	5–10	4–10	0–2	5–15
22	Textile mill products	0–2	40–50	0–2	0–2	0–2	3–10	0–2	0–2	20–40	0–5
23	Apparel and other finished products	0–2	40–60	0–2	0–2	0–2	0–2	0–2	0–2	30–50	0–5
24	Lumber and wood products	0–2	10–20	60–80	0–2	0–2	0–2	0–2	0–2	0–2	5–10
25a	Furniture, wood	0–2	20–30	30–50	0–2	0–2	0–2	0–2	0–2	0–5	0–5
25b	Furniture, metal	0–2	20–40	10–20	0–2	0–2	0–2	20–40	0–2	0–5	0–10
26	Paper and allied products	0–2	40–60	10–15	0–2	0–2	0–2	5–15	0–2	0–2	10–20
27	Printing and publishing	0–2	60–90	5–10	0–2	0–2	0–2	0–2	0–2	0–2	0–5
28	Chemicals and related products	0–2	40–60	2–10	0–2	0–2	5–15	5–10	0–5	0–2	15–25
29	Petroleum refining and related industries	0–2	60–80	5–15	0–2	0–2	10–20	2–10	0–2	0–2	2–10
30	Rubber and miscellaneous plastic products	0–2	40–60	2–10	0–2	5–20	10–20	0–2	0–2	0–2	0–5
31	Leather and leather products	0–2	5–10	5–10	40–60	0–2	0–2	10–20	0–2	0–2	0–5
32	Stone, clay, and glass products	0–2	20–40	2–10	0–2	0–2	0–2	5–10	10–20	0–2	30–50
33	Primary metal industries	0–2	30–50	5–15	0–2	0–2	2–10	2–10	0–5	0–2	20–40
34	Fabricated metal products	0–2	30–50	5–15	0–2	0–2	0–2	15–30	0–2	0–2	5–15
35	Machinery (except electrical)	0–2	30–50	5–15	0–2	0–2	1–5	15–30	0–2	0–2	0–5
36	Electrical	0–2	60–80	5–15	0–2	0–2	2–5	2–5	0–2	0–2	0–5
37	Transportation equipment	0–2	40–60	5–15	0–2	0–2	2–5	0–2	0–2	0–2	15–30
38	Professional scientific controlling instruments	0–2	30–50	2–10	0–2	0–2	5–10	5–15	0–2	0–2	0–5
39	Miscellaneous manufacturers	0–2	40–60	10–20	0–2	0–2	5–15	2–10	0–2	0–2	5–15

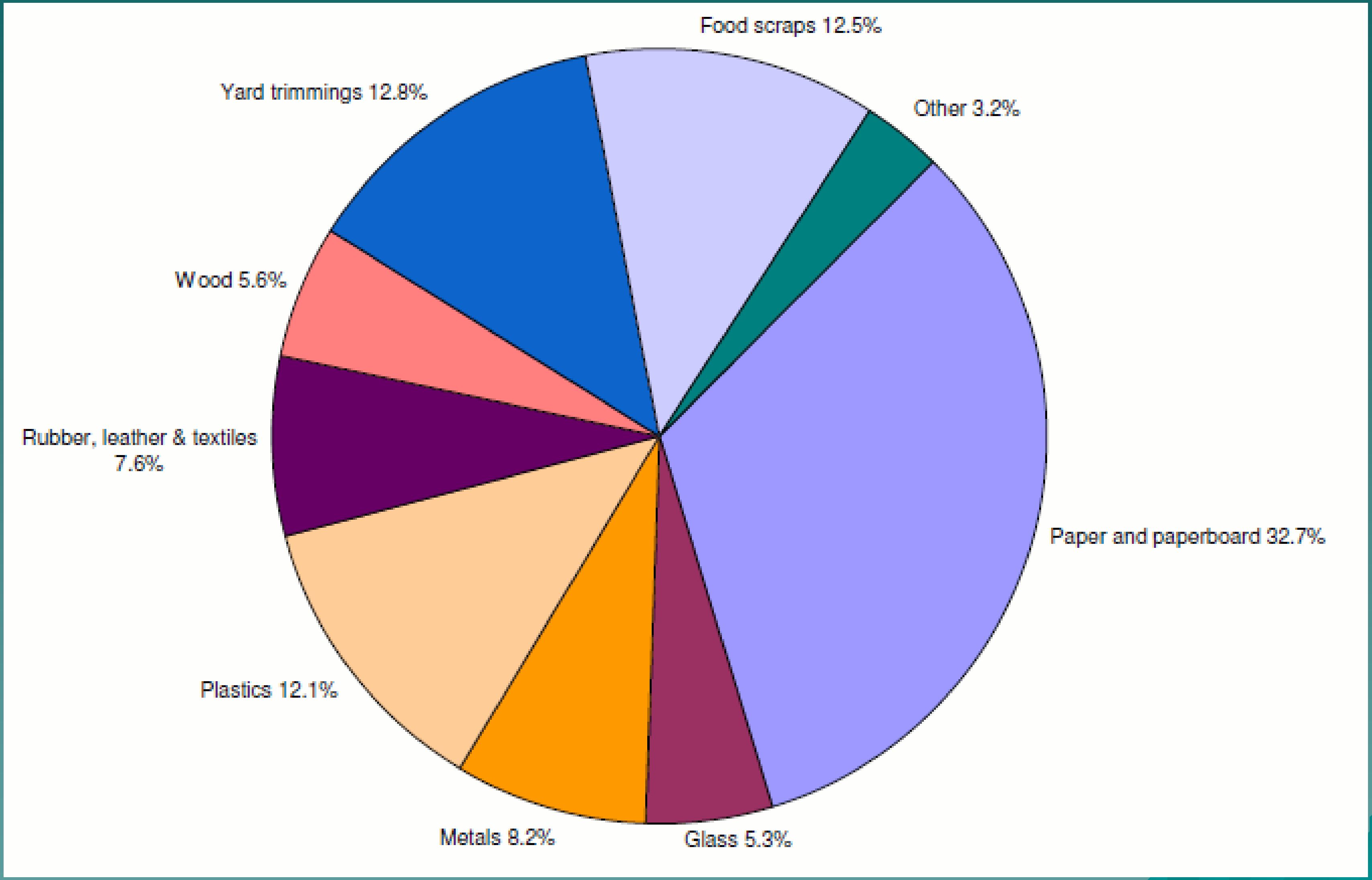
[a] From Ref. 13.

[b] With the exception of food and kindred products, food wastes are from company cafeterias, canteens, etc.

Component	Solid Waste *as collected* excluding waste components now recycled and excluding food waste that is ground up. excluding Recycle; excluding Food	Solid Waste *as collected* plus food waste that is ground up, but excluding waste components now recycled excluding Recycle; including Food	Solid Waste *as collected* plus waste components now recycled, but excluding food waste that is ground up including Recycle; excluding Food	Solid Waste *as collected* plus waste components now recycled and plus food waste that is ground up including Recycle; including Food
Food wastes	9.0	9.4	8.0	8.4
Paper	34.0	33.8	35.8	35.6
Cardboard	6.0	6.0	6.4	6.4
Plastics	7.0	7.0	6.9	6.9
Textiles	2.0	2.0	1.8	1.8
Rubber	0.5	0.5	0.4	0.4
Leather	0.5	0.5	0.4	0.4
Yard Wastes	18.5	18.4	17.3	17.2
Wood	2.0	2.0	1.8	1.8
Misc. Organics				
Inorganic				
Glass	8.0	7.9	9.1	9.0
Tin cans	6.0	6.0	5.8	5.8
Aluminum	0.5	0.5	0.6	0.6
Other metal	3.0	3.0	3.0	3.0
Dirt, ash, etc.	3.0	3.0	2.7	2.7
Total	100.0	100.0	100.0	100.0



Typical Physical Composition of MSW
Percent by Weight
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
excluding Recycle; excluding Food
excluding Recycle; including Food
including Recycle; excluding Food
including Recycle; including Food
Solid Waste As Collected
Food wastes
Paper
Cardboard
Plastics
Textiles
Rubber
Leather
Yard Wastes
Wood
Glass
Tin cans
Aluminum
Other metal
Dirt, ash, etc.


Food scraps 12.5%
Other 3.2%
Yard trimmings 12.8%
Wood 5.6%
Rubber, leather & textiles 7.6%
Paper and paperboard 32.7%
Plastics 12.1%
Metals 8.2%
Glass 5.3%

Component (1)	Percent by weight: Solid waste *as collected* excluding recycled waste components and ground up food waste[a] (2)	Percent by weight: Solid waste components now recycled (not reflected in *as collected* distribution) (3)	Weight of solid waste components now recycled (11 lb based on a total of 100 lb excluding ground up food waste), lb[b] (4)	Solid waste *as collected* excluding waste now recycled (89 lb based on a total 100 lb excluding ground up food waste), lb[c] (5)	Percent by weight: Solid waste *as collected* plus recycled wastes[b] (6) = (4) + (5)	Percent by weight: Solid waste *as collected* plus recycled and ground up food waste[d] (7)
Organic						
Food wastes	9.0	0.0	0.00	8.01	8.0	8.4
Paper	34.0	50.0	5.50	30.26	35.8	35.6
Cardboard	6.0	10.0	1.10	5.34	6.4	6.4
Plastics	7.0	6.0	0.66	6.23	6.9	6.9
Textiles	2.0	0.0	0.00	1.78	1.8	1.8
Rubber	0.5	0.0	0.00	0.45	0.4	0.4
Leather	0.5	0.0	0.00	0.45	0.4	0.4
Yard wastes	18.5	8.0	0.88	16.46	17.3	17.2
Wood	2.0	0.0	0.00	1.78	1.8	1.8
Misc. organics	—	—	—	—	—	—
Inorganic						
Glass	8.0	18.0	1.98	7.12	9.1	9.0
Tin cans	6.0	4.0	0.44	5.34	5.8	5.8
Aluminum	0.5	1.0	0.11	0.44	0.6	0.6
Other metal	3.0	3.0	0.33	2.67	3.0	3.0
Dirt, ash, etc.	3.0	0.0	0.00	2.67	2.7	2.7
Total	100.0	100.0	11.00[b]	89.00	100.0	100.0

[a] From Table 3-4.

[b] Amount now recycled = 11 percent or 11 lb based on 100 lb.

[c] 89.0 lb = 100 lb − 11 lb (amount now recycled).

[d] Column 7 represents the percentage distribution of the total amount of waste generated including the waste components that are now recycled and the food wastes that are ground up.

TABLE 3-10
Materials that have been recovered for recycling from MSW[a]

Recyclable material	Types of materials or uses
Aluminum	Soft drink and beer cans
Paper	
Old newspaper (ONP)	Newsstand and home-delivered newspaper
Corrugated cardboard	Bulk packaging; largest single source of waste paper for recycling
High-grade paper	Computer paper, white ledger paper, and trim cuttings
Mixed paper	Various mixtures of clean paper, including newsprint, magazines, and white and colored long-fiber paper
Plastics	
Polyethylene terephthalate (PETE/1)	Soft drink bottles, salad dressing and vegetable oil bottles; photographic film
High-density polyethylene (HDPE/2)	Milk jugs, water containers, detergent and cooking oil bottles
Polyvinyl chloride (PVC/3)	Home landscaping irrigation piping, some food packaging, and bottles
Low-density polyethylene (LDPE/4)	Thin-film packaging and wraps; dry cleaning film bags; other film material
Polypropylene (PP/5)	Closures and labels for bottles and containers, battery casings, bread and cheese wraps, cereal box liners
Polystyrene (PS/6)	Packaging for electronic and electrical components, foam cups, fast food containers, tableware and microwave plates
Multilayer and other (7)	Multilayered packaging, ketchup and mustard bottles
Mixed plastics	Various combinations of the above products
Glass	Clear, green, and brown glass bottles and containers
Ferrous metal	Tin cans, white goods, and other metals
Nonferrous metals	Aluminum, copper, lead, etc.
Yard wastes, collected separately	Used to prepare compost; biomass fuel; intermediate landfill cover
Organic fraction of MSW	Used to prepare compost for soil applications; compost for use as intermediate landfill cover; methane; ethanol and other organic compounds; refuse-derived fuel (RDF)
Construction and demolition wastes	Soil, asphalt, concrete, wood, drywall, shingles, metals
Wood	Packing materials, pallets, scraps, and used wood from construction projects
Waste oil	Automobile and truck oil; reprocessed for reuse or fuel
Tires	Automobile and truck tires; road building material; fuel
Lead-acid batteries	Automobile and truck batteries; shredded to recover individual components such as acid, plastic, and lead
Household batteries	Potential recovery of zinc, mercury, and silver

[a]Detailed information on the recycling opportunities for the individual materials may be found in Chapter 15.

Moisture Content:

$$M = \left(\frac{w - d}{w}\right) \times 100$$

M = Moisture Content (%)
w = initial weight of sample as delivered, (kg)
d = weight of sample after drying at 105 °C

Particle Size:

$$S_c = l$$

$$S_c = \left(\frac{l + w}{2}\right)$$

$$S_c = \left(\frac{l + w + h}{3}\right)$$

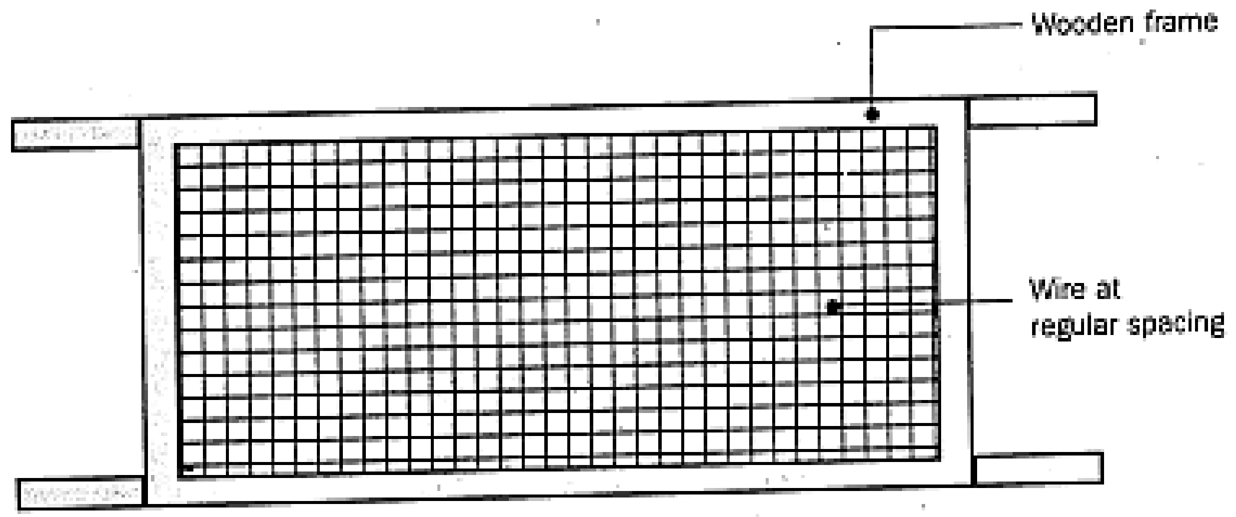
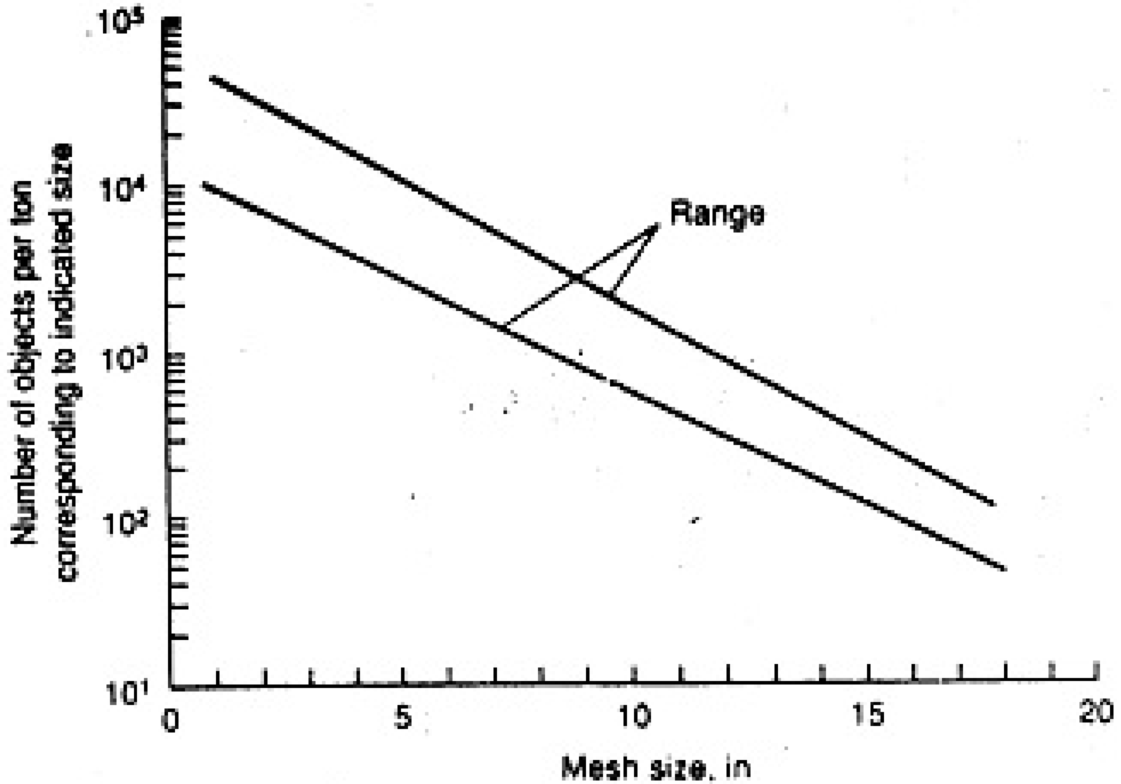
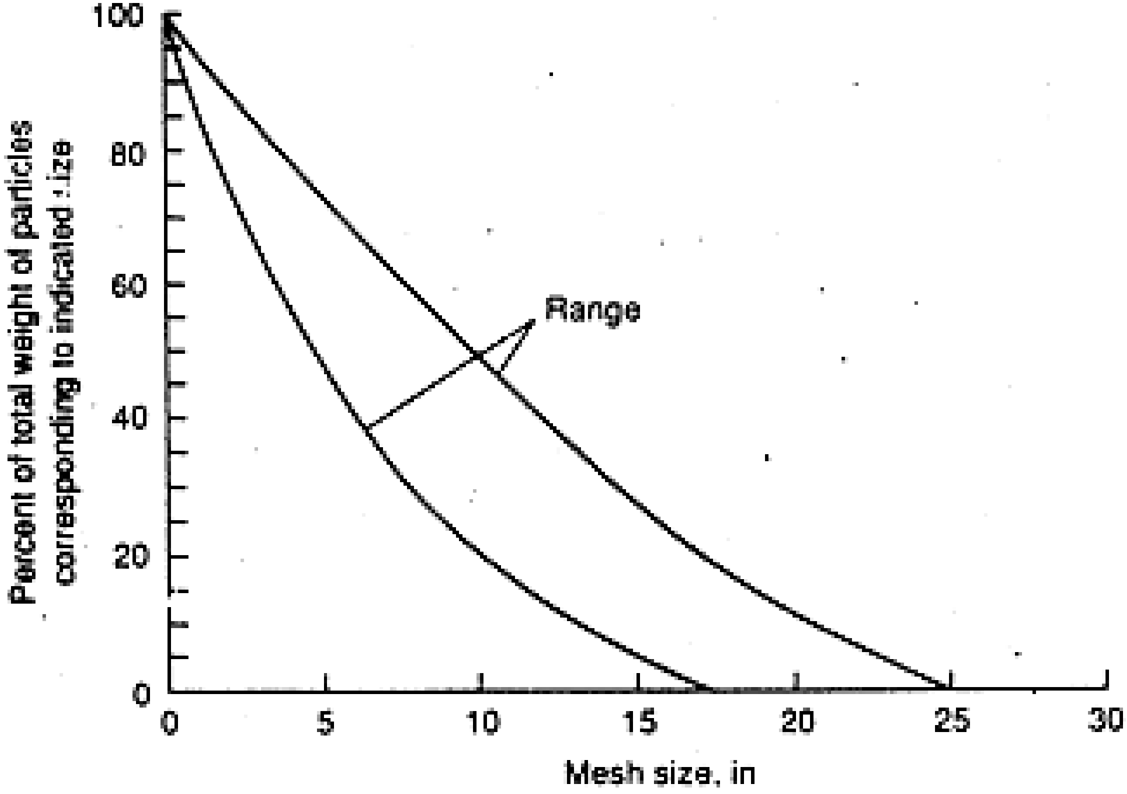


Figure 2.1. A typical screen for determining size distribution



Typical sizes of individual components comprising residential and commercial MSW [4, 12].



Percentage of total mass of residential and commercial MSW as a function of mesh size [4, 12

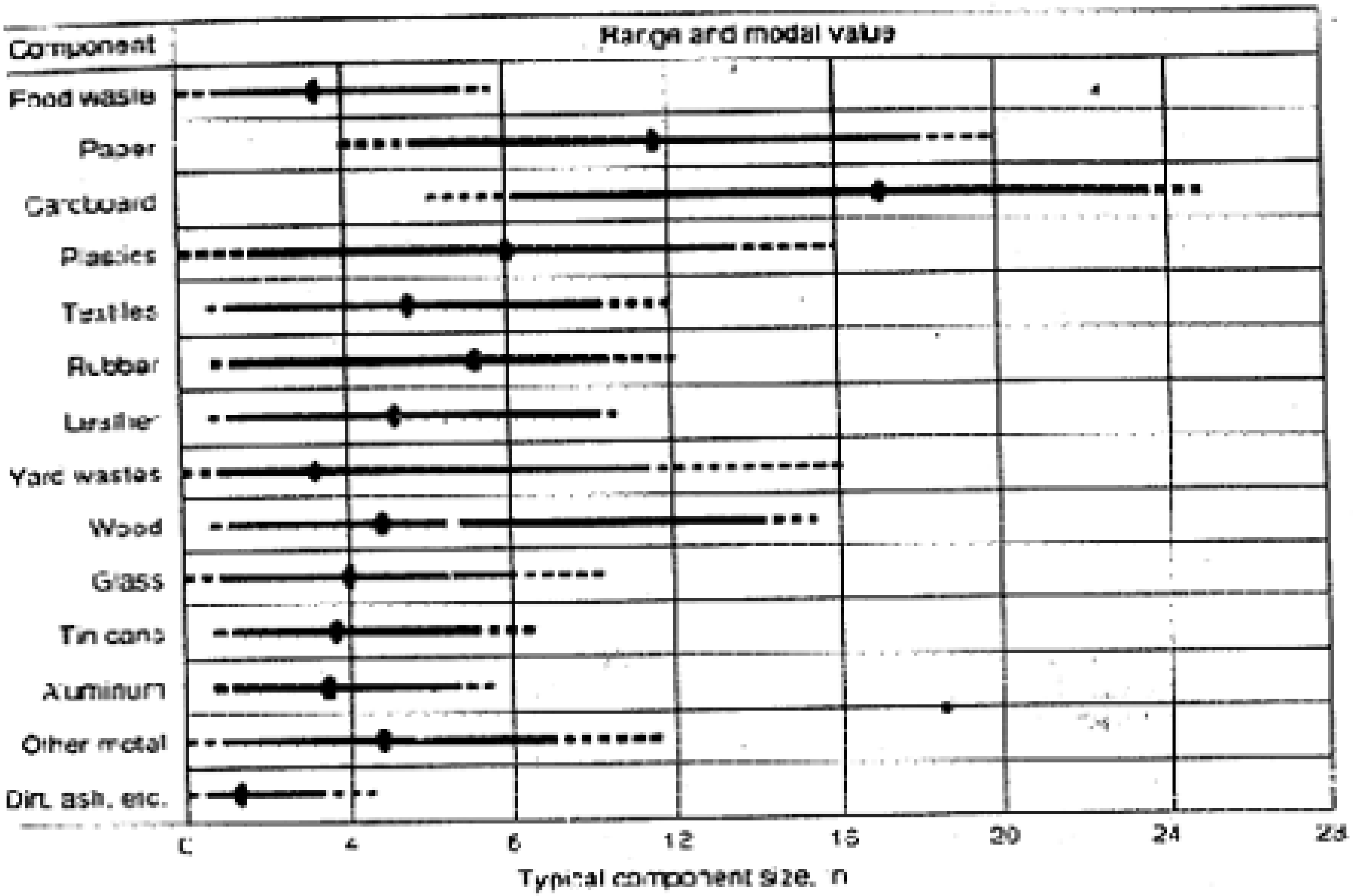


FIGURE 4-3
Typical size distribution of the components found in residential MSW (adapted, in part, from Ref. 4).

