Chapter 12

Solid Waste

Solid wastes other than hazardous and radioactive materials are considered in this chapter. Such solid wastes are often called *municipal solid waste* (MSW) and consist of all the solid and semisolid materials discarded by a community. The fraction of MSW produced in domestic households is called *refuse*. Until fairly recently, refuse was mostly food wastes, but new materials such as plastics and aluminum cans have been added to refuse, and the use of kitchen garbage grinders has decreased the food waste component. Most of the 2000 new products created each year by American industry eventually find their way into MSW and contribute to individual disposal problems.

The components of refuse are *garbage* or food wastes; *rubbish*, including glass, tin cans, and paper; and *trash*, including larger items like tree limbs, old appliances, and pallets that are not usually deposited in garbage cans.

The relationship between solid waste and human disease is intuitively obvious but difficult to prove. If a rat is sustained by an open dump, and that rat sustains a flea that transmits murine typhus to a human, the absolute proof of the pathway would require finding the particular rat and flea, an obviously impossible task. Nonetheless, we have observed more than 20 human diseases associated with solid waste disposal sites, and there is little doubt that improper solid waste disposal is a health hazard.

Disease vectors are the means by which disease organisms are transmitted, and water, air, and food may all be vectors. The two most important disease vectors related to solid wastes are rats and flies. Flies are such prolific breeders that 70,000 flies can be produced in 1 ft^3 of garbage, and carry many diseases like bacillary dysentery. Rats not only destroy property and infect by direct bite, but carry insects like fleas and ticks that may also act as vectors. The plagues of the Middle Ages were directly associated with the rat populations.

Public health is also threatened by infiltration of leachate from MSW disposal into groundwater, and particularly into drinking water supplies. Leachate is formed when rainwater collects in landfills, pits, waste ponds, or waste lagoons, and stays in contact with waste material long enough to leach out and dissolve some of its chemical and biochemical constituents. Leachate may be a major groundwater and surface water contaminant, particularly where there is heavy rainfall and rapid percolation through the soil.

In this chapter, the quantities and composition of MSW are discussed, and a brief introduction is given to disposal options and the specific problems of litter. Disposal is

discussed further in Chap. 13, and Chap. 14 is devoted to the problems and promises of recovery of energy and materials from refuse.

QUANTITIES AND CHARACTERISTICS OF MUNICIPAL SOLID WASTE

The quantities of MSW generated in a community may be estimated by one of three techniques: input analysis, secondary data analysis, or output analysis. Input analysis estimates MSW based on use of a number of products. For example, if 100,000 cans of beer are sold each week in a particular community, the MSW, including litter, can be expected to include 100,000 aluminum cans per week. The estimation technique is highly inaccurate except in small and isolated communities.

Secondary data may be used to estimate solid waste production by some empirical relationship. For example, one study (Shell and Shure 1972) concluded that solid waste generation could be predicted as

$$W = 0.01795S - 0.00376F - 0.00322D + 0.0071P - 0.0002I + 44.7, \quad (12.1)$$

where

W = waste generated (tons),
S = number of stops made by the MSW pickup truck,
F = number of families served,
D = number of single family dwellings,
P = population, and
I = adjusted income per dwelling unit (dollars).

Models like this one are inherently inaccurate and may have no general application.

When possible, solid waste generation should be measured by output analysis, that is, by weighing the refuse dumped at the disposal site, either with truck scales or with portable wheeled scales. Refuse must generally be weighed in any case, because fees for use of the dump (called *tipping fees*) depend on weight dumped. Daily weight of refuse varies with the day of the week and the week of the year. Weather conditions also affect refuse weight, since moisture content can vary between 15 and 30%. If every truckload cannot be weighed, statistical methods must be used to estimate the total quantity from sample truckload weights.

Characteristics of Municipal Solid Waste

Refuse management depends on both the characteristics of the site and the characteristics of the MSW itself: gross composition, moisture content, particle size, chemical composition, and density.

Gross composition may be the most important characteristic affecting MSW disposal, or the recovery of materials and energy from refuse. Composition varies from one community to another, as well as with time in any one community. Refuse composition

Table 12-1. Average Annual Composition of MSW in the United States

	As generated		As disposed	
	Millions of tons	%	Millions of tons	%
Paper	37.2	36.7	44.9	41.5
Glass	13.3	13.1	13.5	12.5
Metal				
Ferrous	8.8	8.7	8.8	8.1
Aluminum	0.9	0.9	0.9	0.8
Other nonferrous	0.4	0.4	0.4	0.4
Plastics	6.4	6.3	6.4	5.9
Rubber and leather	2.6	2.6	3.4	3.1
Textiles	2.1	2.1	2.2	2.0
Wood	4.9	4.8	4.9	4.5
Food waste	22.8	22.5	20.0	18.5
Miscellaneous	1.9	1.9	2.8	2.6
Total	101.3		108.2	

is expressed either "as generated" or "as disposed," since moisture transfer takes place during the disposal process and thereby changes the weights of the various fractions of refuse. Table 12-1 shows typical components of average U.S. refuse. The numbers in Table 12-1 are useful only as guidelines; each community has characteristics that influence its solid waste production and composition.

The moisture content of MSW may vary between 15 and 30%, and is usually about 20%. Moisture is measured by drying a sample at 77°C (170°F) for 24 h, weighing, and calculating as

$$M = \frac{w - d}{w} \times 100, \tag{12.2}$$

where

M = moisture content, percent,
w = initial, wet weight of sample, and
d = final, dry weight of sample.

Particle size distribution is particularly important in refuse processing for resource recovery, and is discussed further in Chap. 14.

The chemical composition of typical refuse is shown in Table 12-2. The use of both proximate and ultimate analysis in the combustion of MSW and its various fractions is discussed further in Chaps. 13 and 14. The density of MSW varies depending upon location, season, humidity, and so on. Table 12-3 shows some typical MSW densities.

Table 12-2. Proximate and Ultimate Chemical Analysis of MSW

	Proximate analysis (%)	Ultimate analysis (%)
Moisture	15–35	15–35
Volatile matter	50–60	
Fixed carbon	3–9	
Noncombustibles	15–25	
Higher heat value	3000–6000 Btu/lb	
Carbon		15–30
Hydrogen		2–5
Oxygen		12–24
Nitrogen		0.2–1.0
Sulfur		0.02–0.1

Source. U.S. Department of Health, Education, and Welfare, *Incinerator Guidelines*, 1969.

Table 12-3. Refuse Densities

	kg/m^3	lb/yd^3
Loose refuse	60–120	100–200
Dumped refuse from a collection vehicle	200–240	350–400
Refuse in a collection vehicle	300–400	500–700
Refuse in a landfill	300–540	500–900
Baled refuse	470–700	800–1200

COLLECTION

In the United States, and in most other industrialized countries, solid waste is collected by trucks. These are usually packers, trucks that carry hydraulic rams to compact the refuse to reduce its volume and can thus carry larger loads (Fig. 12-1). Collections are facilitated by the use of containers that are emptied into the truck with a mechanical or hydraulic mechanism. Commercial and industrial containers, "dumpsters," either are emptied into the truck or are carried by truck to the disposal site (Fig. 12-2). Collection is an expensive part of waste management, and many new devices and methods have been proposed in order to cut costs.

Garbage grinders reduce the amount of garbage in refuse. If all homes had garbage grinders, the frequency of collection could be decreased. Garbage grinders are so ubiquitous that in most communities garbage collection is needed only once a week. Garbage grinders put an extra load on the wastewater treatment plant, but sewage is relatively dilute and ground garbage can be accommodated easily both in sewers and in treatment plants.

Pneumatic pipes have been installed in some small communities, mostly in Sweden and Japan. The refuse is ground at the residence and sucked through underground lines. Walt Disney World in Florida also has a pneumatic pipe system in which the collection

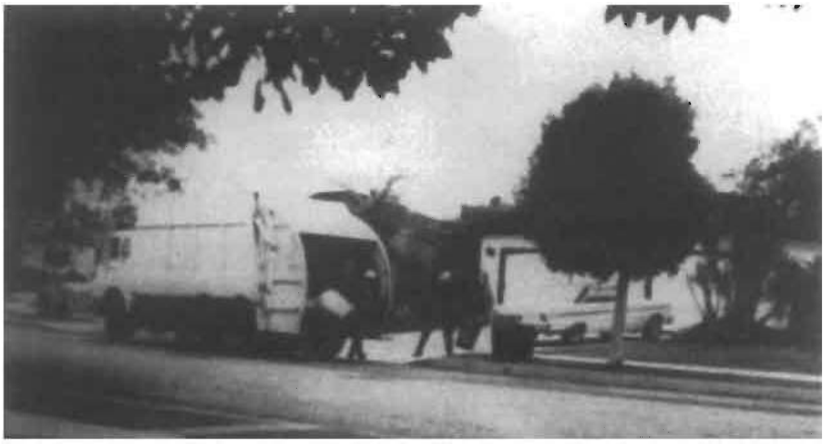

Figure 12-1. Packer truck used for residential refuse collection.

stations scattered throughout the park receive the refuse and pneumatic pipes deliver the waste to a central processing plant (Fig. 12-3). There are no garbage trucks in the Magic Kingdom.