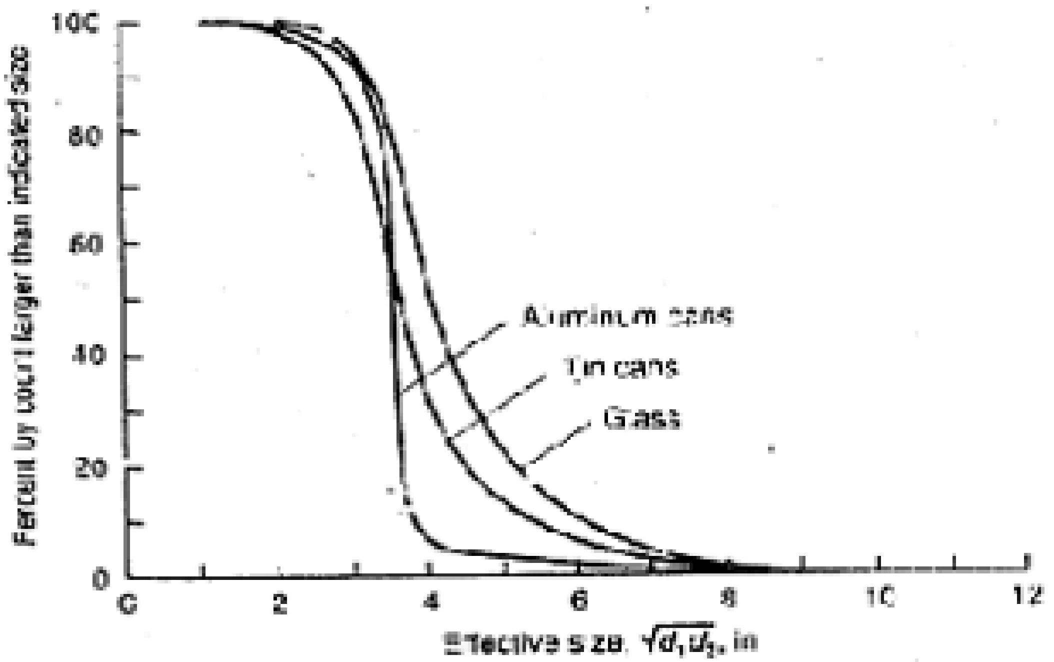


FIGURE 4-4
Typical distribution by count of effective sizes $(l \times w)^{1/2}$ of aluminum cans, tin cans, and glass containers found in residential MSW as delivered to a landfill.

Table 7.2.5 : Moisture Content (%) of As-Discarded Solid Waste Components at Different Locations of Dhaka City

Classification	Location	Food waste	Paper	Polythene	Cloth	Garden trimming	Brick, wood, metal and glass	Leaves and branches	Shredded skin and leather
C A	Motijheel (Prime Bank)	76.77	69.43	70.61	0.00	0.00	18.96	56.99	0.00
C A	Newmarket	78.70	74.80	70.00	43.20	0.00	0.00	80.50	0.00
C A	Motijheel (Shilpa Bhaban)	54.60	55.70	51.60	60.30	0.00	0.00	0.00	0.00
I A	Tejgaon (Apollo Steel Mills)	68.76	52.00	76.29	60.91	0.00	20.00	80.77	0.00
I A	Hajaribag (Paramount Tanneries)	0.00	68.99	0.00	0.00	0.00	0.00	0.00	63.87
I A	Hajaribag	70.00	30.00	22.00	0.00	0.00	23.70	0.00	32.30
I A	Tejgaon (Kohinoor Co.)	61.90	27.10	21.10	0.00	0.00	0.00	0.00	0.00
I A	Tejgaon (Eastern Tubes)	66.00	40.50	54.30	0.00	0.00	0.00	0.00	0.00
HIG-R	Banani (Chairman bari)	53.20	44.77	54.73	31.58	0.00	8.03	37.55	0.00
HIG-R	Banani R / A	62.18	-46.43	49.83	17.78	66.81	1.47	46.34	0.00
HIG-R	Gulshan (south of central mosque)	61.17	55.61	47.89	76.70	0.00	0.00	0.00	0.00
HIG-R	Dhanmondi R/A road No. 8	43.55	26.56	49.04	47.62	51.14	0.00	0.00	0.00
HIG-R	Dhanmondi R/A road No 4	60.30	71.00	70.70	0.00	0.00	89.30	57.90	0.00
UMIG-R	BUET campus	69.70	53.70	43.90	0.00	0.00	7.30	75.00	0.00
UMIG-R	Magbazaar / Mouchak	63.83	50.00	54.55	29.32	0.00	0.00	0.00	48.06
UMIG-R	Lalmatia (near Sankar)	71.42	47.83	36.78	19.78	45.96	0.00	0.00	0.00
UMIG-R	Banani (DPHE quarter)	66.44	62.34	40.47	32.45	73.14	17.14	18.45	0.00
LMIG-R	Lalbag	63.62	43.91	36.36	48.67	0.00	0.00	59.92	0.00
LMIG-R	M. Badda	48.20	38.01	40.79	45.45	0.00	27.54	55.28	0.00
LMIG-R	Badda	72.10	45.70	50.50	63.60	0.00	0.00	0.00	0.00
LIG-R	Azad quarter. Lalbag	44.63	53.45	31.99	53.76	0.00	0.00	63.24	0.00

Notes : CA : Commercial Area
IA : Industrial Area
HIG -R : High Income Group-Residential
UMIG -R : Upper Middle Income Group-Residential
LMIG -R : Lower Middle Income Group-Residential
LIG -R : Low Income Group-Residential

Source : Rahman et al (1999). " Characterization of Municiple Solid Waste and Preliminary Environmental Impact Assessment of Collection and Disposal Works in Dhaka City". Bureau of Research, Testing and Consultation, BUET, Dhaka.

Table 7.2.6 : Average Moisture Content (%) of Different Components of Commercial, Industrial and Residential Solid Waste

No. of locations	Classification	Food waste	Paper	Polythene	Cloth	Garden trimming	Brick, wood, metal and glass	Leaves and branches	Shredded skin and leather
3	CA	70.02	66.64	64.07	51.75	0.00	18.96	68.74	0.00
5	IA	66.67	43.72	43.42	60.91	0.00	21.85	80.77	48.08
5	HIG -R	56.08	48.88	54.44	43.42	58.97	32.93	47.26	0.00
4	UMIG -R	67.85	53.47	43.92	27.18	59.55	12.22	46.72	48.06
3	LMIG -R	61.31	42.54	42.55	52.58	0.00	27.54	57.60	0.00
1	LIG -R	44.63	53.45	31.99	53.76	0.00	0.00	63.24	0.00

Notes : ibid
Source : ibid

TABLE 4-1
Typical specific weight and moisture content data for residential, commercial, industrial, and agricultural wastes

	Specific weight, lb/yd^3		Moisture content, % by weight	
Type of waste	Range	Typical	Range	Typical
Residential (uncompacted)				
Food wastes (mixed)	220–810	490	50–80	70
Paper	70–220	150	4–10	6
Cardboard	70–135	85	4–8	5
Plastics	70–220	110	1–4	2
Textiles	70–170	110	6–15	10
Rubber	170–340	220	1–4	2
Leather	170–440	270	8–12	10
Yard wastes	100–380	170	30–80	60
Wood	220–540	400	15–40	20
Glass	270–810	330	1–4	2
Tin cans	85–270	150	2–4	3
Aluminum	110–405	270	2–4	2
Other metals	220–1940	540	2–4	3
Dirt, ashes, etc.	540–1685	810	6–12	8
Ashes	1095–1400	1255	6–12	6
Rubbish	150–305	220	5–20	15
Residential yard wastes				
Leaves (loose and dry)	50–250	100	20–40	30
Green grass (loose and moist)	350–500	400	40–80	60
Green grass (wet and compacted)	1000–1400	1000	50–90	80
Yard waste (shredded)	450–600	500	20–70	50
Yard waste (composted)	450–650	550	40–60	50
Municipal				
In compactor truck	300–760	500	15–40	20
In landfill				
Normally compacted	610–840	760	15–40	25
Well compacted	995–1250	1010	15–40	25
Commercial				
Food wastes (wet)	800–1600	910	50–80	70
Appliances	250–340	305	0–2	1

(*continued*)

Specific Weight:

Sp. Wt. = Mass / Volume

Permeability of Compacted Wastes:

$$K = C d^2 \frac{\gamma}{\mu} = k \frac{\gamma}{\mu}$$

K = coefficient of permeability
C = dimensionless constant or shape factor
d = average pore size
γ = specific weight of water
μ = dynamic viscosity of water
κ = intrinsic permeability

Typical value for the intrinsic permeability of compacted solid waste is 10^{-11} to 10^{-12} m^2 in the vertical direction and 10^{-10} m^2 in horizontal Direction.

Properties of Solid Waste

- **Chemical composition of solid wastes includes:**
  i. Proximate analysis –
     - Moisture (loss at 105°C for 1 hr.)
     - Volatile materials:

The volatile matter is that portion of the wastes which is converted into gas before and during combustion as the temperature increases. The sample is weighed and ignited in furnace at 950º C according to (ASTM D3175). After combustion the sample is weighed to determine the ash dry weight and the volatile matter is given by;

%VM = [(Weight of dry sample – Ash weight) / Dry sample weight] ×100

- Ash (residue after burning)

Ash content of the wastes is the non-combustible residue left after the waste is burnt.

- Fixed carbon (45remainder)

Fixed carbon is the residue or char remaining after volatile matters escape.

The sample is dried at a temperature of 700ºC. In this, fixed carbon is determined by removing the mass of volatile from original mass of the sample according to equation;

Fixed carbon (Wt %wet basis) = 100 – (Wt % moisture content+%Wt Ash + Wt %volatile matter

Properties of Solid Waste

- Chemical composition of solid wastes includes:
    i. Fusing point of ash
    ii. Ultimate analysis - percent Carbon, Hydrogen, Oxygen, Nitrogen, and ash
    iii. Heating value (energy value)

TABLE 4-3
Typical data on the ultimate analysis of the combustible materials found in residential, commercial, and industrial solid wastes[a]

Type of waste	Percent by weight (dry basis) Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food and food products						
Fats	73.0	11.5	14.8	0.4	0.1	0.2
Food wastes (mixed)	48.0	6.4	37.6	2.6	0.4	5.0
Fruit wastes	48.5	6.2	39.5	1.4	0.2	4.2
Meat wastes	59.6	9.4	24.7	1.2	0.2	4.9
Paper products						
Cardboard	43.0	5.9	44.8	0.3	0.2	5.0
Magazines	32.9	5.0	38.6	0.1	0.1	23.3
Newsprint	49.1	6.1	43.0	<0.1	0.2	1.5
Paper (mixed)	43.4	5.8	44.3	0.3	0.2	6.0
Waxed cartons	59.2	9.3	30.1	0.1	0.1	1.2
Plastics						
Plastics (mixed)	60.0	7.2	22.8	—	—	10.0
Polyethylene	85.2	14.2	—	<0.1	<0.1	0.4
Polystyrene	87.1	8.4	4.0	0.2	—	0.3
Polyurethane[b]	63.3	6.3	17.6	6.0	<0.1	4.3
Polyvinyl chloride[b]	45.2	5.6	1.6	0.1	0.1	2.0
Textiles, rubber, leather						
Textiles	48.0	6.4	40.0	2.2	0.2	3.2
Rubber	69.7	8.7	—	—	1.6	20.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Wood, trees, etc.						
Yard wastes	46.0	6.0	38.0	3.4	0.3	6.3
Wood (green timber)	50.1	6.4	42.3	0.1	0.1	1.0
Hardwood	49.6	6.1	43.2	0.1	<0.1	0.9
Wood (mixed)	49.5	6.0	42.7	0.2	<0.1	1.5
Wood chips (mixed)	48.1	5.8	45.5	0.1	<0.1	0.4
Glass, metals, etc.						
Glass and mineral[c]	0.5	0.1	0.4	<0.1	—	98.9
Metals (mixed)[c]	4.5	0.6	4.3	<0.1	—	90.5
Miscellaneous						
Office sweepings	24.3	3.0	4.0	0.5	0.2	68.0
Oils, paints	66.9	9.6	5.2	2.0	—	16.3
Refuse-derived fuel (RDF)	44.7	6.2	38.4	0.7	<0.1	9.9

[a] Adapted in part from Ref. 6.

[b] Remainder is chlorine.

[c] Organic content is from coatings, labels, and other attached materials.

TABLE 4-4

Typical data on the ultimate analysis of the combustile components in residential MSW[a]

Component	Percent by weight (dry basis)					
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Organic						
Food wastes	48.0	6.4	37.6	2.6	0.4	5.0
Paper	43.5	6.0	44.0	0.3	0.2	6.0
Cardboard	44.0	5.9	44.6	0.3	0.2	5.0
Plastics	60.0	7.2	22.8	—	—	10.0
Textiles	55.0	6.6	31.2	4.6	0.15	2.5
Rubber	78.0	10.0	—	2.0	—	10.0
Leather	60.0	8.0	11.6	10.0	0.4	10.0
Yard wastes	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
Inorganic						
Glass[b]	0.5	0.1	0.4	<0.1	—	98.9
Metals[b]	4.5	0.6	4.3	<0.1	—	90.5
Dirt, ash, etc.	26.3	3.0	2.0	0.5	0.2	68.0

[a]Adapted in part from Ref. 6.

[b]Organic content is from coatings, labels, and other attached materials.

Ultimate Analysis

EXAMPLE 4-2 Estimation of the chemical composition of a solid waste sample. Determine the chemical composition of the organic fraction, without and with sulfur and without and with water, of a residential MSW with the typical composition shown in Table 3-4.

Chemical Composition of MSW

Component, Basis 100 lbs total weight	Wet weight, lbs	Moisture Content, %,	Dry weight, %	Dry weight, lbs	C, % by weight, dry basis	C, Composition, lbs	H, % by weight, dry basis	H, Composition, lbs	O, % by weight, dry basis	O, Composition, lbs	N, % by weight, dry basis	N, Composition, lbs	S, % by weight, dry basis	S, Composition, lbs	Ash, % by weight, dry basis	Ash, Composition, lbs
[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8[	[9]	[10]	[11]	[12]	[13]	[14]	[15]	[16]	[17]
			100-[3]	[2]x[5] /100		[5]x[6] /100		[5]x[8] /100		[5]x[10]/100		[5]x[12]/100		[5]x[14]/100		[5]x[16]/100
Organic																
Food wastes	9.0	70.0	30.0	2.7	48.0	1.30	6.4	0.17	37.60	1.02	2.6	0.07	0.4	0.01	5.0	0.14
Paper	34.0	6.0	94.0	32.0	43.5	13.90	6.0	1.92	44.00	14.06	0.3	0.10	0.2	0.06	6.0	1.92
Cardboard	6.0	5.0	95.0	5.7	44.0	2.51	5.9	0.34	44.60	2.54	0.3	0.02	0.2	0.01	5.0	0.29
Plastics	7.0	2.0	98.0	6.9	60.0	4.12	7.2	0.49	22.80	1.56	0.0	0.00	0	0.00	10.0	0.69
Textiles	2.0	10.0	90.0	1.8	55.0	0.99	6.6	0.12	31.20	0.56	4.6	0.08	0.15	0.00	2.5	0.05
Rubber	0.5	2.0	98.0	0.5	78.0	0.38	10.0	0.05	0.00	0.00	2.0	0.01	0	0.00	10.0	0.05
Leather	0.5	10.0	90.0	0.5	60.0	0.27	8.0	0.04	11.60	0.05	10.0	0.05	0.4	0.00	10.0	0.05
Yard Wastes	18.5	60.0	40.0	7.4	47.8	3.54	6.0	0.44	38.00	2.81	3.4	0.25	0.3	0.02	4.5	0.33
Wood	2.0	20.0	80.0	1.6	49.5	0.79	6.0	0.10	42.70	0.68	0.2	0.00	0.1	0.00	1.5	0.02
Total	79.5			59.0		27.79		3.66		23.29		0.58		0.11		3.52

Component, weight (lbs)	Without H_2O	With H_2O, includes moisture as indicated below
Carbon	27.79	27.79
Hydrogen	3.66	5.95
Oxygen	23.29	41.55
Nitrogen	0.58	0.58
Sulfur	0.11	0.11
Ash	3.52	3.52
Total	59.0	79.5

Molar Composition With H2O and Without H2O, Neglecting the Ash

Component, weight (lbs)	Atomic Weight, lbs/mole	Without H_2O, moles	With H_2O, moles
Carbon	12.01	2.314	2.314
Hydrogen	1.01	3.628	5.888
Oxygen	16	1.456	2.597
Nitrogen	14.01	0.041	0.041
Sulfur	32.07	0.004	0.004

Approximate Chemical Formula

Component, mole ratios	Nitrogen=1, Without H_2O	Nitrogen=1, With H_2O	Sulfur=1, Without H_2O	Sulfur=1, With H_2O
Carbon	56.3	56.3	648.6	648.6
Hydrogen	88.3	143.3	1016.9	1650.2
Oxygen	35.4	63.2	408.0	727.9
Nitrogen	1.0	1.0	11.5	11.5
Sulfur	0.1	0.1	1.0	1.0

	Chemical formula without sulfur	Chemical formula with sulfur
Without H_2O	$C_{56.3}H_{88.3}O_{35.4}N$	$C_{648.6}H_{1016.9}O_{408}N_{11.5}S$
With H_2O	$C_{56.3}H_{143.3}O_{63.2}N$	$C_{648.6}H_{1650.2}O_{727.9}N_{11.5}S$

Note: Formulae must be manually adjusted based on table

Biological Properties of MSW

Excluding plastic, rubber, and leather components, the organic fraction of most MSW can be classified as follows:

1. Water-soluble constituents, such as sugars, starches, amino acids, and various organic acids,
2. Hemicellulose, a condensation product of the five- and six-carbon sugars,
3. Cellulose, a condensation product of the six-carbon sugar glucose.
4. Fat, oils, and waxes, which are esters of alcohols and long chain fatty acids,
5. Lignin, a polymeric material containing aromatic rings with methoxyl groups ($-OCH_3$) [present in some papers: newsprint and fiberboard],
6. Lignocellulose, a combination of lignin and cellulose, and
7. Proteins, which are composed of chains of amino acids.

Biodegradability of Organic Waste Components

Volatile Solids (VS) content, determined by ignition at 500°C, is often used as a measure of the biodegradability of the organic fraction of MSW. The use of VS in describing the biodegradability of the organic fraction of MSW is misleading, as some of these organic constituents are highly volatile but low in biodegradability (e.g. newsprint, some plant trimmings).

Biodegradability of MSW (contd…)

Alternatively, the lignin content of MSW can be used to estimate the biodegradable fraction, using the following:

$$BF = 0.83 - 0.028\ LC$$

Where,

BF = biodegradable fraction expressed on a volatile solids (VS) basis

0.83 & 0.028 = empirical constants

LC = lignin constant of the VS expressed as a % of dry wt.

Data on the Biodegradable Fraction of selected organic waste components based on Lignin Content

Component	Volatile Solids (VS) % of Total Solids	Lignin Content (LC), % of VS	Biodegradable Fraction, BF
Food Wastes	7 – 15	0.4	0.82
Paper			
Newsprint	94.0	21.9	0.22
Office Paper	96.4	0.4	0.82
Cardboard	94.0	12.9	0.47
Yard Wastes	50 – 90	4.1	0.72

Energy Values of MSW

Computation from Approximate Chemical Composition Using Modified Dulong Formula:

$$Btu\ per\ lb = 145C + 610\left(H_2 - \frac{1}{8}O_2\right) + 40S + 10N$$

$$kj\ per\ Kg = 337\,C + 1428\left(H - \frac{O}{8}\right) + 95\,S$$

C = carbon, %
H = hydrogen, %
N = nitrogen, %
S = Sulfur, %

TABLE 4-5
Typical values for inert residue and energy content of residential MSW[a]

Component	Inert residue,[b] percent		Energy,[c] Btu/lb	
	Range	Typical	Range	Typical
Organic				
Food wastes	2–8	5.0	1,500–3,000	2,000
Paper	4–8	6.0	5,000–8,000	7,200
Cardboard	3–6	5.0	6,000–7,500	7,000
Plastics	6–20	10.0	12,000–16,000	14,000
Textiles	2–4	2.5	6,500–8,000	7,500
Rubber	6–20	10.0	9,000–12,000	10,000
Leather	8–20	10.0	6,500–8,500	7,500
Yard wastes	2–6	4.5	1,000–8,000	2,800
Wood	0.6–2	1.5	7,500–8,500	8,000
Misc. organics	—	—	—	—
Inorganic				
Glass	96–99+	98.0	50–100[d]	60
Tin cans	96–99+	98.0	100–500[d]	300
Aluminum	90–99+	96.0	—	—
Other metal	94–99+	98.0	100–500[d]	300
Dirt, ashes, etc.	60–80	70.0	1,000–5,000	3,000
Municipal solid wastes			4,000–6,000	5,000[e]

[a] Adapted in part from Refs. 6 and 8.

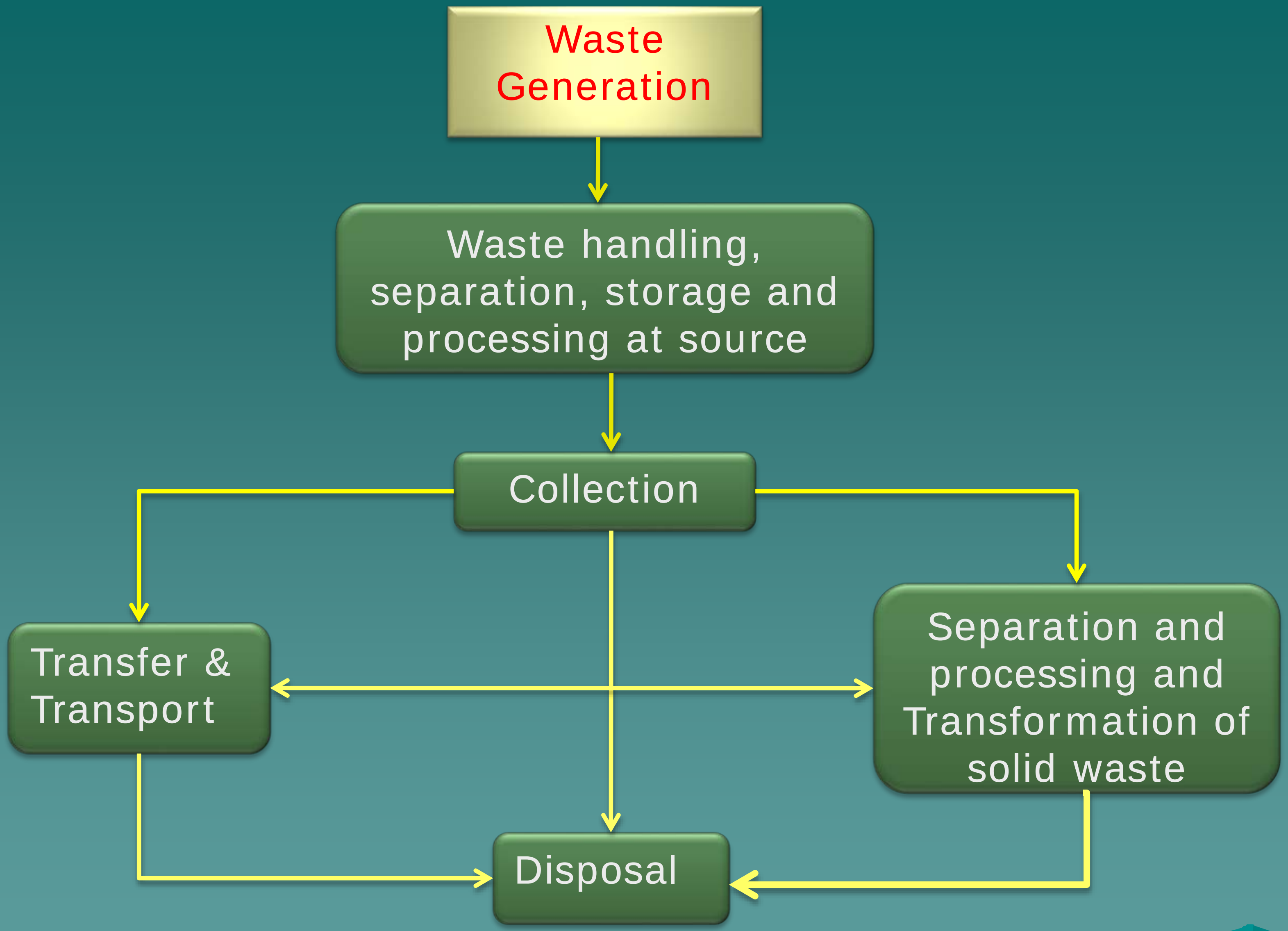
[b] After complete combustion.

[c] As discarded basis.

[d] Energy content is from coatings, labels, and attached materials.

[e] The typical energy value given in this table is higher than the corresponding value given in the predecessor of this text (see Table 4-10) [11]. The reason is due largely to (1) the reduced amount of raw food waste and (2) the increased percentage distribution of plastic (7 versus 4 percent) in residential MSW.

Note: Btu/lb × 2.326 = kJ/kg


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

Measures and Methods Used to Assess Quantities

MSW should be measured as a weight as opposed to a volume because the weight measurements are consistent and reproducible while the volume can vary considerably attendant to compaction. Ultimately, however, the capacity of a landfill is a volume consideration.

Units - lb/capita/day for residential and commercial, a repeatable measure of production for industry and agriculture e.g. lb of manure/chicken.

Estimation of Waste Quantities :

Load-count analysis - A landfill without scales may estimate the vehicular capacity and the number of vehicles of that capacity.

Weight-Volume Analysis – A landfill equipped with weighing scale records the weight-volume data to assess the waste quantities.

Example:

Given: On a single day you observe the following at a landfill:

- 10-16 yd^3 compactor trucks
- 18-3 yd^3 pickup trucks hauling loose and dry leaves
- 56-1 yd^3 private cars
- 2-45 yd^3 trucks with broken concrete

Find: If there are 3.82 lb/cap.day with 2.7 cap/home and all the waste comes from the town, estimate the number of homes in the town. What's wrong with the answer?

1. Compute the total weight

Item	**Number of loads**	**Avg. Vol. yd^3**	**Specific Wt. lb/yd^3**	**Total Wt., 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**

Steps:

Determine the number of homes
number of residence = 331,270 (lb/day) x(capita.day/3.82 lb) x (residence/2.7cap)
number of residence = 32,118

What's wrong with the answer?

The demolition load, broken concrete may not be representative; calculate the number of houses without the concrete.

number of residence = (331,270-233,550) (lb/day) x(capita.day/3.82 lb) x (residence/2.7cap)

number of residence = 9,475 vs. 32,118 with the broken concrete

Material Balance Approach

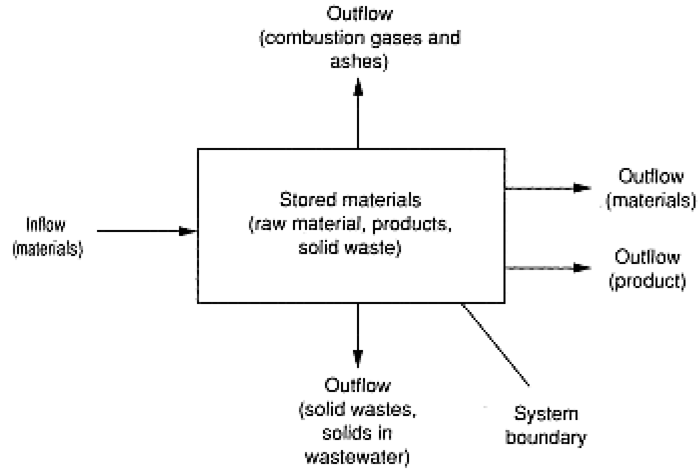


FIGURE 6-3
Definition sketch for materials balance analysis used to determine solid waste generation rates.

quantity of wastes generated, collected, and stored. The materials mass balance can be formulated as follows:

1. General word statement:

$$\begin{array}{c}\text{Rate of}\\\text{accumulation of}\\\text{material within the}\\\text{system boundary}\end{array} = \begin{array}{c}\text{rate of flow of}\\\text{material into the}\\\text{system boundary}\end{array} - \begin{array}{c}\text{rate of flow of}\\\text{material out of the}\\\text{system boundary}\end{array} + \begin{array}{c}\text{rate of generation}\\\text{of waste material}\\\text{within the}\\\text{system boundary}\end{array} \qquad (6\text{-}1)$$

2. Simplified word statement:

$$\text{Accumulation} = \text{inflow} - \text{outflow} + \text{generation} \qquad (6\text{-}2)$$

3. Symbolic representation (refer to Fig. 6-3):

$$\frac{dM}{dt} = \Sigma M_{\text{in}} - \Sigma M_{\text{out}} + r_w \qquad (6\text{-}3)$$

where dM/dt = rate of change of the weight of material stored (accumulated) within the study unit, lb/d
ΣM_{in} = sum of all of the material flowing into study unit, lb/d
ΣM_{out} = sum of all of the material flowing out of study unit, lb/d
r_w = rate of waste generation, lb/d
t = time, d

Example 6-2 Materials-balance analysis. A cannery receives on a given day 12 tons of raw produce, 5 tons of cans, 0.5 tons of cartons, and 0.3 tons of miscellaneous materials. Of the 12 tons of raw produce, 10 tons become processed product, 1.2 tons end up as produce waste, which is fed to cattle, and the remainder is discharged with the wastewater from the plant. Four tons of the cans are stored internally for future use, and the remainder is used to package the product. About 3 percent of the cans used are damaged. Stored separately, the damaged cans are recycled. The cartons are used for packaging the canned product, except for 5 percent that are damaged and subsequently separated for recycling. Of the miscellaneous materials, 25 percent is stored internally for future use; 50 percent becomes waste paper, of which 35 percent is separated for recycling with the remainder being discharged as mixed waste; and 25 percent becomes a mixture of solid waste materials. Assume the materials separated for recycling and disposal are collected daily. Prepare a materials balance for the cannery on this day and a materials flow diagram accounting for all of the materials. Also determine the amount of waste per ton of product.

Solution

1. On the given day, the cannery receives

   12 tons of raw produce
   5 tons of cans
   0.5 tons of cartons
   0.3 tons of miscellaneous materials

2. As a result of internal activity,
   (*a*) 10 tons of product is produced, 1.2 tons of produce waste is generated, and the remainder of the produce is discharged with the wastewater
   (*b*) 4 tons of cans are stored and the remainder is used, of which 3 percent are damaged
   (*c*) 0.5 tons of cartons are used of which 3 percent are damaged
   (*d*) 25 percent of the miscellaneous materials is stored; 50 percent becomes paper waste, of which 35 percent is separated and recycled, with the remainder disposed of as mixed solid waste; the remaining 25 percent of the miscellaneous materials are disposed of as mixed waste.
3. Determine the required quantities
   (*a*) Wastes generated from raw produce
      i. Solid waste fed to cattle = 1.2 ton (1089 kg)
      ii. Waste produce discharged with wastewater = (12 − 10 − 1.2) ton = 0.8 ton (726 g)

(b) Cans

i. Damaged and recycled = (0.03)(5 − 4) ton = 0.03 ton (27 kg)
ii. Used for production of product = (1 − 0.03) ton = 0.97 ton (880 kg)

(c) Cartons

i. Damaged and recycled = (0.03)(0.5 ton) = 0.015 ton (14 kg)
ii. Cartons used in product = (0.5 − 0.015) ton = 0.485 ton (440 kg)

(d) Miscellaneous material

i. Amount stored = (0.25)(0.3 ton) = 0.075 ton (68 kg)
ii. Paper separated and recycled = (0.50)(0.35)(0.3 ton) = 0.053 ton (48 kg)
iii. Mixed waste = (0.3 − 0.075) − 0.053) ton = 0.172 ton (156 kg)

(e) Total weight of product = (10 + 0.97 + 0.485) ton = 11.455 ton (10,392 kg)

(f) Total material stored = (4 + 0.075) ton = 4.075 ton (3696 kg)

4. Prepare a materials balance and flow diagram for the cannery for the day in question

(a) The appropriate materials balance equation is

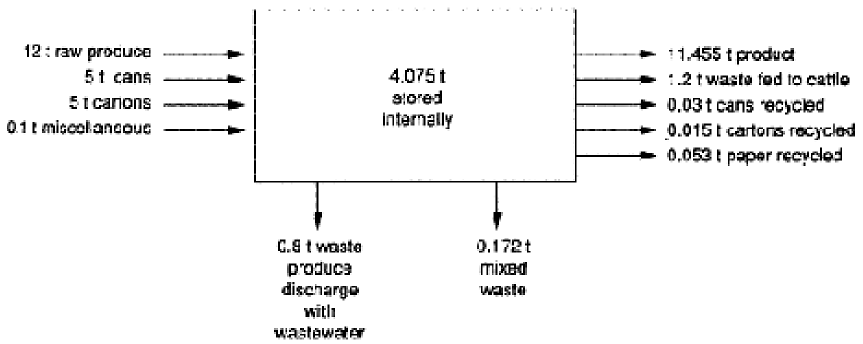
$$\text{Amount of material stored} = \text{inflow} - \text{outflow} - \text{waste generation}$$

(b) The materials balance quantities are as follows:

i. Material stored = (4.0 + 0.075) ton = 4.075 ton
ii. Material input = (12.0 + 5.0 + 0.5 + 0.3) ton = 17.8 ton
iii. Material output = (10.0 + 0.97 + 0.485 + 1.2 + 0.03 + 0.015 + 0.053) ton = 12.753 ton
iv. Waste generation = (0.8 + 0.172) ton = 0.972 ton
v. The final materials balance is

$$4.075 = 17.8 - 12.753 - 0.972 \text{ (mass balance checks)}$$

(c) Materials balance flow diagram is given below



5. Determine the amount of waste per ton of product:

(a) Recyclable material = (1.2 + 0.03 + 0.015 + 0.053) ton/11.455 ton = 0.11 ton/ton

(b) Mixed waste = (0.8 + 0.172) ton/11.455 ton = 0.085 ton/ton

Estimation of Generation Rate

Example 6-3 Statistical analysis of solid waste collection data. Determine the statistical characteristics of the weekly waste production data obtained from an industrial account for a calendar quarter of operation.

Week no.	Waste, yd^3/wk	Week no.	Waste, yd^3/wk
1	29	8	37
2	30	9	38
3	35	10	35
4	34	11	33
5	38	12	32
6	41	13	31
7	40		

Solution

1. Determine graphically whether the waste production data are distributed normally or are skewed (log normal) using probability paper.

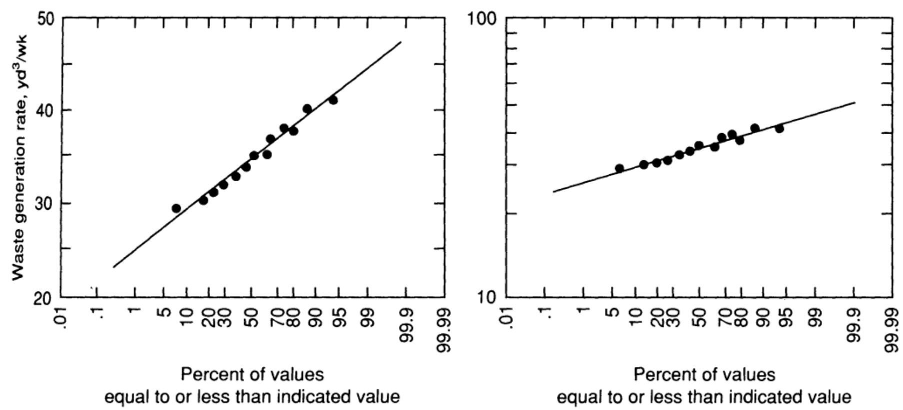
(*a*) Set up a data analysis table with three columns as described below.

i. In column 1, enter the rank serial number starting with number 1
ii. In column 2, arrange the waste production data in ascending order
iii. In column 3, enter the probability plotting position (see Appendix D)

Rank serial no., *m*	Waste, yd^3/wk	Plotting position,[a] %
1	29	7.1
2	30	14.3
3	31	21.4
4	32	28.6
5	33	35.7
6	34	42.9
7	35	50.0
8	35	57.1
9	37	64.3
10	38	71.4
11	38	78.6
12	40	85.7
13	41	92.9

[a] Plotting position $= [m/(n+1)]100, n = 13$

(*b*) Plot the weekly quantity of waste, expressed in yd^3/wk, versus the plotting position (determined above) on both arithmetic and logarithmic probability graph paper. The resulting plots are presented below. Because the data fall on a straight line in both plots, the waste production data can be described adequately by either type of distribution. The fact that the data can be described adequately with both distributions is often the case with waste production data.



2. Determine the statistical characteristics of the waste collection data.

(*a*) Set up a data analysis table to obtain the [illegible] to determine the statistical characteristics (refer to Appendix D for equations and definitions).

Waste, yd³/wk	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$	$(x_i - \bar{x})^4$
29	−5.8	33.6	1131.6
30	−4.8	23.0	530.8
31	−3.8	14.4	208.5
32	−2.8	7.8	61.5
33	−1.8	3.2	10.2
34	−0.8	0.6	0.4
35	0.2	0.0	0.0
35	0.2	0.0	0.0
37	2.2	4.8	23.4
38	3.2	10.2	104.9
38	3.2	10.2	104.9
40	5.2	27.0	731.2
41	6.2	38.4	1477.6
453		173.2	4385.0
$\bar{x} = 453/13 = 34.8$			

(*b*) Determine the statistical characteristics

i. Mean

$$\bar{x} = \frac{\Sigma x}{n}$$

$$\bar{x} = \frac{453}{13} = 34.8 \text{ yd}^3/\text{wk}$$

ii. Median (the middle value)

Median = 35 yd³/wk (see data table above)

iii. Mode

Mode = 3 Med − $2\bar{x}$ = 3(35) − 2(34.8) = 35.4

iv. Standard deviation

$$s = \sqrt{\frac{\Sigma(x - \bar{x})^2}{n}}$$

$$s = \sqrt{\frac{173.2}{13}} = 3.65$$

v. Coefficient of variation

$$CV = \frac{100s}{\bar{x}}$$

$$CV = \frac{100(3.65)}{34.8} = 10.5$$

vi. Coefficient of skewness

$$\alpha_3 = \frac{2(\bar{x} - \text{Mod})}{s}$$

$$\alpha_3 = \frac{2(34.8 - 35.4)}{\text{[illegible]}} = -0.33$$

vii. Coefficient of kurtosis

$$\alpha_4 = \frac{\Sigma(x_i - \bar{x})^4/n}{s^4}$$

$$\alpha_4 = \frac{4385.0/13}{(3.65)^4} = 1.9$$

Comment. The term $(n + 1)$ is used to obtain the plotting positions in Step 1, as opposed to just n, to account for the fact that there may be an observation that is either larger or smaller than the largest or smallest in the data set. Reviewing the statistical characteristics it can be seen that the distribution is skewed ($\alpha_3 = -0.33$ versus 0 for a normal distribution) and is considerably flatter than a normal distribution would be ($\alpha_4 = 1.9$ versus 3.0 for a normal distribution).

TABLE 6-2
Estimated total per capita solid waste quantities generated in the United States and selected states for the year 1990[a]

	Waste generation rate, lb/capita · yr					
	United States		California		Florida	
Waste	Range	Typical	Range	Typical	Range	Typical
MSW[b]	1450–3000	2225	1850–3500	2500	1350–2400	2200
Industrial waste	500–1750	750	750–1500	1000	250–750	500
Agricultural waste	250–3000	—[c]	1500–4000	3000	500–1500	1000
Total	2500–7750		3700–9000	6500	2050–4650	3500

[a] Developed in part from Refs. 1–4, 5, 8, 10.

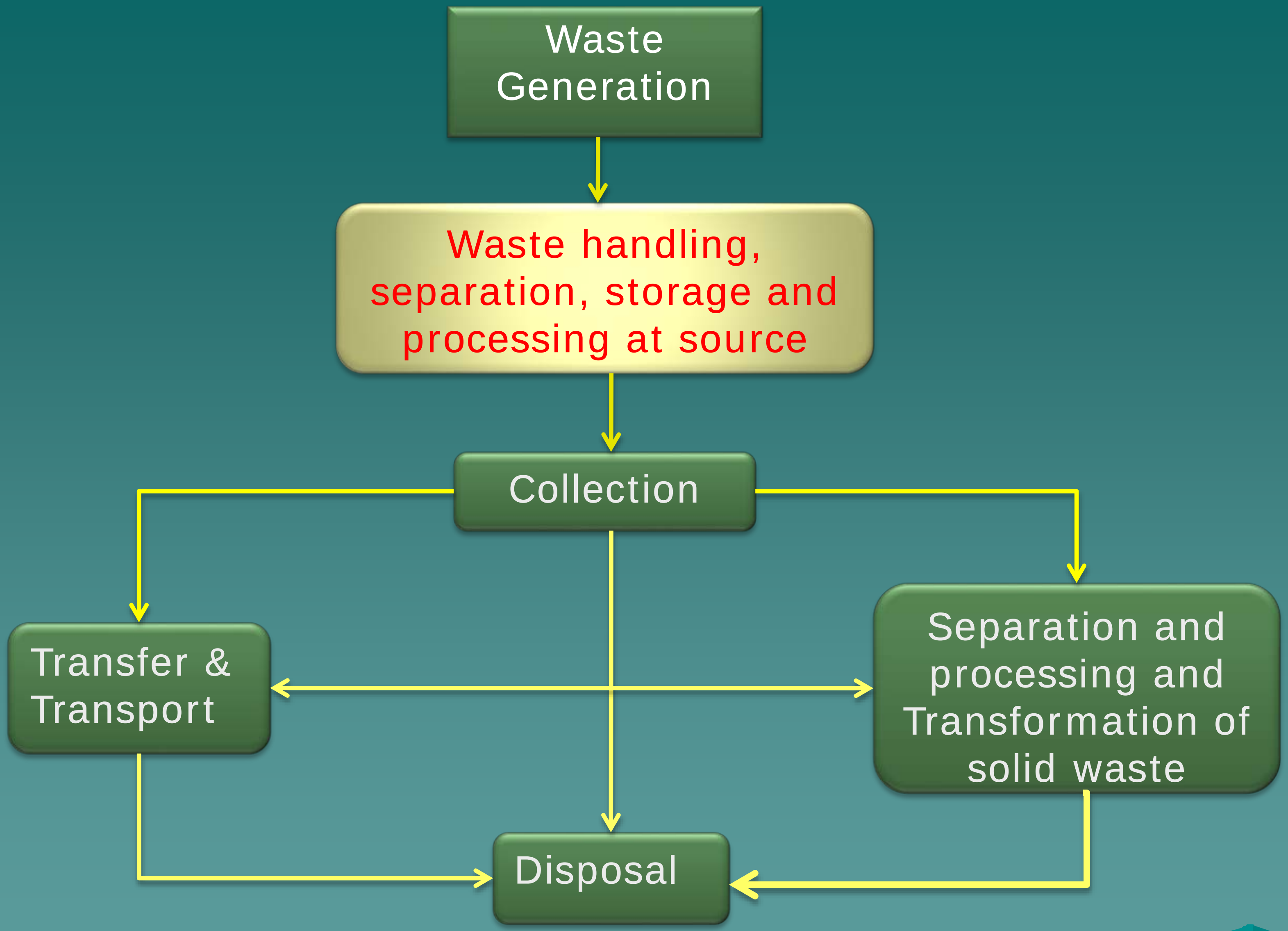
[b] A detailed analysis of the waste categories that compose MSW are presented in Table 6-3.

[c] Must be estimated separately for each location.