Kitchen garbage compactors can reduce collection and MSW disposal costs and thus reduce local taxes, but only if every household has one. A compactor costs about as much as other large kitchen appliances, but uses special high-strength bags, so that the operating cost is also a consideration. At present they are beyond the means of many households. Stationary compactors for commercial establishments and apartment houses, however, have already had significant influence on collection practices.

Transfer stations are part of many urban refuse collection systems. A typical system, as shown in Fig. 12-4, includes several stations, located at various points in a city, to which collection trucks bring the refuse. The drive to each transfer station is relatively short, so that workers spend more time collecting and less time traveling. At the transfer station, bulldozers pack the refuse into large containers that are trucked to the landfill or other disposal facility. Alternatively, the refuse may also be baled before disposal.

Cans on wheels, often provided by the community, are widely used for transfer of refuse from the household to the collection truck. As shown in Fig. 12-5, the cans are pushed to the curb by the householder and emptied into the truck by a hydraulic lift. This system saves money and has reduced occupational injuries dramatically. Garbage collection workers suffer higher lost-time accident rates than other municipal or industrial workers.

Route optimization may result in significant cost saving as well as increased effectiveness. Software is available for selecting least-cost routes and collection frequencies. Route optimization is not new. It was first addressed by the mathematician Leonard Euler in 1736. He was asked to design a parade route for the city of Königsberg in East Prussia (now Kaliningrad in Russia) in such a way that the parade would not

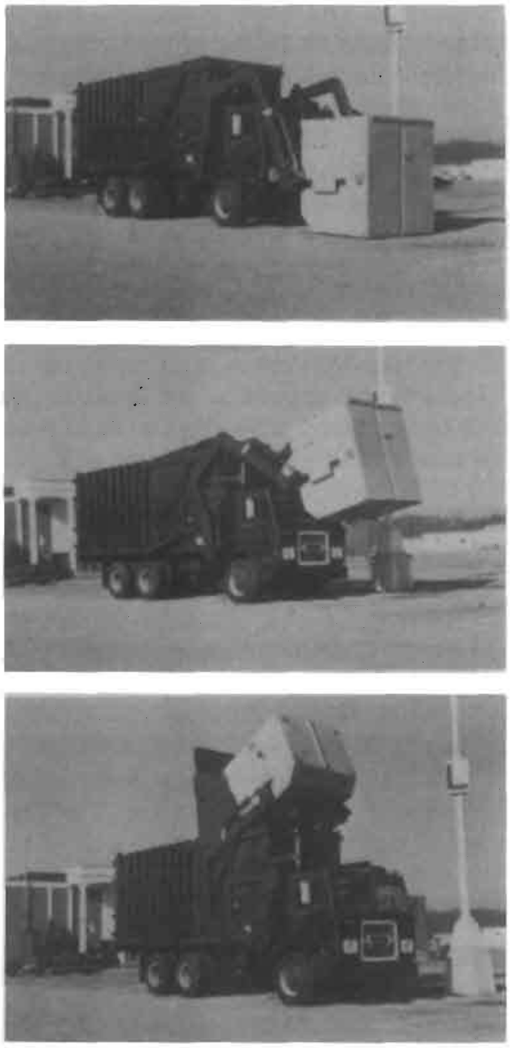

Figure 12-2. Containerized collection system. (Courtesy of Dempster Systems.)

cross any bridge over the River Pregel more than once (Fig. 12-6). Euler showed that such a route was not possible, and, in a further generalization, that in order to arrive back at the starting point by such an *Euler's tour*, an even number of *nodes* had to be connected by an even number of *links*. The objective of garbage collection truck routing is to create a Euler's tour and thereby eliminate *deadheading*, or retracing a link without additional collection.

Although sophisticated routing programs are available, it is often just as easy to develop a route by common sense or *heuristic* means. Some heuristic rules for routing