Note: lb/capita · yr × 0.4536 = kg/capita · yr

Factors affecting Solid Waste generation rates

- Source reduction
- Extent of recycling
- Public attitudes
- Local legislation
- Geographic location
- Season of the year
- Use of kitchen grinder


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

Persons responsible for and auxiliary equipment used in the handling and separation of solid waste at the source

Source	Persons responsible	Auxiliary equipment and facilities
Residential		
Low-rise	Residents, tenants	Household compactors, large-wheeled containers, small-wheeled handcarts
Medium-rise	Tenants, building maintenance crews, janitorial services, unit managers	Gravity chutes, service elevators, collection carts, pneumatic conveyors
High-rise	Tenants, building maintenance crews, janitorial services	Gravity chutes, service elevators, collection carts, pneumatic conveyors
Commercial	Employees, janitorial services	Wheeled or castered collection carts, container trains, burlap drop cloths, service elevators, conveyors, pneumatic conveyors
Industrial	Employees, janitorial services	Wheeled or castered collection carts, container trains, service elevators, conveyors
Open areas	Owners, park officers, municipal employees	Vandalproof containers
Treatment plant sites	Plant operators	Various conveyors and other manually operated equipment and facilities
Agricultural	Owners, workers	Varies with the individual commodity

In High-rise apartments most common approaches for handling solid wastes are:

1. Wastes are picked up by building maintenance personnel
2. Wastes are taken to the basement by tenants
3. Wastes, usually bagged, are placed by tenants in specially designed vertical chutes

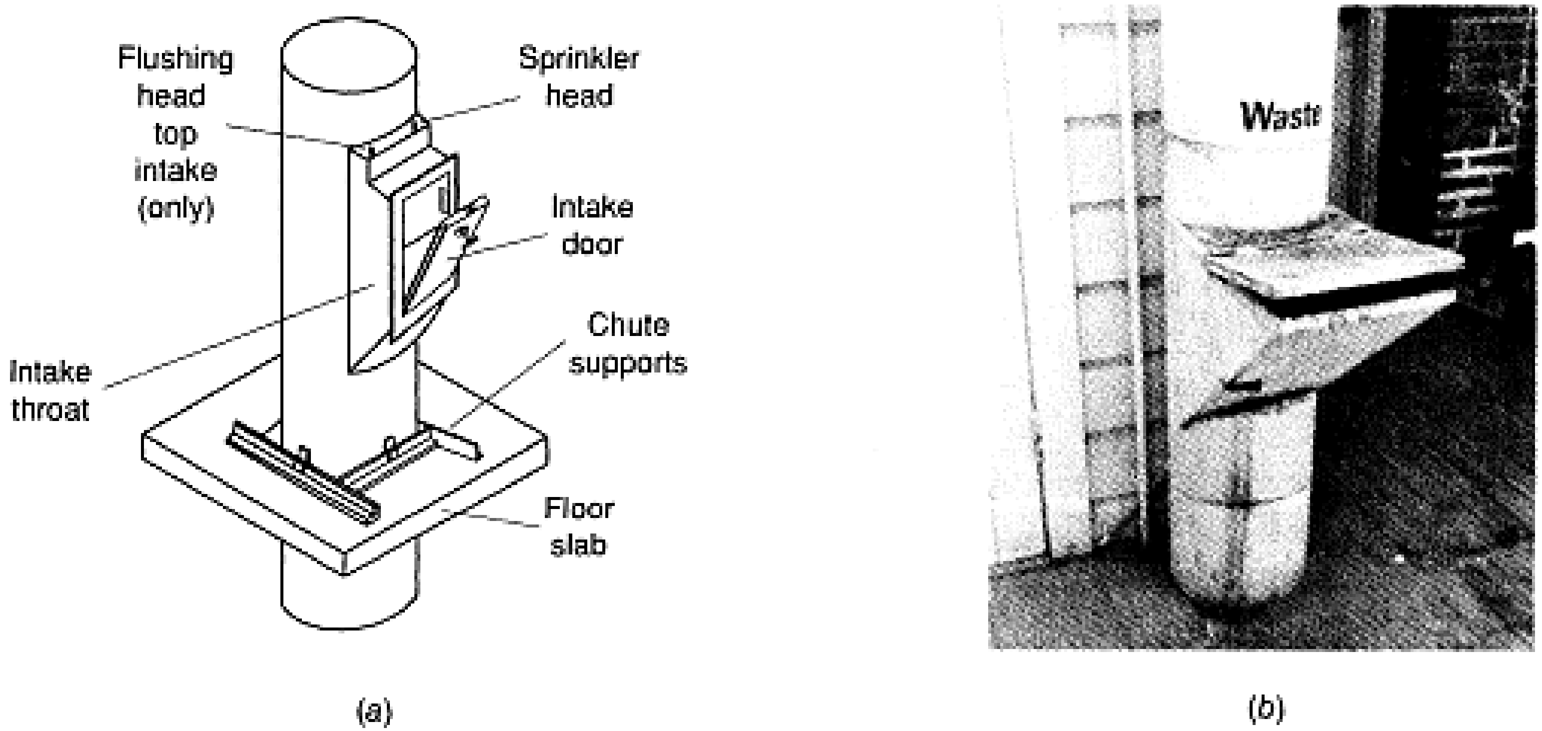


FIGURE 7-4
Typical chute openings for the discharge of waste materials in high-rise apartment buildings: (*a*) isometric view of waste chute opening on individual floor (courtesy of Cutler Manufacturing Corp.) and (*b*) outdoor type used in some older high-rise apartment buildings.

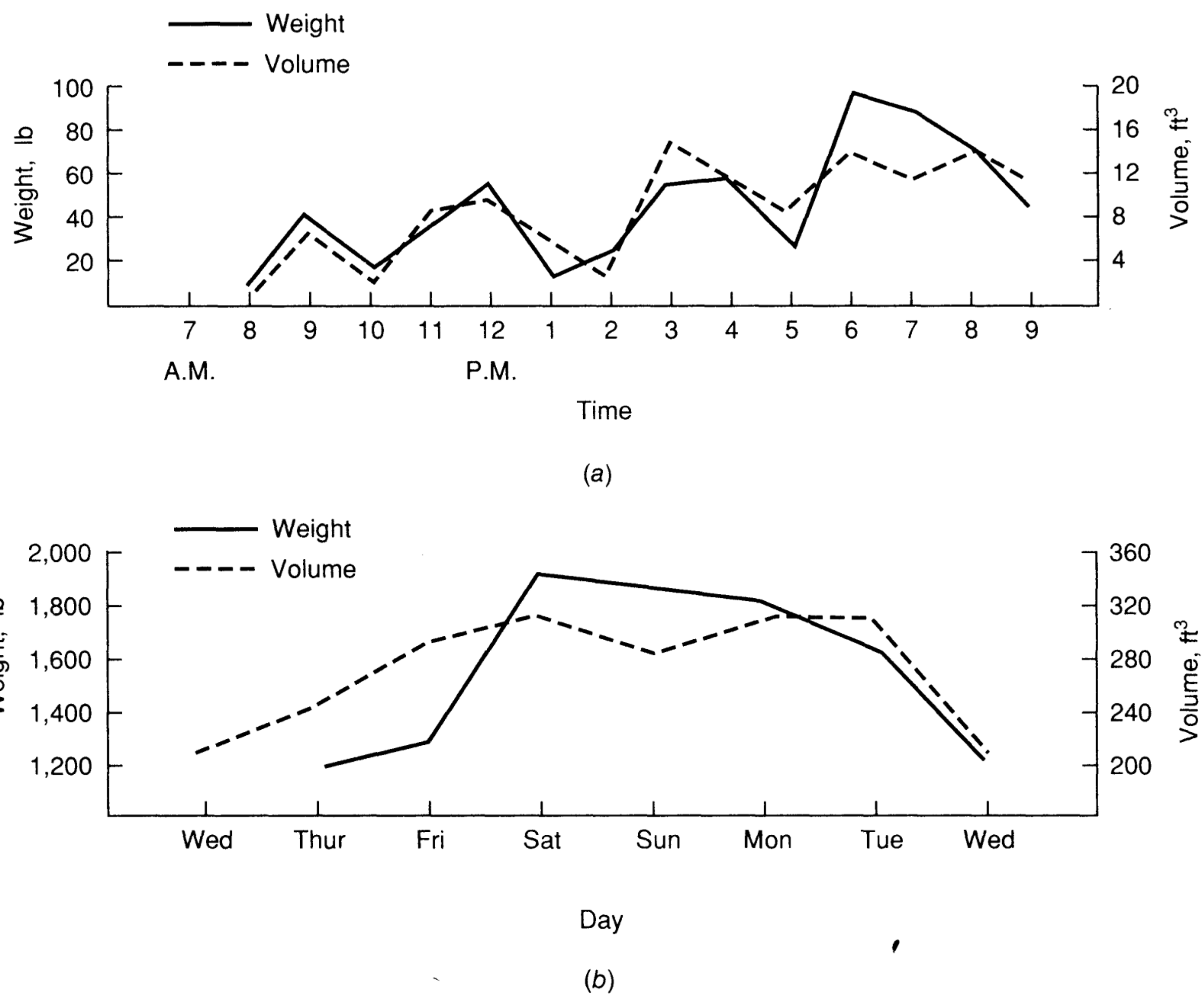
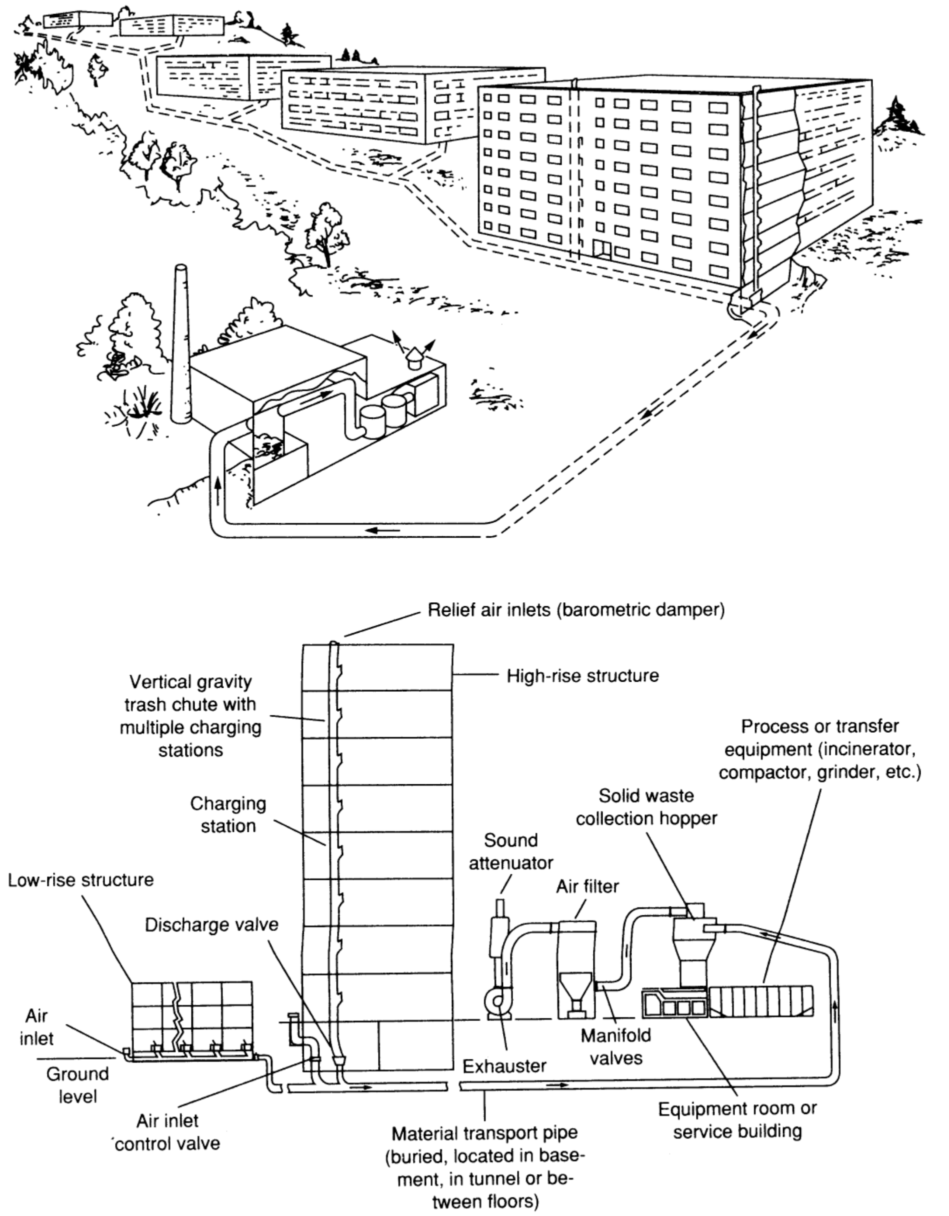


FIGURE 7-5

Typical waste discharge rates in apartments with waste chutes: (*a*) hourly and (*b*) daily.



Typical underground pneumatic waste transport system for high-rise apartment buildings.

ON-SITE HANDLING:

- Activities associated with the handling of SW until they are placed in the containers used for storage before collection

ON-SITE STORAGE:

Factors considered:

1. Types of containers used
2. Container Locations
3. Public health
4. Aesthetics
5. Methods of Collection

Factors considered:

i) Types of Containers:

- Depend on:
  - characteristics of SW collected
    - E.g. Large storage containers (Domestic SW: flats/apartment)
    - Containers at curbs
    - Large containers on a roller (Commercial/Industrial)
  - Collection frequency
  - Space available for the placement of containers(Refer to Table 11-4)

- Residential; refuse bags (7 -10 litres)
- Rubbish bins - 20 -30 litres
- Large mechanical containers - more commonly used to cut costs (reduce labor, time , & collection costs)
- must be standardized to suit collection equipment .

ii) Container Locations:

- side/rear of house
- alleys
- special enclosures (apartment/condos)
- Basement (apts. in foreign countries)/ newer complexes

iii) Public Health:

- relates to on-time collection to avoid the spread of diseases by vectors, etc.

iv) Aesthetics:

- must be pleasing to the eye (containers must be clean, shielded from public's view).

Factors to be considered in case of On-site Storage

- Effect of storage on the waste components
  - Biological decomposition
  - Absorption of fluids
  - Contamination of waste components
- Type of containers to be used
- Container location
- Public health and aesthetics

TABLE 7-4
Data on the types and sizes of containers used for onsite storage of solid wastes

Type	Capacity			Dimensions[a]	
	Unit	Range	Typical	Unit	Typical
Small					
Container, plastic or galvanized metal	gal	20–40	30	in	20D × 26H (30 gal)
Barrel, plastic, aluminum, or fiber	gal	20–65	30	in	20D × 26H (30 gal)
Disposable paper bags					
Standard	gal	20–55	30	in	15W × 12d × 43H (30 gal)
Leak-resistant	gal	20–55	30	in	as above
Leakproof	gal	20–55	30	in	as above
Disposable plastic bag				in	18W × 15d × 40H (30 gal)
				in	30W × 40H (30 gal)
Medium					
Container	yd^3	1–10	4	in	72W × 42d × 65H (4 yd^3)
Large					
Container					
Open top, roll off (also called debris boxes)	yd^3	12–50	—[b]	ft	8W × 6H × 20L (35 yd^3)
Used with stationary compactor	yd^3	20–40	—[b]	ft	8W × 6H × 18L (30 yd^3)
Equipped with self-contained compaction mechanism	yd^3	20–40	—[b]	ft	8W × 8H × 22L (30 yd^3)
Container, trailer-mounted					
Open top	yd^3	20–50	—[b]	ft	8W × 12H × 20L (35 yd^3)
Enclosed, equipped with self-contained compaction mechanism	yd^3	20–40	—[b]	ft	8W × 12H × 24L (35 yd^3)

[a] D = diameter, H = height, L = length, W = width, d = depth.

[b] Size varies with waste characteristics and local site conditions.

Note: gal × 0.003785 = m^3

in × 2.54 = cm

yd^3 × 0.7646 = m^3

ft × 0.3048 = m


What goes where?

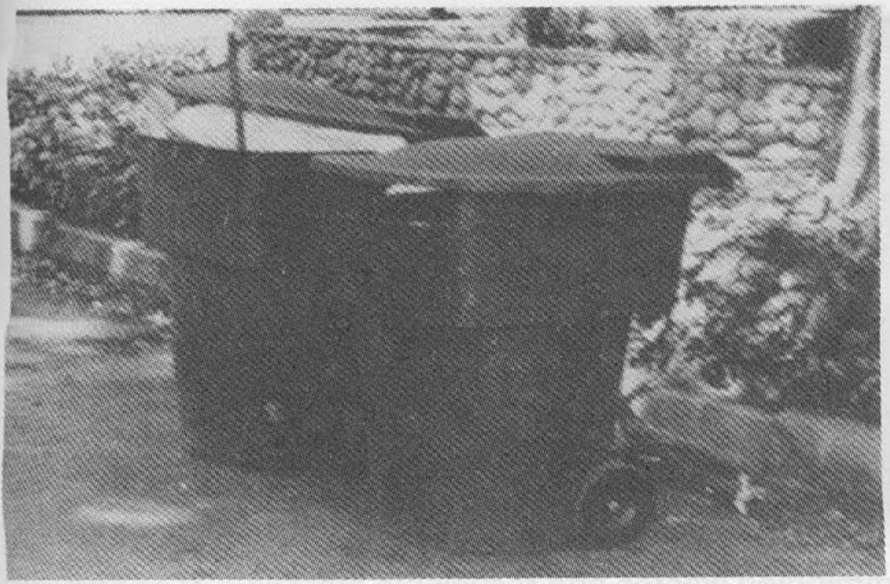


FIGURE 7-8
Typical containers used for the storage of commingled wastes. Containers are designed for curbside collection with mechanized collection vehicles.

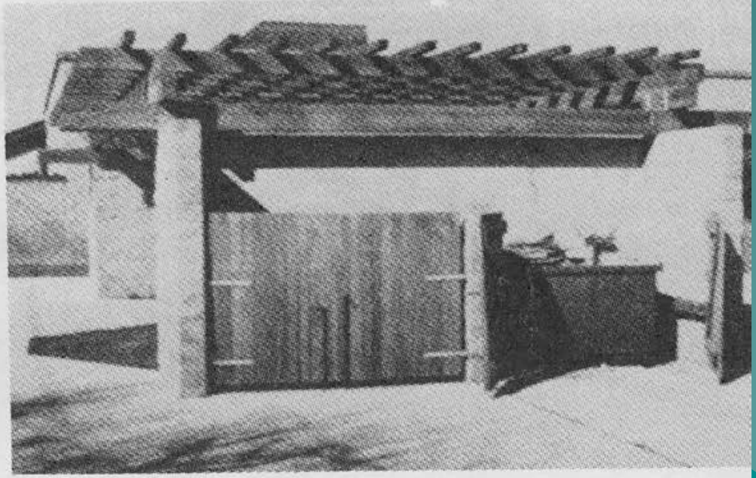


FIGURE 7-9
Typical containers used for the storage of commingled wastes and recyclable materials at apartme buildings.

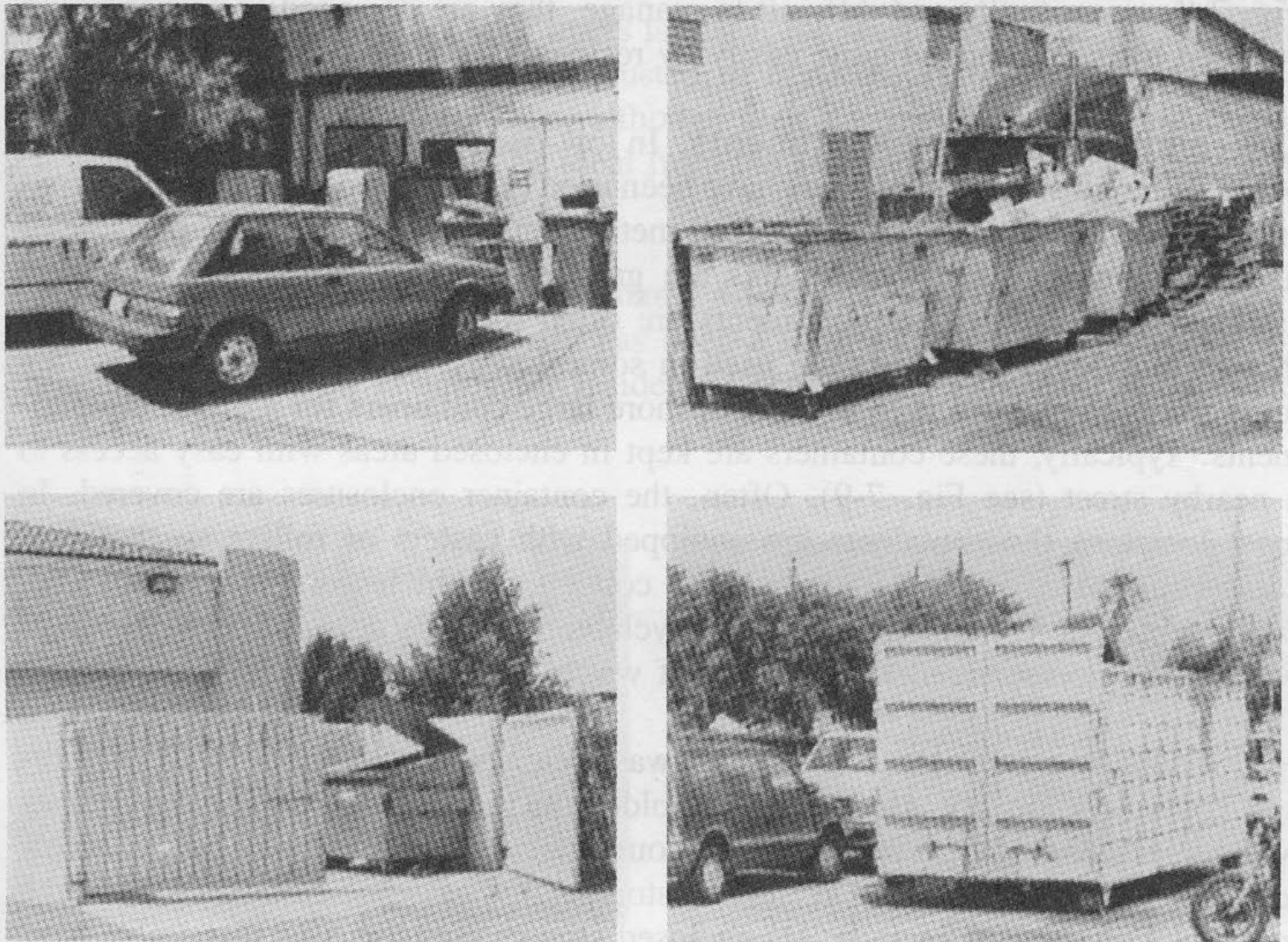
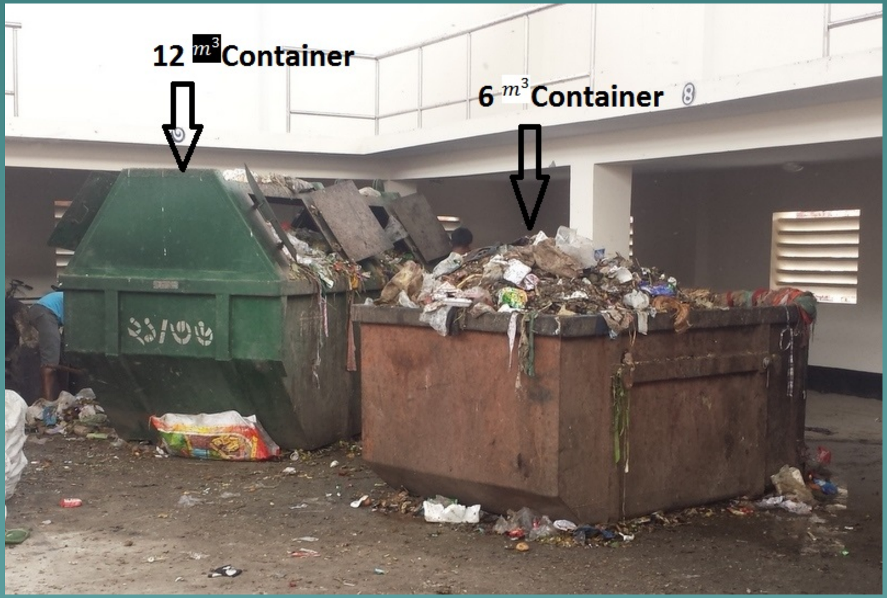


FIGURE 7-10
Typical container-storage locations for containers used at commercial facilities.

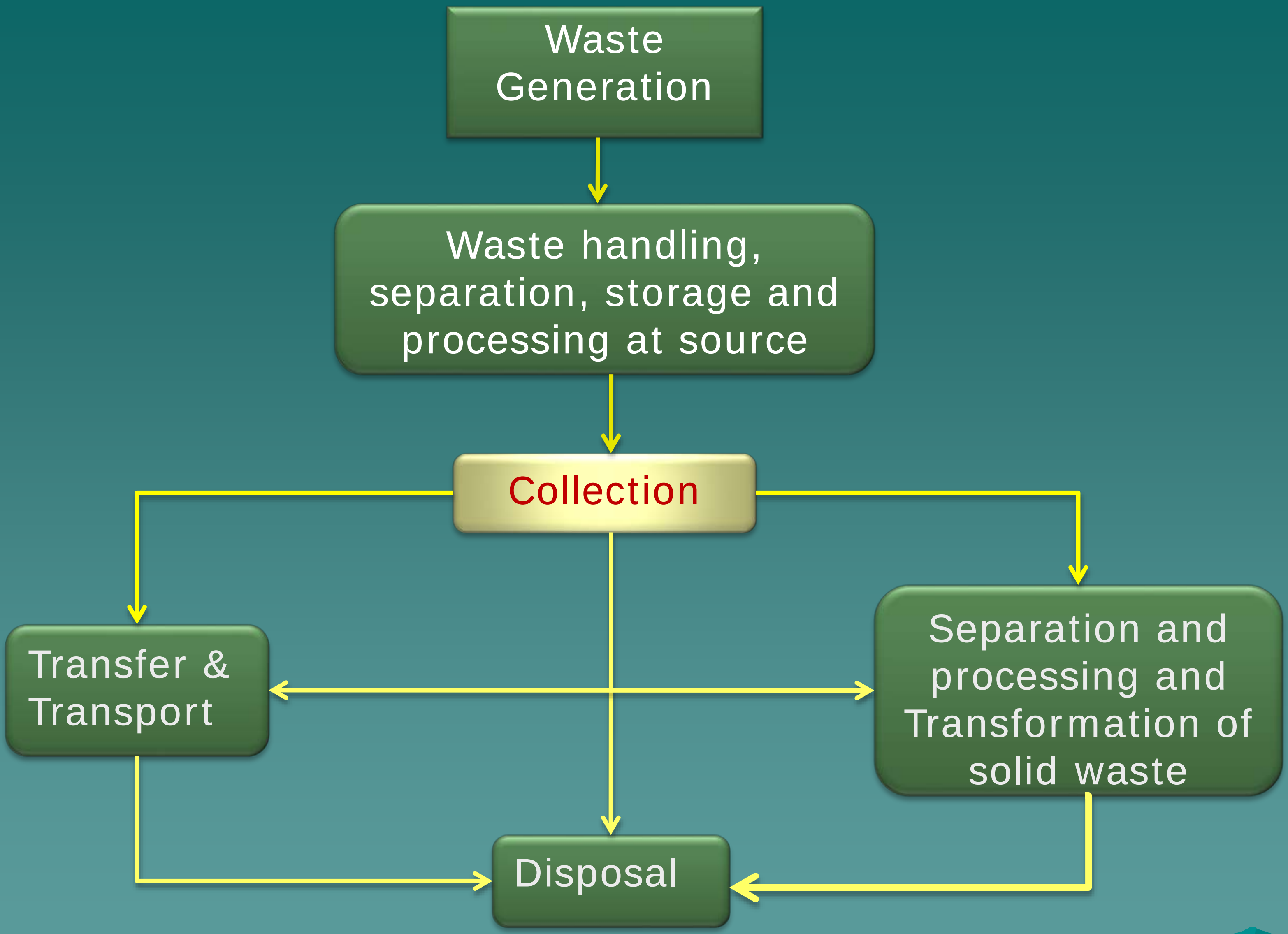
Processing of Solid Waste at Site

- Reduce the volume
- Recover usable materials
- Alter the physical form of the waste
  - Food waste grinding
  - Component separation
  - Compaction
  - Incineration
  - Composting
  - Lawn mulching


Stage


12 m^3 Container
6 m^3 Container


ALUMINUM
STEEL/TIN
THANK YOU!!!
PLASTIC #1 (PETE)
THANK YOU!!!
PLASTIC #2 (HDPE)
THANK YOU!!!
UNLV
STEEL
ALUMINUM
PLASTIC #1
PLASTIC #2


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

Collection of Unseparated (Comingled) Waste

- Low-rise detached buildings:
  - Curbside
  - Alley
  - Setout-setback
  - Setback
- Low and Medium-rise Apartments:
  - Curbside
- High-rise Apartments
  - Large containers

In Cities of Bangladesh door to door collection and large containers are used.

Solid Waste Collection Systems

- Hauled Container System (HCS)
  - Hoist Truck System
  - Tilt-frame System
  - Trash Trailer System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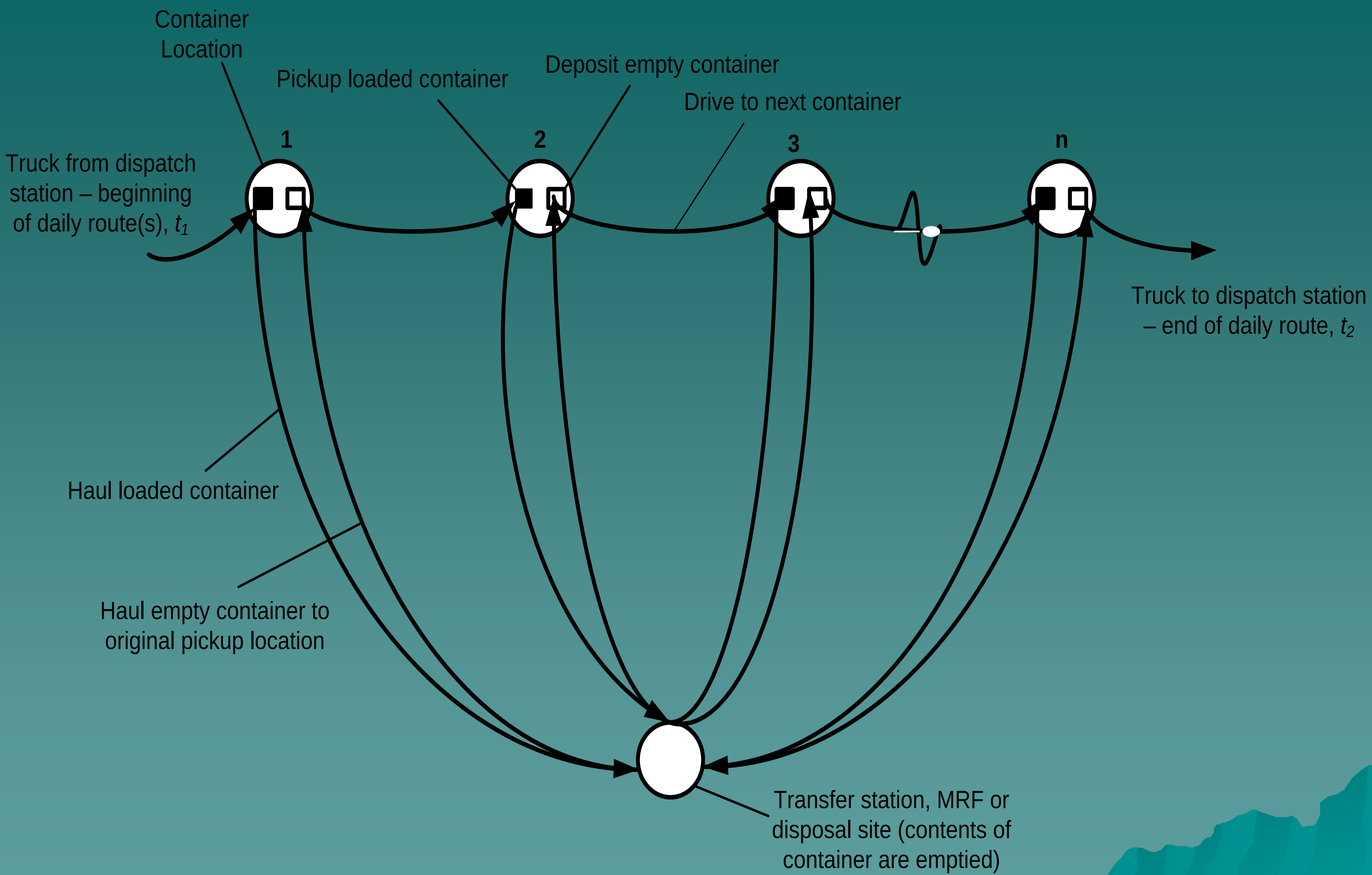
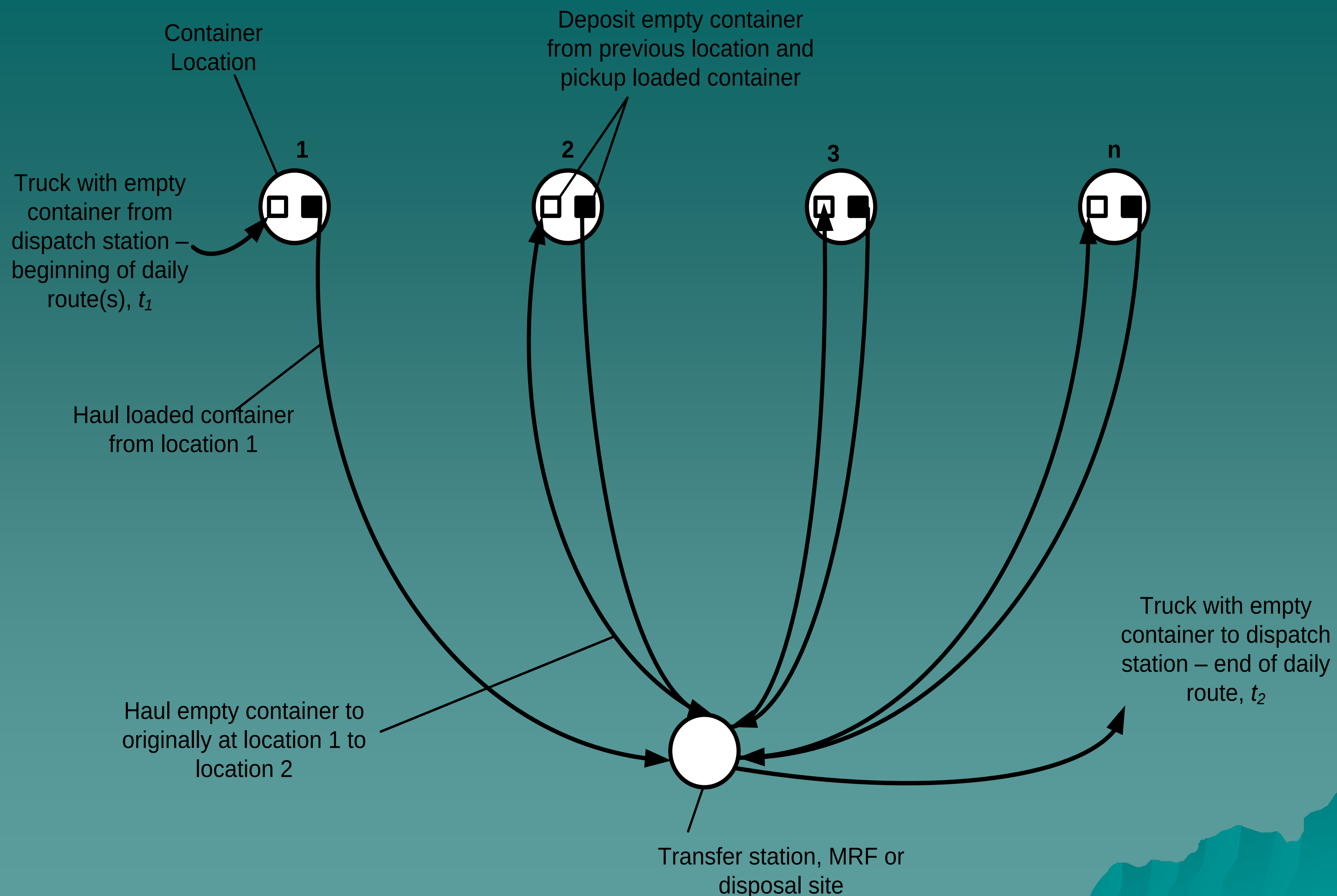
Stationary Container System (SCS)

- Mechanically loaded collection vehicles
- Manually loaded collection vehicles



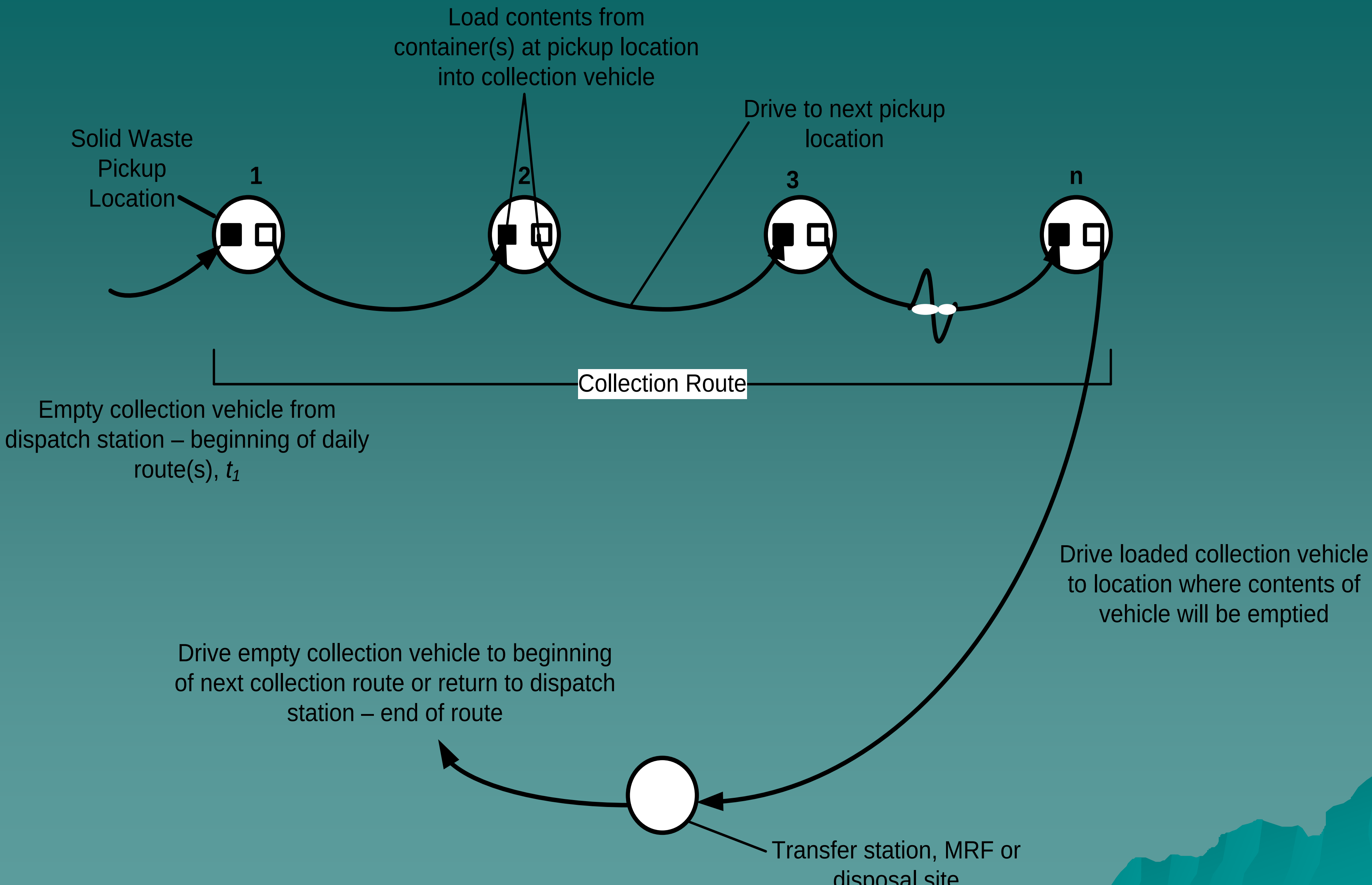
Haul Container System

Dr. A. B. M. Badruzzaman



Exchange Mode Hauled Container System

Dr. A. B. M. Badruzzaman



Stationary Container System

Dr. A. B. M. Badruzzaman

Definition of Terms

- **Pick Up for HCS (P_{hcs})**

  The time spent picking up the loaded container, time required to redeposit the container after its contents have been emptied, and the time spent diving to the next container.

Pick Up for SCS (P_{scs})

The time spent for loading the vehicle, beginning with the stopping of the vehicle prior to loading the contents of the first container and ending when the contents of the last container to be emptied have been loaded.

Haul for HCS (h_{hcs})

Time required o 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 has to be re-deposited. Time spent at the disposal site is not included. $h_{hcs} = a + bx$

Haul for SCS (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 has been 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. $h_{scs} = a + bx$

At-site (s)

Time spent at the disposal site, including time spent waiting to unload as well as time spent unloading.

Off-route (W)

All time spent on activities that are nonproductive from the view of the overall collection process. 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 repair and maintenance. Unnecessary off route time includes time spent for lunch in excess of the stated lunch period and time spent on taking unauthorized breaks, talking to friends, etc.

- For HCS:

$$T_{hcs} = P_{hcs} + s + a + bx$$

$$P_{hcs} = pc + uc + dbc$$

pc = time required to pick up loaded container, h/trip

uc = time required to unload container, h/trip

dbc = average time spent driving between container locations, h/trip

h = haul time, h/trip = a + bx

a = empirical haul-time constant, h/trip

b = empirical haul-time constant, h/mi

x = average round-trip haul distance, mi/trip

Number of Trips per vehicle per day for HCS:

$$N_d = [(1 - W)H - (t_1 + t_2)] / (P_{hcs} + s + a + bx)$$

N_d = number of trips per day, trips/day

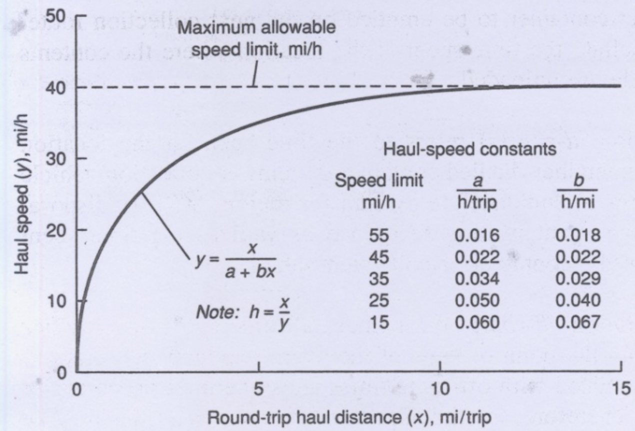
H = length of work day, h/day

W = off-route factor, expressed as fraction

t_1 = time to drive from dispatch station (garage) to 1st container location to be serviced for the day, h

t_2 = time to drive from last container to be serviced for the day to the dispatch station (garage), h

T_{hcs} = pickup time per trip, h/trip



Speed limit mi/h	a h/trip	b h/mi
55	0.016	0.018
45	0.022	0.022
35	0.034	0.029
25	0.050	0.040
15	0.060	0.067

FIGURE 8-16
Correlation between average haul speed and round-trip haul distance for waste collection vehicles [6].

For places where a number of pickup locations are located in a given service area, the average round-trip haul distance from the center of gravity of the service area to the disposal site can be used in Eq. (8-2). Determination of the haul-time constants is illustrated in Example 8-2, presented at the end of this discussion.

Substituting in Eq. (8-1) the expression for h given in Eq. (8-2), the time per trip can be expressed as follows:

$$T_{hcs} = (P_{hcs} + s + a + bx) \tag{8-3}$$

The pickup time per trip, P_{hcs}, for the hauled container system is equal to

$$P_{hcs} = pc + uc + dbc \tag{8-4}$$

where P_{hcs} = pickup time per trip, h/trip
pc = time required to pick up loaded container, h/trip
uc = time required to unload empty container, h/trip
dbc = time required to drive between container locations, h/trip

If the average time required to drive between containers is unknown, the time can be estimated by using Eq. (8-2). The distance between containers is substituted for the round-trip haul distance and the haul-time constants for 15 mi/h (see Fig. 8-16) should be used.

The number of trips that can be made per vehicle per day with a hauled container system, taking into account the off-route factor W, can be determined

Example 8-3 Analysis of a hauled container system. Solid waste from a new industrial park is to be collected in large containers (drop boxes), some of which will be used in conjunction with stationary compactors. Based on traffic studies at similar parks, it is estimated that the average time to drive from the garage to the first container location (t_1) and from the last container location (t_2) to the garage each day will be 15 and 20 min, respectively. If the average time required to drive between containers is 6 min and the one-way distance to the disposal site is 15.5 mi (speed limit: 55 mi/h), determine the number of containers that can be emptied per day, based on an 8-h workday. Assume the off-route factor, W, is equal to 0.15.

Solution

1. Determine the pickup time per trip using Eq. (8-4).

$$P_{hcs} = pc + uc + dbc$$

Use pc + uc = 0.4 h/trip (see Table 8-5)

$$dbc = 0.1 \text{ h/trip (given)}$$

$$P_{hcs} = (0.4 + 0.1) \text{ h/trip}$$

$$= (0.4 + 0.1) \text{ h/trip}$$

$$= 0.5 \text{ h/trip}$$

2. Determine the time per trip using Eq. (8-3).

$$T_{hcs} = (P_{hcs} + s + a + bx)$$

$$P_{hcs} = 0.5 \text{ h/trip (from Step 1)}$$

$$s = 0.133 \text{ h/trip (see Table 8-5)}$$

$$a = 0.016 \text{ h/trip (see Fig. 8-16)}$$

$$b = 0.018 \text{ h/trip (see Fig. 8-16)}$$

$$T_{hcs} = [0.5 + 0.133 + 0.016 + 0.018(31)] \text{ h/trip}$$

$$= 1.21 \text{ h/trip}$$

3. Determine the number of trips that can be made per day using Eq. (8-5).

$$N_d = [H(1 - W) - (t_1 + t_2)]/T_{hcs}$$

$$\text{Use } H = 8 \text{ h (given)}$$

$$W = 0.15 \text{ (assumed)}$$

$$t_1 = 0.25 \text{ h (given)}$$

$$t_2 = 0.33 \text{ h (given)}$$

$$T_{hcs} = 1.21 \text{ h/trip}$$

$$N_d = [8(1 - 0.15) - (0.25 + 0.33)]/(1.21 \text{ h/trip})$$

$$= (6.8 - 0.58)/(1.21 \text{ h/trip})$$

$$= 5.14 \text{ trips/d}$$

$$\text{Use } N_d = 5.0 \text{ trips/d}$$

4. Determine the actual length of the workday.

$$5 \text{ trips/d} = [H(1 - 0.15) - 0.58]/(1.21 \text{ h/trip})$$

$$H = 7.80 \text{ h (essentially 8 h)}$$

Comment. Where fractional equipment and labor requirements are obtained, the use of large containers and reduced collection frequency should be investigated. If it is assumed that no off-route activities occur during times t_1 and t_2, then theoretically 5.21 trips/d could be made. Again, only 5 trips/d would be made in an actual operation. If, however, the number of trips per day that could be made were 5.8, for example, it may be cost-effective to pay the driver for the overtime and make 6 trips/d.

For SCS

Mechanically Loaded Collection System:

$$T_{scs} = P_{scs} + s + a + bx$$

$$P_{scs} = C_t\, uc + (n_p - 1)\,(dbc)$$

C_t = # of containers emptied per trip, container/trip

uc = av. unloading time per container for SCS, h/ container

n_p = # of container pick up locations per trip.

dbc = average time spent driving between container locations, h/trip

The number of containers that can be emptied per collection trip is related to volume of the collection vehicle and the compaction ratio that can be achieved.

$$C_t = (vr \,/\, cf)$$

Manually Loaded Vehicles:

Once the pickup time per trip is known, the number of pickup locations from which wastes can be collected per trip can be estimated as follows;

$$N_p = 60\, P_{scs} \,.\, n / t_p$$

N_p = number of pickup locations per trip, #/trip

P_{scs} = pickup time per trip, h/trip

n = number of collectors

t_p = pickup time per pickup location, collector-min/location

$$t_p = dbc + k_1 C_n + k_2 (PRH)$$

k_1 = constant related to pickup time per container, min/cont

C_n = av. number of containers at each pickup location

K_2 = constant related to time required to collect waste from backyard of a residence min/PRH

PRH = rear-of-house pickup locations, %

Labor requirements for manual curbside collection using a one-person crew	
Average number of containers and/or boxes per pickup location	**Pick-up time, Collector.min/location**
1 or 2	0.50 – 0.60
3 or more or unlimited service	0.92

Once the number of pick-up locations per trip is known, the proper size of collection vehicle can then be estimated as follows;

$$v = V_p N_p / r$$

Where,

v = volume of collection vehicle, yd^3/trip

V_p = volume of solid wastes collected per pick-up location, yd^3/location

Np = number of pick-up locations per trip locations/trip

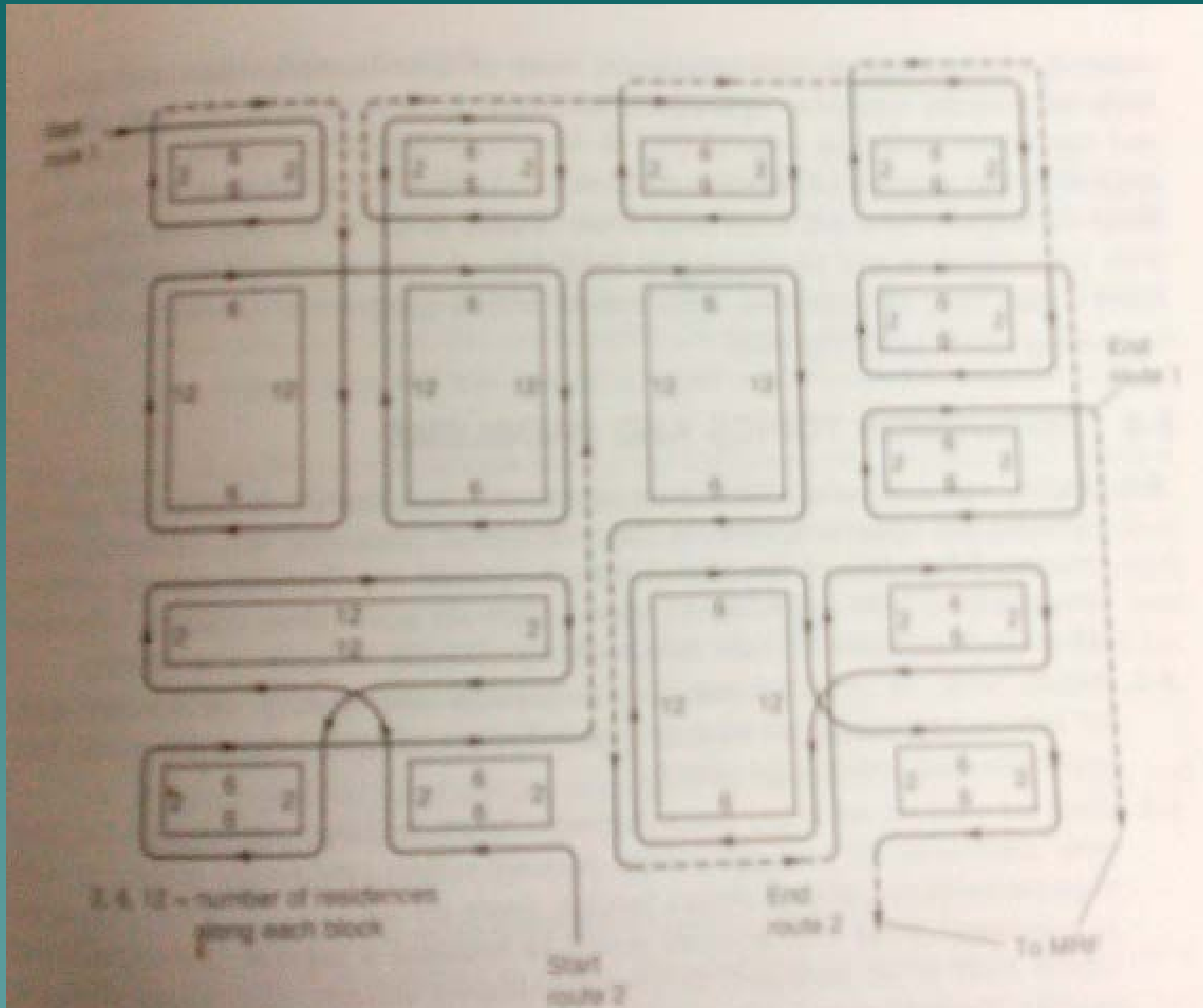
r = compaction ratio

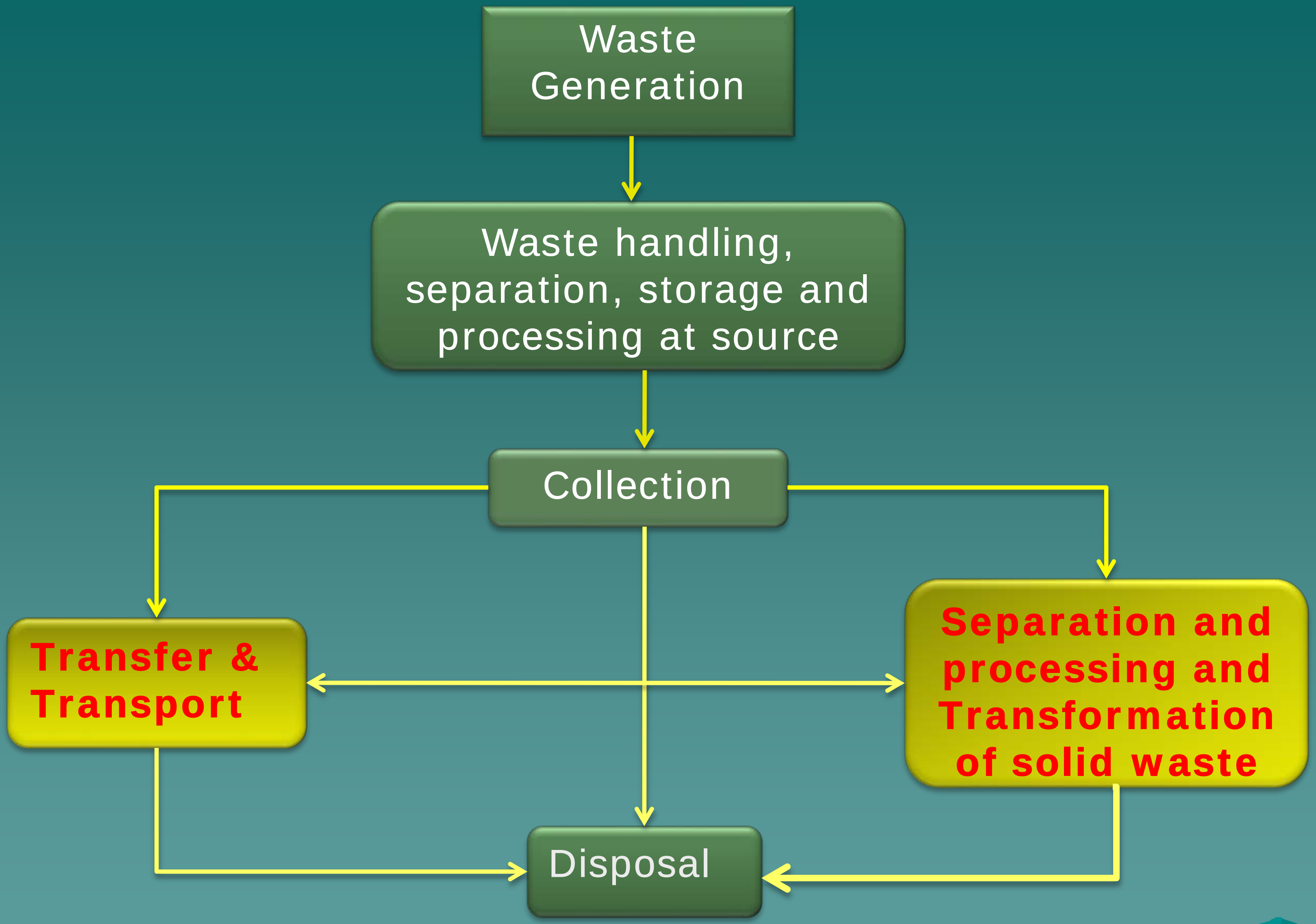
Guidelines for Laying out Collection Routes

- Existing policies and regulations related to such items as the point of collection and frequency of collection must be identified.
- Existing system characteristics such as crew size and vehicle type must be identified.
- Whenever possible, routes should be laid out so that they begin and end near arterial streets, using topographical and physical barriers as toute boundaries.
- In hilly areas, route should start at the top of the grade and end and proceed downhill as vehicle gets loaded.

Guidelines for Laying out Collection Routes (Contd..)

- Route should be laid out so that the last container to be collected on the route is located nearest to the disposal site.
- Wastes generated at traffic congested locations should be collected as early in the day as possible.
- Sources at which extremely large quantities of wastes are generated should be serviced during the first part of the day.
- Scattered pickup points (where small quantities of solid wastes are generated) that receive the same collection frequency should, if possible, be serviced during one trip or on the same day.


End
route 2
Start
route 2


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

Waste Separation

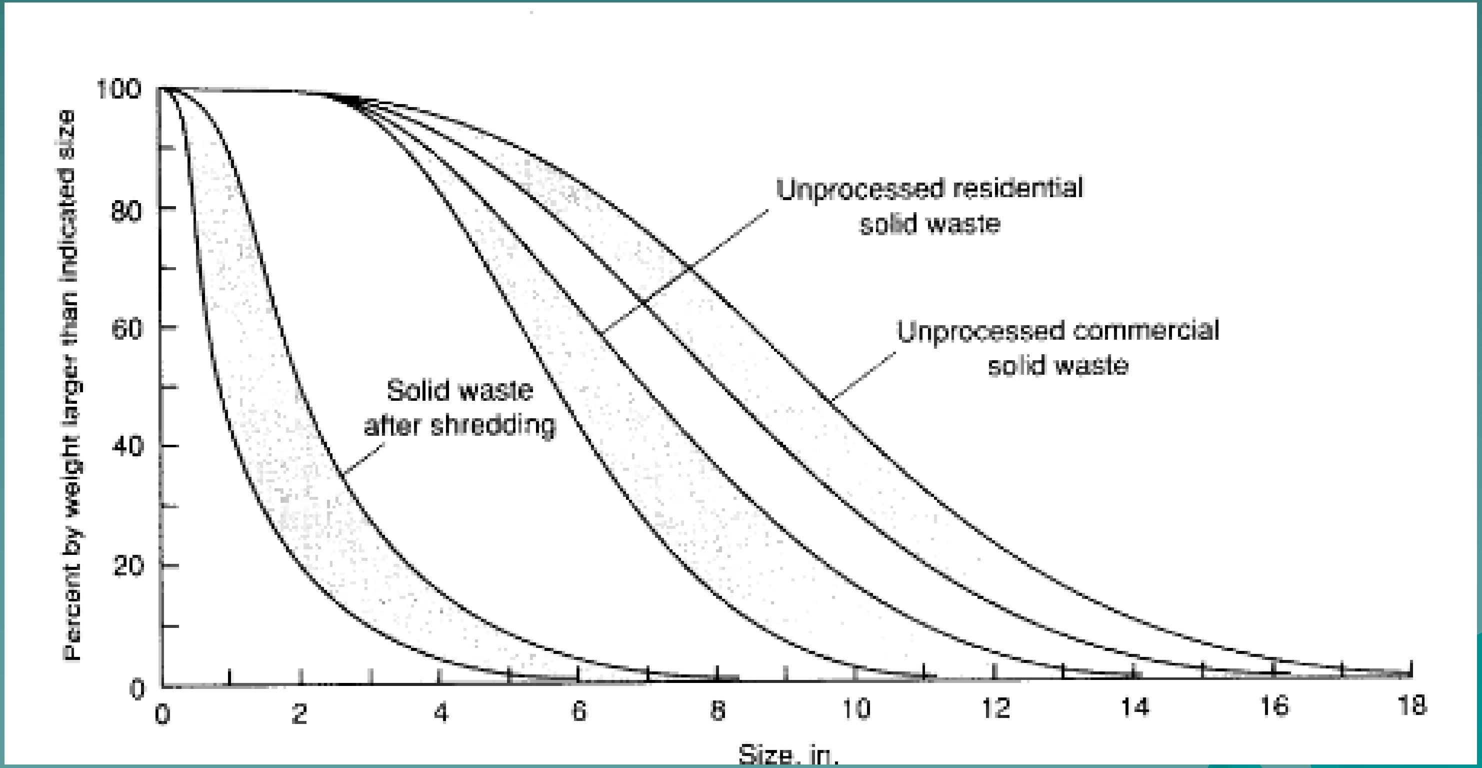
- Type of wastes:
  - Source separated
  - Comingled
- Way of separation of wastes:
  - Manual (Primarily used for separation at source)
  - Manual and Mechanical (at separating facilities: Material Recovery Facility, MRF and MR/Transfer Facility, TF)

Type of MRFs

- MRFs for Source-Separated Wastes:
  - Paper & cardboard from mixed paper & cardboard; aluminum from aluminum & tin cans; plastics by class from comingled plastics; glass by color; aluminum cans, tin cans, plastics from mixture of these materials.
- MRFs for Comingled Wastes:
  - All types of comingled materials
  - Sophistication depends on the number & types of components to be separated; the waste diversion goals established for the waste recovery program; the specifications to which the separated product must conform.

Units of Operations Used for Separation and Processing at MRFs

- **Size Reduction:**
  - The unit operation in which as collected waste materials are mechanically reduced in size (by Shredders, Glass Crushers, Wood Grinders, etc.)



- Size Reduction is done by shredding, grinding, and milling.

Examples of Shredding equipment are:

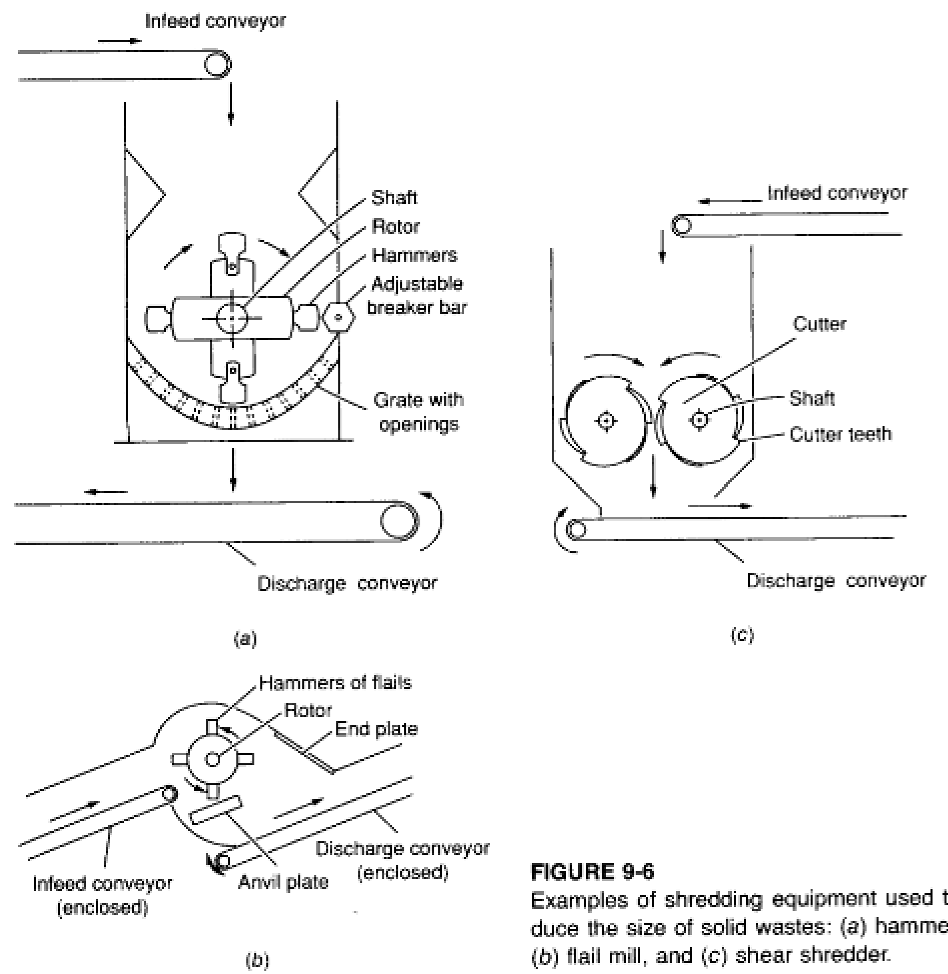
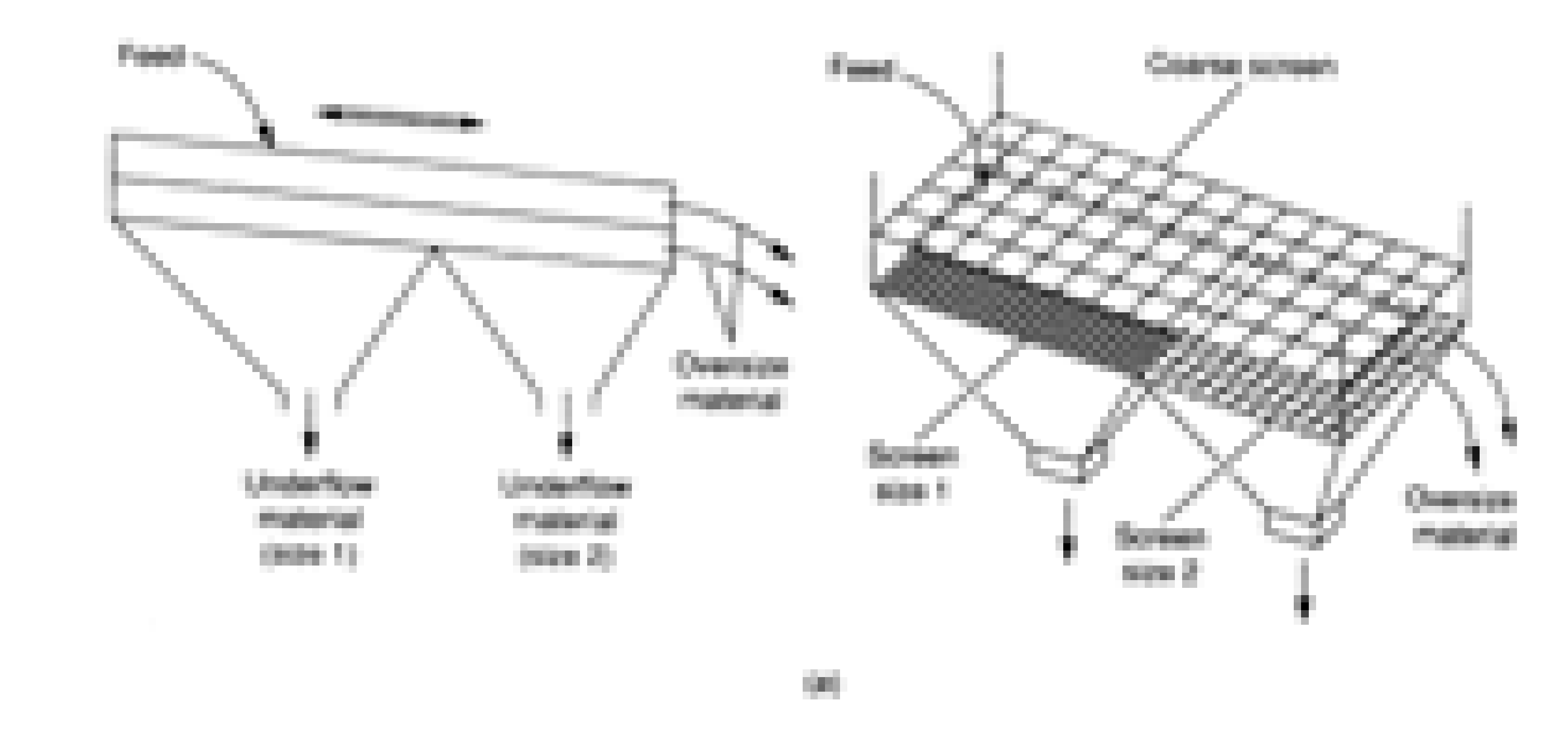
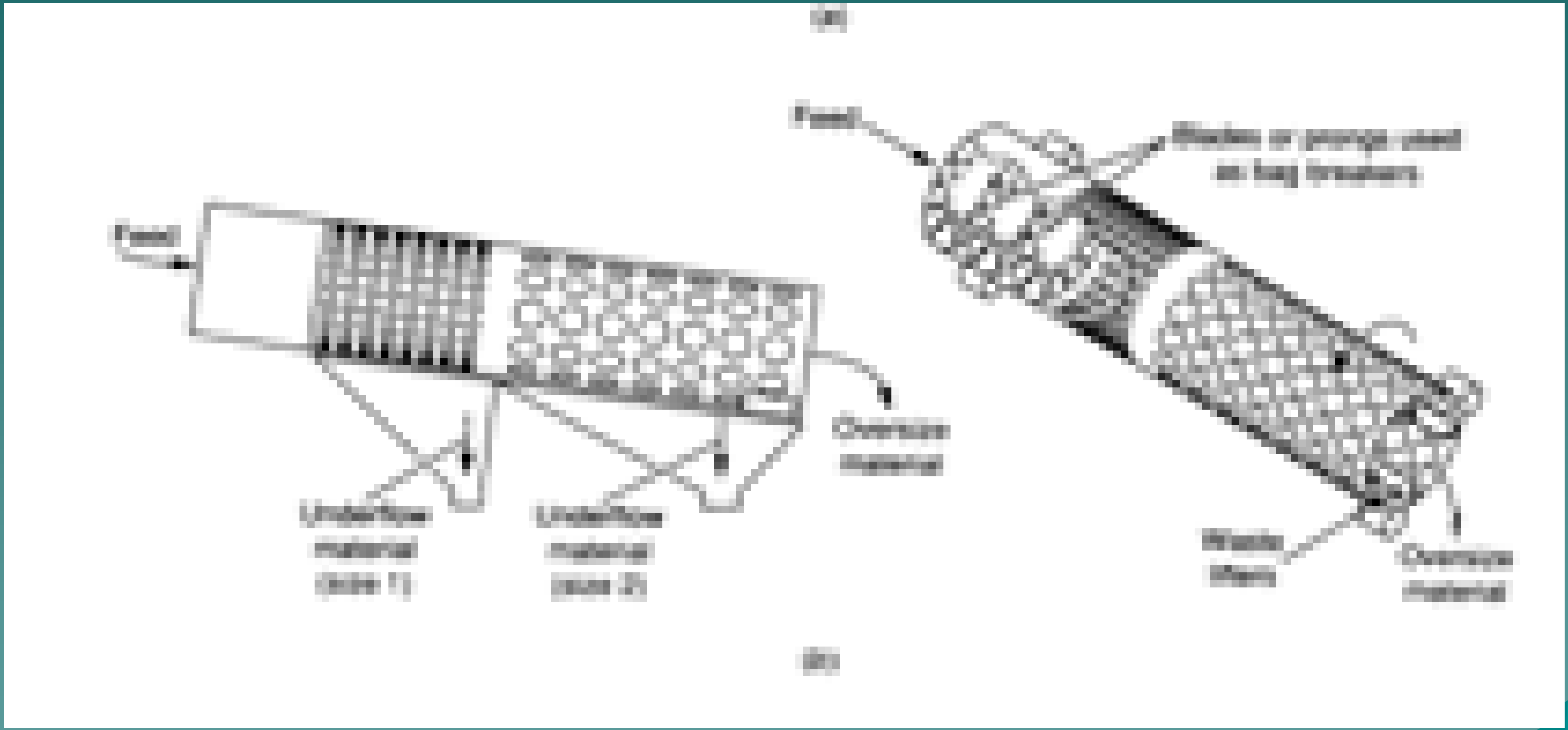
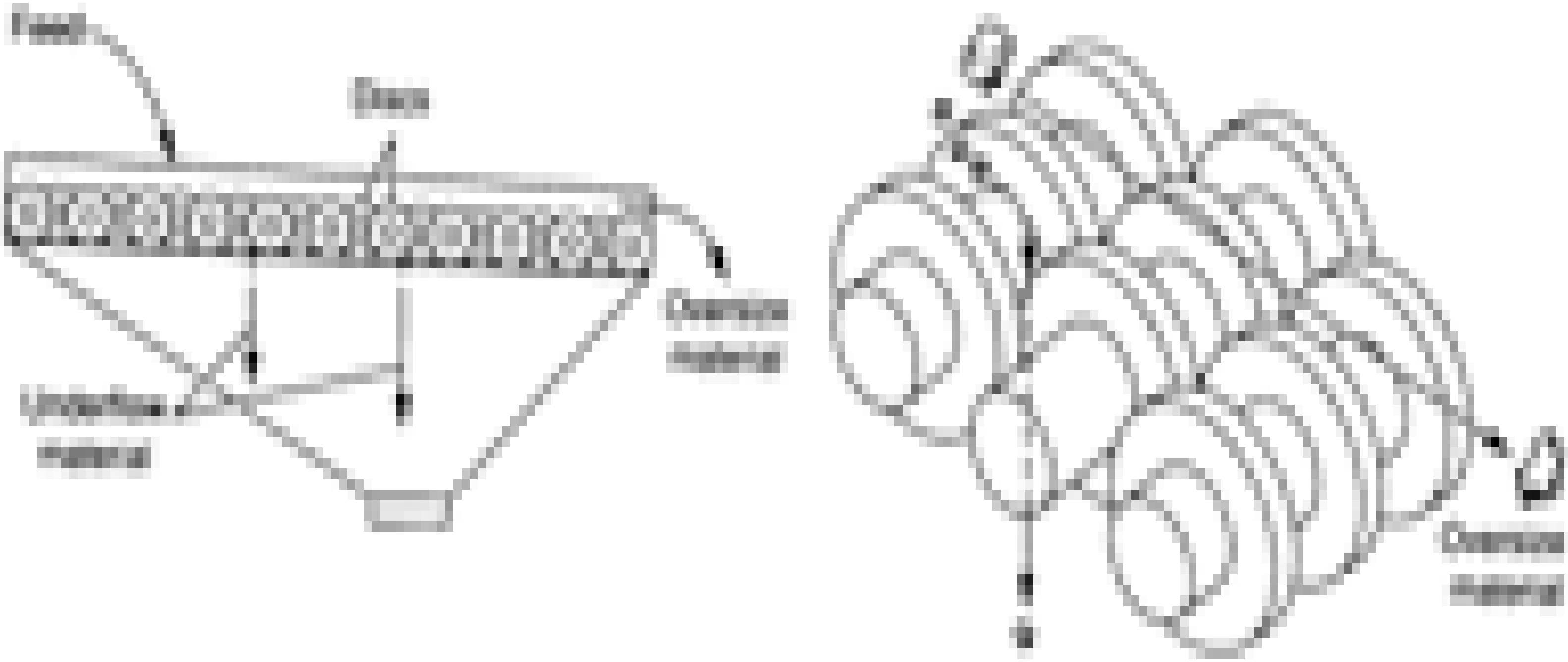


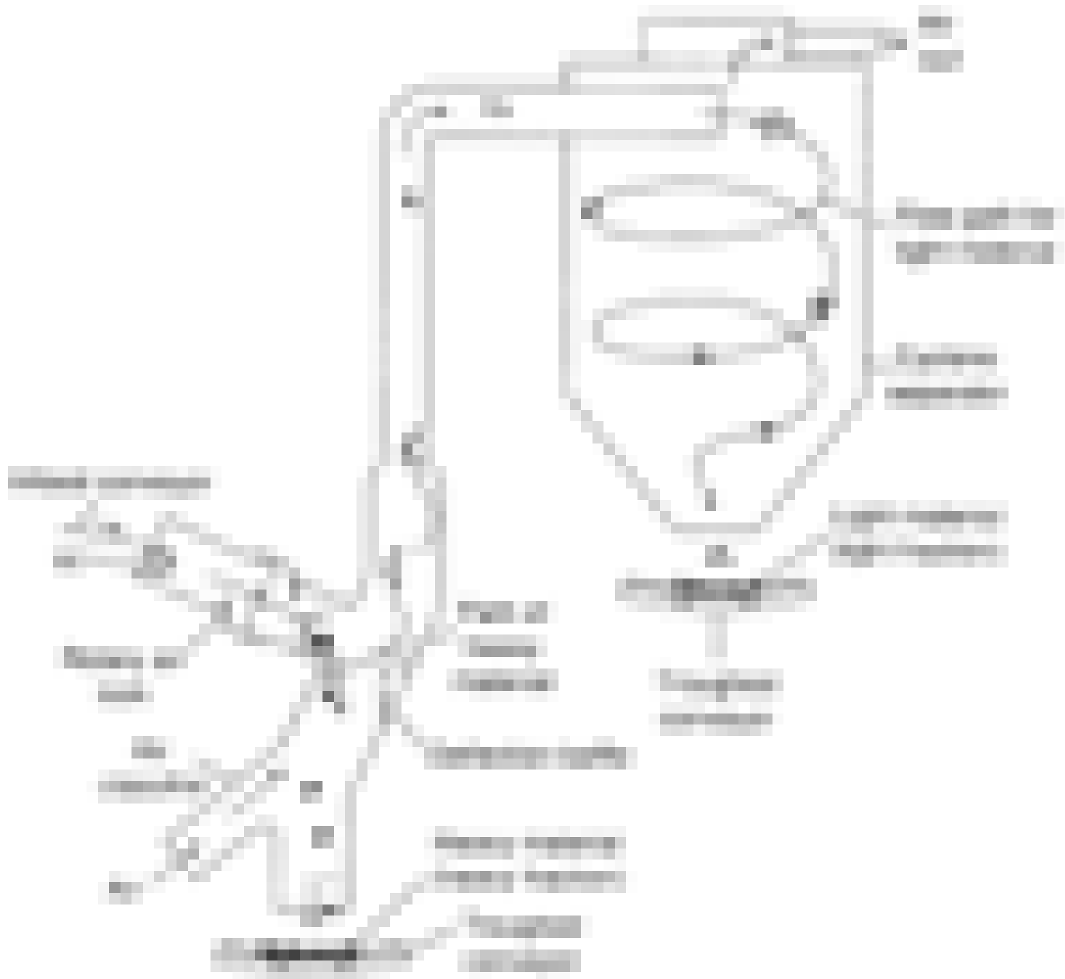
FIGURE 9-6
Examples of shredding equipment used to reduce the size of solid wastes: (*a*) hammermill, (*b*) flail mill, and (*c*) shear shredder.

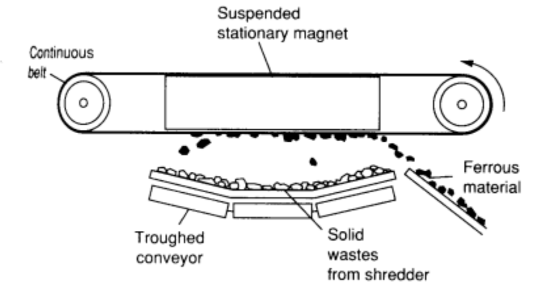

Feed
Oversize material
Underflow material (size 1)
Underflow material (size 2)
Feed
Coarse screen
Screen size 1
Screen size 2
Oversize material
(a)


(a)
Feed
Underflow material (size 1)
Underflow material (size 2)
Oversize material
Feed
Blades or prongs used as bag breakers
Waste fibers
Oversize material
(b)

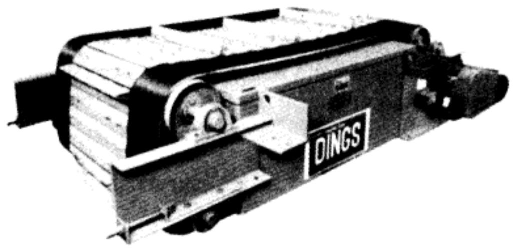

Feed
Discs
Oversize material
Underflow material
Oversize material

(b)

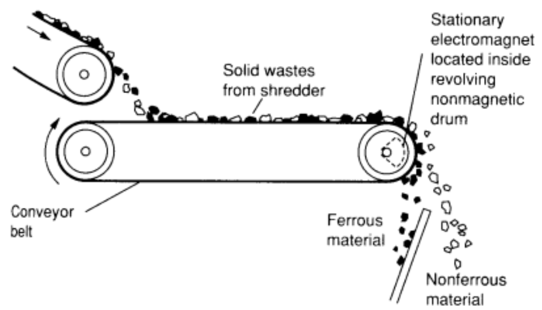




(a)

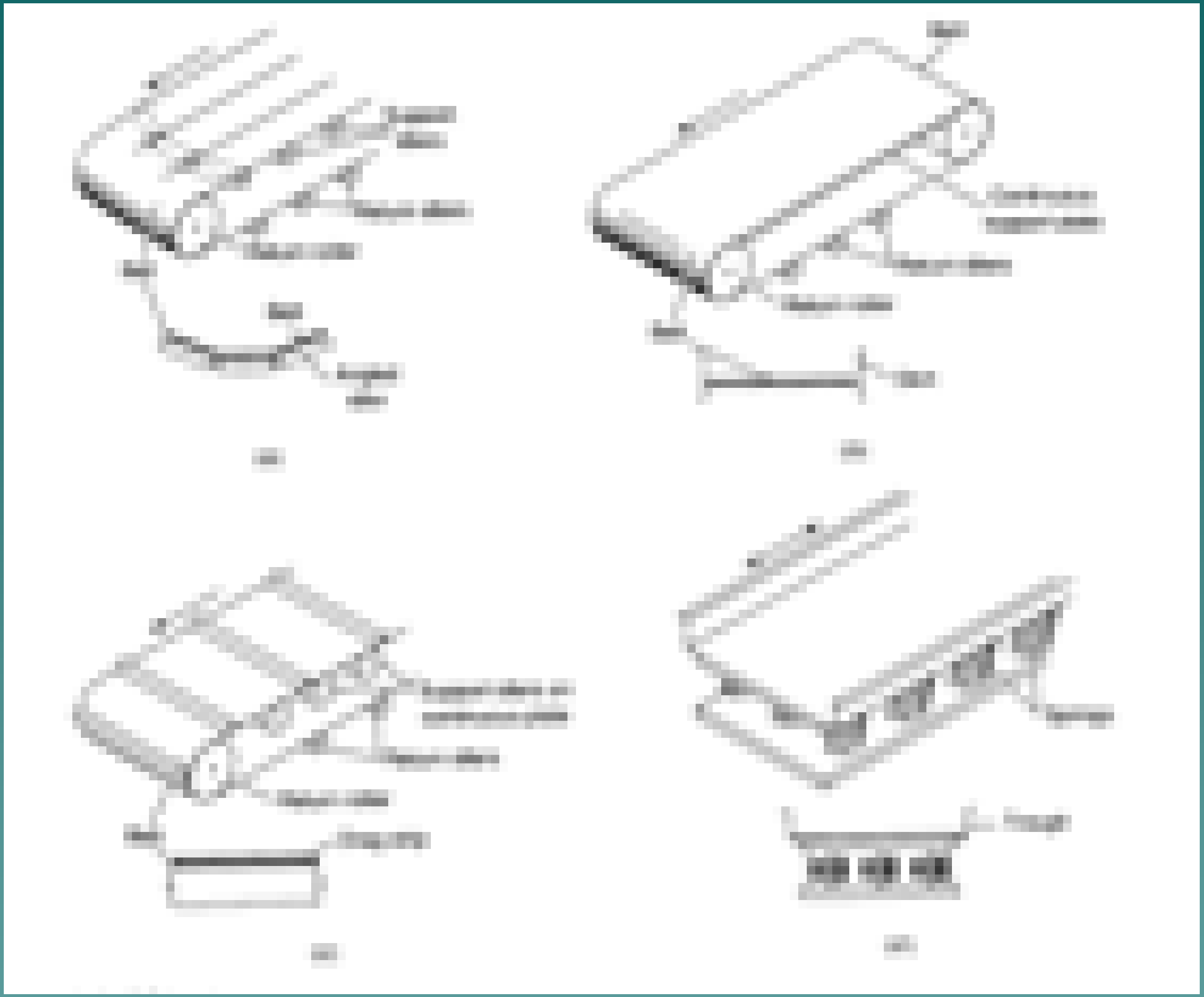


(b)



(c)

FIGURE 9-11
Typical magnet separators: (a) schematic overhead magnet and (b) view of commercial overhead magnet. The unit shown is equipped with an armored stainless steel self-cleaning belt for severe duty applications such as solid waste. (Courtesy of Dings Co., Magnetic Group), and (c) pulley magnet.



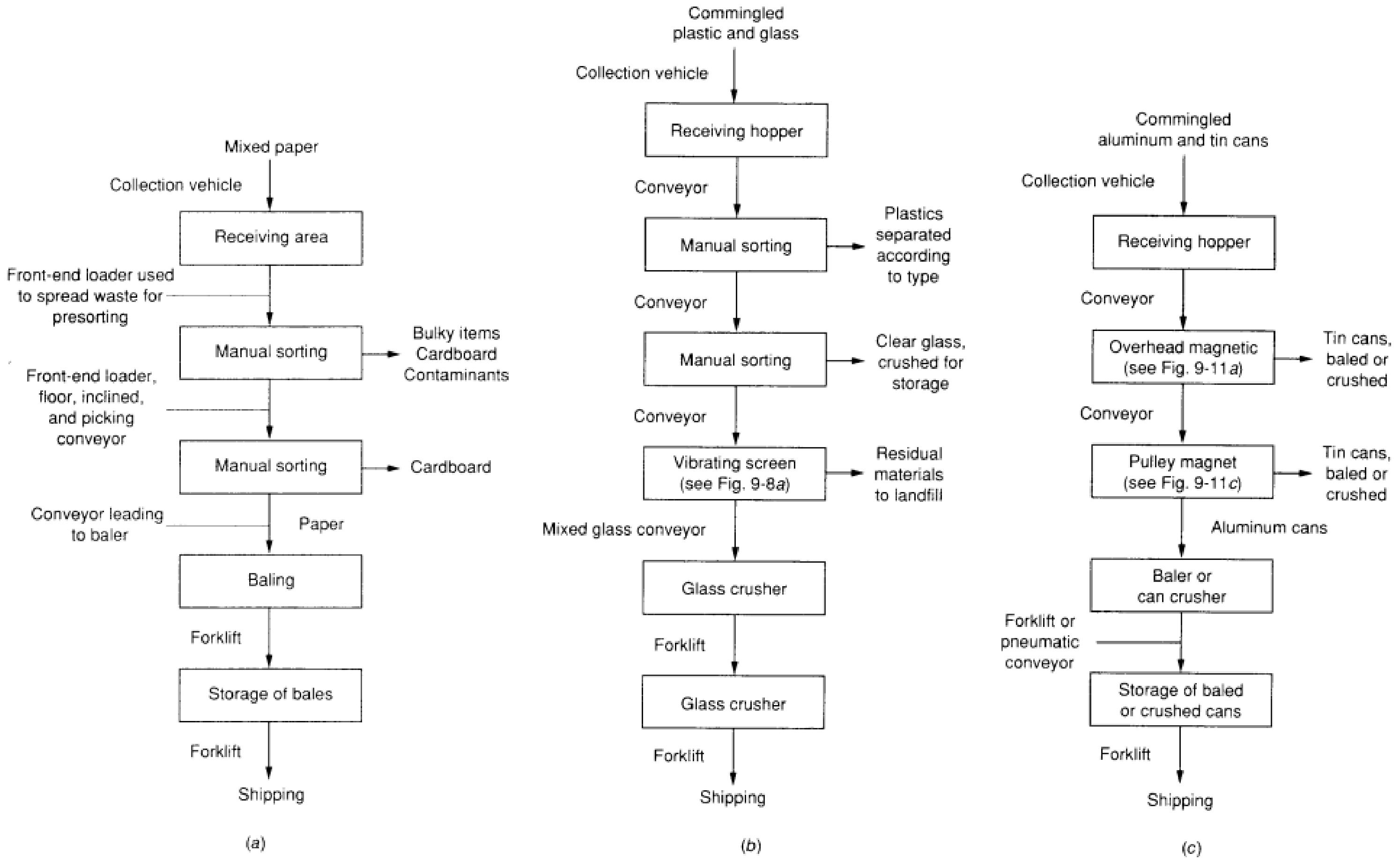


FIGURE 9-21
Flow diagrams for the separation of source-separated waste: (*a*) mixed paper, (*b*) commingled plastics and glass, and (*c*) aluminum and tin cans.

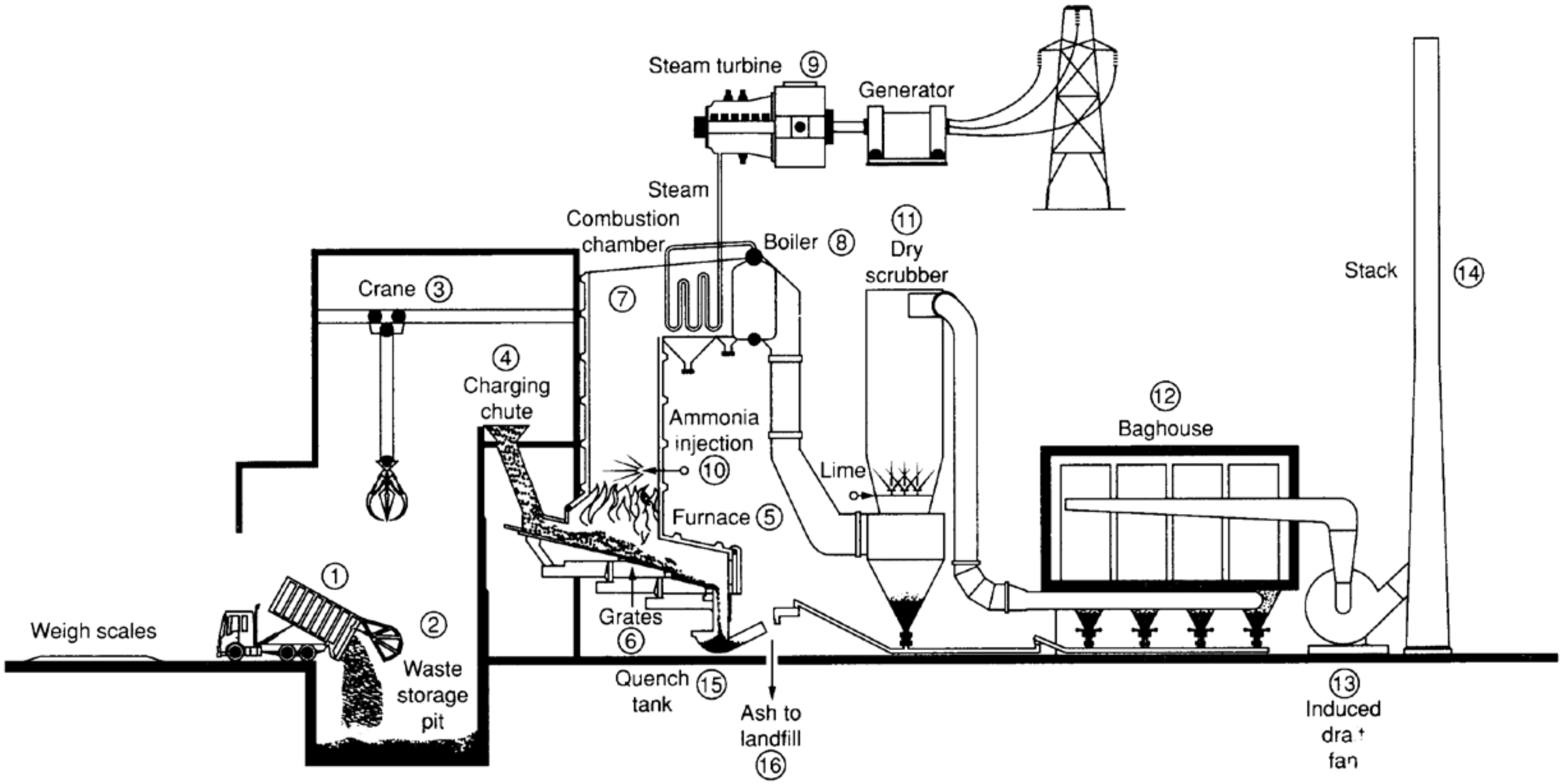


FIGURE 9-31
Section through a typical continuous-feed mass-fired municipal combustor used for the production of energy from MSW. (Courtesy of County Sanitation Districts of Los Angeles County.)

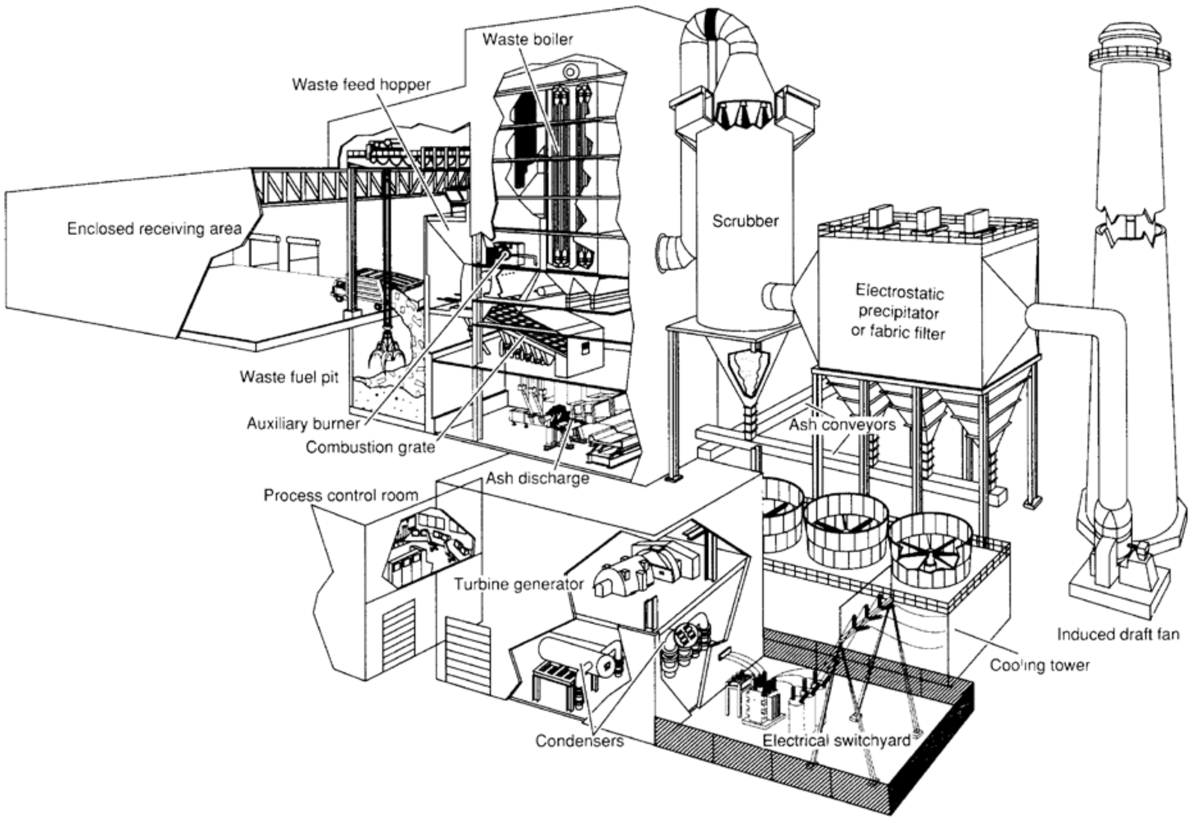


FIGURE 9-32
Section through water-wall mass-fired combustor used for the production of energy from MSW. (Courtesy of Wheelabrator Environmental Systems, Inc.)

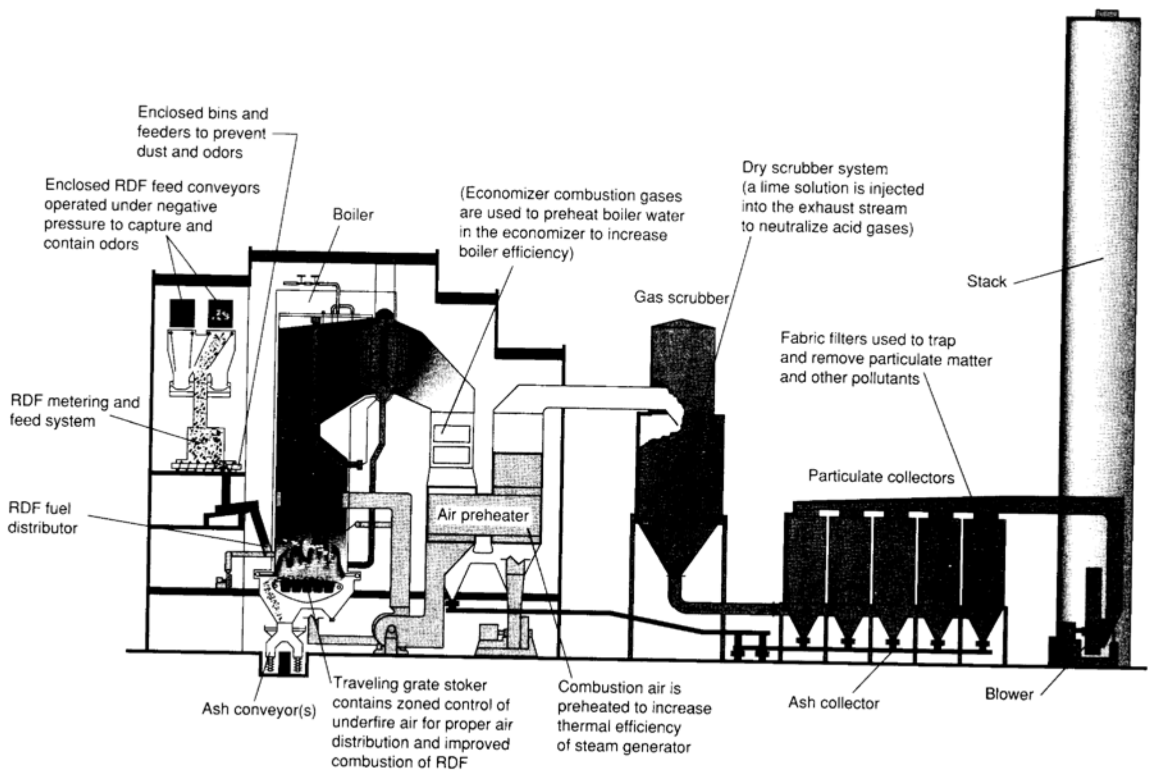


FIGURE 9-34
View of industrial water-wall boiler combustion system used for the production of energy from processed solid wastes, natural gas, oil, and coal. (Courtesy of ABB Resource Recovery Systems.)

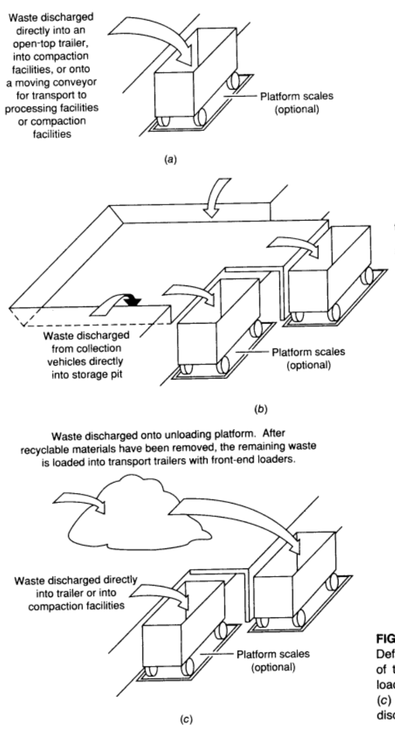


FIGURE 10-1
Definition sketch for the types of transfer stations: (*a*) direct-load, (*b*) storage-load, and (*c*) combined direct-load and discharge-load.

that are transported to the disposal site (see Fig. 10-1*a*). In some cases, the wastes may be emptied onto an unloading platform and then pushed into the transfer vehicles, after recyclable materials have been removed. The volume of waste that can be stored temporarily on the unloading platform is often defined as the *surge capacity* or the *emergency storage capacity* of the station.

= 5 trips/wk

(*d*) Determine the time required per week, T_w, as a function of the round-trip haul distance using the following expression. The term T_w represents the integer number of trips made to the location where the contents of the collection vehicle will be unloaded. The numerical value of T_w is obtained by rounding up the value of N_w to an integer value.

$$T_{w(scs)} = [(N_w)P_{scs} + t_w(s + a + bx)]/[H(1 - W)]$$

$$= [(5\ \text{trips/wk})(1.22\ \text{h/trip}) + (5\ \text{trips/wk})$$

$$\times [0.10\ \text{h/trip} + 0.022\ \text{h/trip} + (0.022\ \text{h/mi})(x)]]$$

$$/[(8\ \text{h/d})(1 - 0.15)]$$

$$= [0.99 + (0.016/\text{mi})(x)]\ \text{d/wk}$$

(*e*) Determine the weekly operational costs as a function of the round-trip haul distance.

$$\text{Operational cost} = (\$20/\text{h})(8\ \text{h/d}) \times [0.99 + (0.016/\text{mi})(x)]\ \text{d/wk}$$

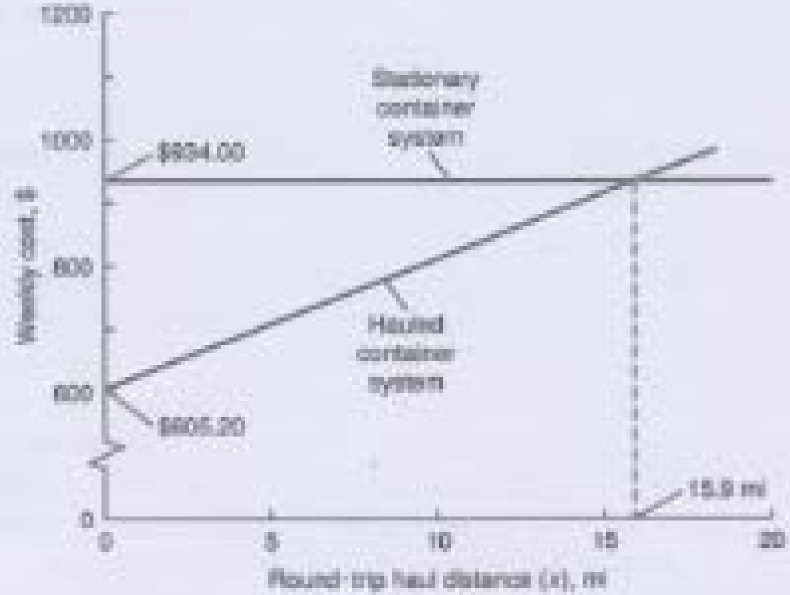
$$= [158.40 + (2.56/\text{mi})(x)]\ \$/\text{wk}$$

3. Comparison of systems

(*a*) Determine the maximum round-trip haul distance at which the cost for hauled container systems equals the cost for the stationary container systems by equating the total costs for the two systems and solving for x.

$$\$400/\text{wk} + [205.20 + (21.7/\text{mi})(x)]\ \$/\text{wk} = \$750/\text{wk}$$
$$+[158.40 + (2.56/\text{mi})(x)]\ \$/\text{wk}$$
$$(19.1/\text{mi})(x) = 303.20$$
$$x = 15.9 \text{ mi (one-way distance} \sim 8.0 \text{ mi)}$$

(*b*) Plot the weekly cost versus round-trip haul distance for each system. The required plot is presented below.



Comment. The curves shown in the figure given above are characteristic of those obtained when hauled container systems are compared with stationary container systems. In most cases the round-trip haul distance at which hauled container systems are no longer competitive is much shorter than in this example.

transfer operations attractive include (1) the occurrence of illegal dumping due to excessive haul distances, (2) the location of disposal sites relatively far from collection routes (typically more than 10 mi), (3) the use of small-capacity collection vehicles (generally under 20 yd^3), (4) the existence of low-density residential service areas, (5) the use of a hauled container system with relatively small containers for the collection of wastes from commercial sources, and (6) the use of hydraulic or pneumatic collection systems.

Excessive Haul Distances

In the early days when horse-drawn carts were used for the collection of solid wastes, it was common practice to empty the contents of the loaded carts into some auxiliary vehicle for transport to some intermediate point for processing or to the disposal site. However, with the advent of the modern motor truck and the availability of low-cost fuel, transfer operations in most cities were abandoned and direct hauling was adopted. Today, with rising labor, operating, and fuel costs and the absence of nearby solid waste disposal sites the trend is reversing, and transfer stations are again becoming common. For example, wastes from the city of Portland, OR, are hauled to a disposal site 150 mi away.

Usually, the decision to use a transfer operation is based on economics. For example, in Examples 8-2 and 8-5 the time and economic advantages of the stationary container system over the hauled container system were demonstrated clearly. Simply stated, it is cheaper to haul a large volume of wastes in large increments over a long distance than it is to haul a large volume of wastes in small increments over a long distance. The economic advantage of a transfer operation is illustrated in Example 10-1.

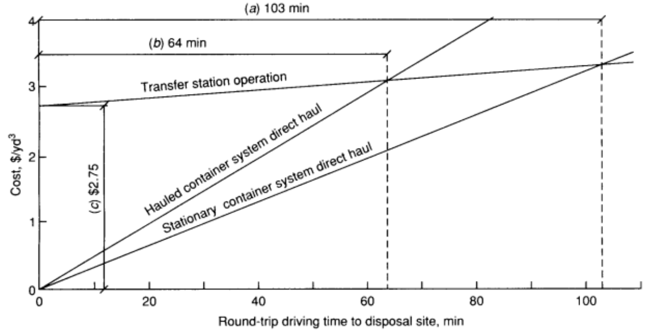
Example 10-1 Economic comparison of transport alternatives. Determine, based on operating costs, the break-even points for a hauled and a stationary container system as compared with a system using transfer and transport operations for transporting wastes collected from a metropolitan area to a landfill disposal site. Assume that the following cost data are applicable:

1. Operating costs
   (*a*) Haul container system using a hoist truck with an 8-yd^3 container = \$25/h
   (*b*) Stationary container system using a 20-yd^3 compactor = \$40/h
   (*c*) Tractor-semitrailer transport unit with a capacity of 105 yd^3 = \$40/h
   (*d*) Transfer station operation cost = \$2.75/yd^3

Solution

1. Convert the haul cost data to units of dollars per cubic yard per minute (see comment at end of this example).
   (*a*) Hoist truck = \$0.052/$yd^3 \cdot$ min
   (*b*) Compactor = \$0.033/$yd^3 \cdot$ min
   (*c*) Transfer station transport equipment = \$0.0063/$yd^3 \cdot$ min

2. Prepare a plot of the cost per cubic yard versus the round-trip driving time expressed in minutes for the three alternatives. The required plot is presented below.



(*a*) Break-even time for stationary container system
(*b*) Break-even time for hauled container system
(*c*) Transfer station operating cost

3. Determine the break-even times for the hauled and stationary container systems using the plot prepared in Step 2.
   (*a*) Hauled container system = 64 min
   (*b*) Stationary container system = 103 min
   Thus, for example, if a stationary container system is used and the round-trip driving time to the disposal site is more than 103 min, the use of a transfer station should be investigated.

Comment. In most cases, articles, and reference books dealing with the long-distance hauling of solid wastes, cost data are expressed in terms of dollars per ton per minute or dollars per ton per mile. This practice is widely accepted for transfer station analysis because weight is the most critical measure for efficient highway or rail movement. Such cost data can be misleading, however, when the densities of solid wastes vary significantly from location to location or container to container. For example, if the density of the wastes in two hoist-truck containers varies by a factor of three, then comparing the costs of hauling two containers of the same size on a per-ton basis would tend to be misleading because the actual cost is the same for both. On the other hand, a comparison based on dollars per cubic yard per minute or dollars per minute would be valuable in comparing the two operations.

Remote Processing Facilities or Disposal Sites

Transfer operations must be used when the processing facilities or disposal sites are in such a remote location that conventional highway transportation alone is not feasible. For example, transfer stations are required when rail cars or ocean-going

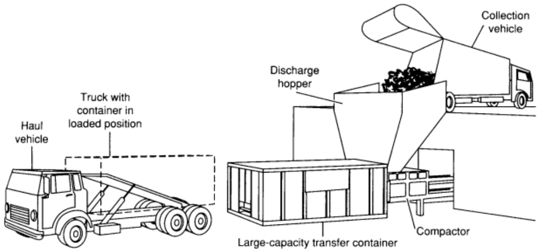


FIGURE 10-8
Small-capacity direct-load a transfer station equipped with a stationary compactor. (Adapted from Schindler Waggon AG, Prattein.)

A small-capacity direct-load transfer station with compaction facilities is shown in Fig. 10-8. As shown, a large container is used with this type of transfer station as opposed to a transfer trailer. The container is hauled to the disposal site using a tilt-frame vehicle (see Fig. 8-10). Depending on the length of time required to haul the loaded container to the disposal site and to return, an empty container may be attached to the compactor before the full container is hauled to the disposal site.

Small-Capacity Direct-Load Transfer Stations Used in Rural Areas. Used in rural and recreational areas, small-capacity direct-load transfer stations like those shown in Figs. 10-9 and 10-10 are designed so that the loaded containers are emptied into a collection vehicle for transport to the disposal site. In the design and layout of such stations, which are usually unattended, the key consideration should be simplicity. Complex mechanical systems are not suitable in such locations. The number of containers used depends on the area served and the collection frequency that can be provided. To facilitate unloading, the tops of the containers may be set about 3 ft above the top of the unloading-area platform (see Fig. 10-9). Alternatively, the tops of the containers may be set level with the unloading area (see Fig. 10-10), and the area behind the containers can be excavated to provide space for maneuvering the collection vehicles when the contents of the containers are emptied.

Small-Capacity Direct-Load Transfer Station Used at Landfill Disposal Site. The transfer station shown in Fig. 10-11 is of the type used at landfill disposal sites for individuals and small-quantity haulers. The transfer facilities are also used for the recovery of recyclable materials. After any recyclable items are dropped off, waste materials are emptied into two large transfer trailers each of which is hauled to the disposal site, emptied, and returned to the transfer station.

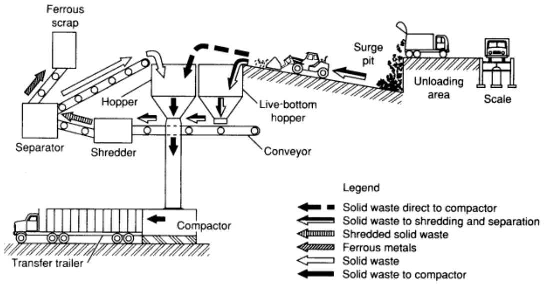


FIGURE 10-14
Storage-load transfer station with processing and compaction facilities. (Courtesy of Municipality of Metropolitan Toronto, Department of Public Works.)

Combined Direct-Load and Discharge-Load Transfer Station

In some transfer stations, both direct-load and discharge-load methods are used (see Fig. 10-1*c*). Usually these are multipurpose facilities that service a broader range of users than a single-purpose facility. A multipurpose transfer station can also house a materials recovery operation. The layout of a multipurpose transfer station, designed for use by the general public and by various waste collection agencies, is shown in Fig. 10-15.

The operation may be described as follows. All waste haulers (general public as well as commercial haulers) wishing to use the transfer station must check in at the scale house. Large commercial collection vehicles are weighed, and a commercial customer ticket is stamped and given to the vehicle driver. The driver then proceeds to the unloading platform and empties the contents of the collection vehicle directly into the transport trailer. After unloading the collection vehicle, the driver returns the vehicle to the scale house for reweighing and turns in her or his customer ticket. The weight of the empty vehicle is recorded while a discharge fee is calculated.

Individual residents as well as small independent noncommercial haulers haul significant quantities of yard wastes, tree trimmings, and bulky wastes (stoves, lawn mowers, refrigerators, etc.) to the transfer station. All automobiles pulling trailers and pickup trucks containing wastes must be checked in at the scale house. These vehicles are not weighed, but users do pay a discharge fee that is collected at the scale house by the attendant, who gives the user a cash receipt. The scale attendant visually checks the waste load to determine if it contains any recyclable materials. If it does, the attendant instructs the driver to deposit the

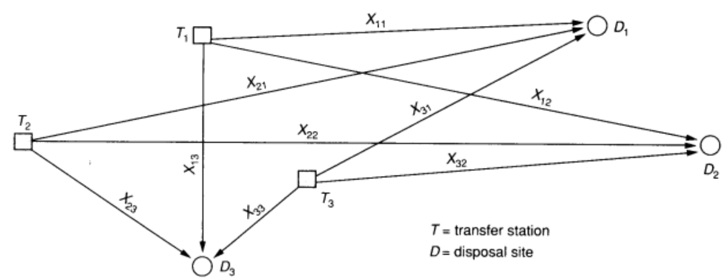


FIGURE 10-24
Definition sketch for allocation of solid wastes from three transfer stations to three disposal sites.

5. Let R_i = the total amount of wastes delivered to transfer station i.

6. Let D_j = the total amount of wastes that can be accepted at disposal site j.

7. If the total haul costs are to be minimized, then an objective function, which is defined as the sum of the following terms, must be minimized subject to the problem constraints:

$$X_{11}C_{11} + X_{12}C_{12} + X_{21}C_{21} + X_{22}C_{22} + X_{23}C_{23} + X_{31}C_{31} + X_{32}C_{32} + X_{33}C_{33} = \text{objective function}$$

8. Expressed in mathematical summation form, the problem is to minimize the function

$$\text{Objective function} = \sum_{j=1}^{3}\sum_{i=1}^{3} X_{ij}C_{ij} \qquad (10\text{-}1)$$

subject to the following constraints:

$$\sum_{j=1}^{3} X_{ij} = R_i \qquad i = 1 \text{ to } 3 \qquad (10\text{-}2)$$

$$\sum_{j=1}^{3} X_{ij} \leq D_j \qquad j = 1 \text{ to } 3 \qquad (10\text{-}3)$$

$$X_{ij} \geq 0 \qquad (10\text{-}4)$$

The fact that the amount of waste hauled to the disposal sites must be equal to the amount brought to the transfer station is given by the first constraint. The condition that the total amount of waste hauled from the transfer station must be equal to or less than the capacity of the disposal sites is given by the second constraint. The third constraint is that the amount of waste hauled from the transfer station must be equal to or greater than zero.