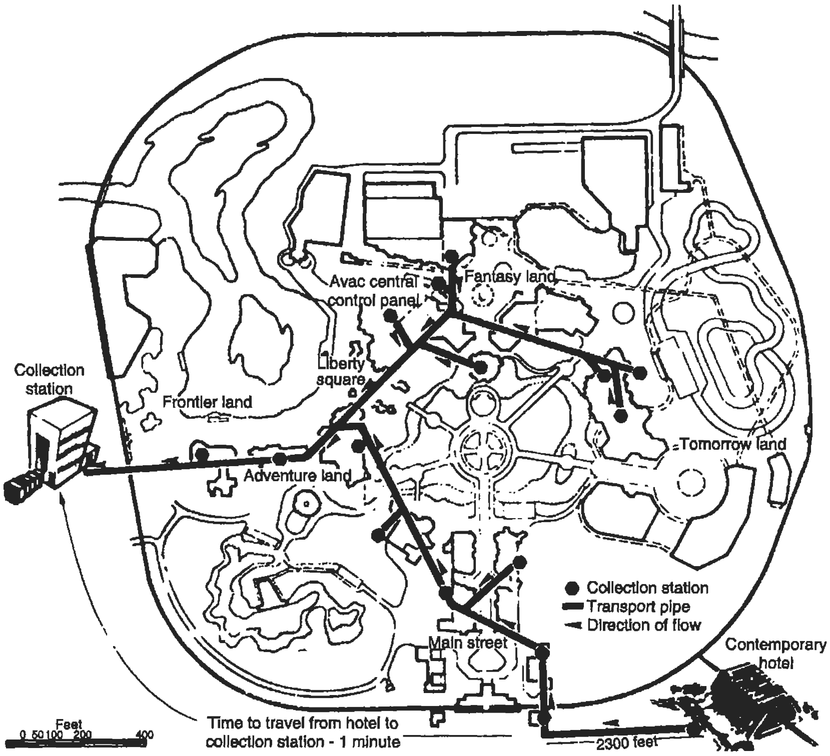

Figure 12-3. Solid waste collection system at Disney World. (Courtesy of AVAC Inc.)

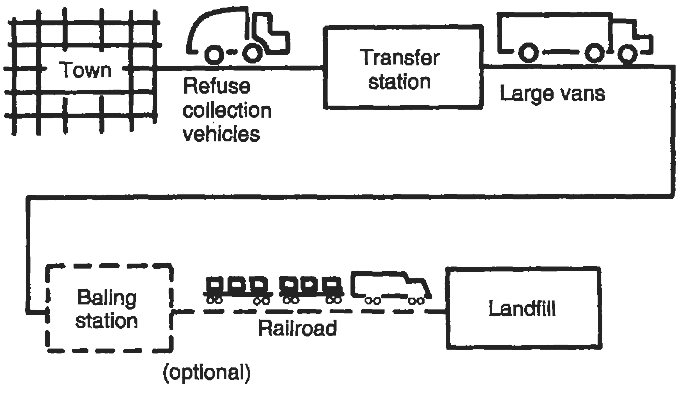

Figure 12-4. Transfer station method of solid waste collection.

Figure 12-5. The "green can" system of solid waste collection.

trucks are (Liebman *et al.* 1975, Shuster and Schur 1974):

- Routes should not overlap.
- Routes should be compact and not fragmented.
- The starting point of the route should be as close to the truck garage as possible.

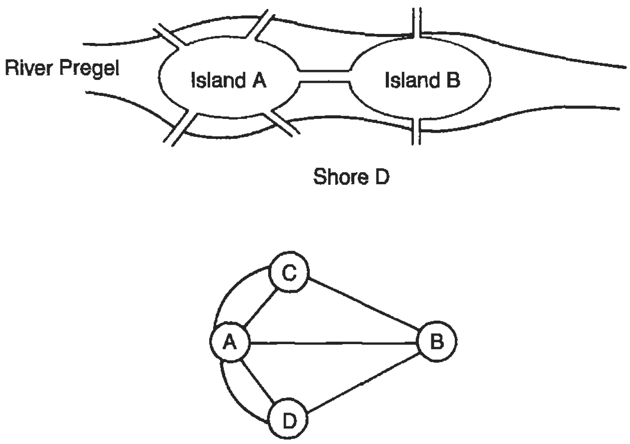

Figure 12-6. The seven bridges of Königsberg; the Euler routing problem.

- Heavily traveled streets should be avoided during rush hours.
- One-way streets that cannot be traversed in one line should be looped from the upper end of the street.
- Dead-end streets should be collected when the truck is on the right side of the street.
- Collection should be downhill on hills, so the truck can coast.
- Long straight paths should be routed before looping clockwise.
- For certain block patterns, standard paths, as shown in Fig. 12-7, should be used.
- U-turns should be avoided.

Figure 12-7 shows three examples of heuristic routing. In the first two, each side of the street is to be collected separately; in the third example, both sides of the street are collected at once.

DISPOSAL OPTIONS

Ever since the Romans invented city dumps, municipal refuse has been disposed of outside the city walls. As cities and suburbs grew, and metropolitan areas grew contiguous, and as the use of "throwaway" packages and containers increased, finding a place for MSW disposal became a critical problem. Many cities in the United States encouraged "backyard burning" of trash, in order to reduce MSW volume and disposal cost. Building codes in many cities mandate the installation of garbage grinders in new homes. Cities like Miami, FL, which has no landfill sites at all, built MSW incinerators.

Increasing urban air pollution has resulted in prohibition of backyard burning, even of leaves and grass clippings, and de-emphasis of municipal incineration. Increased

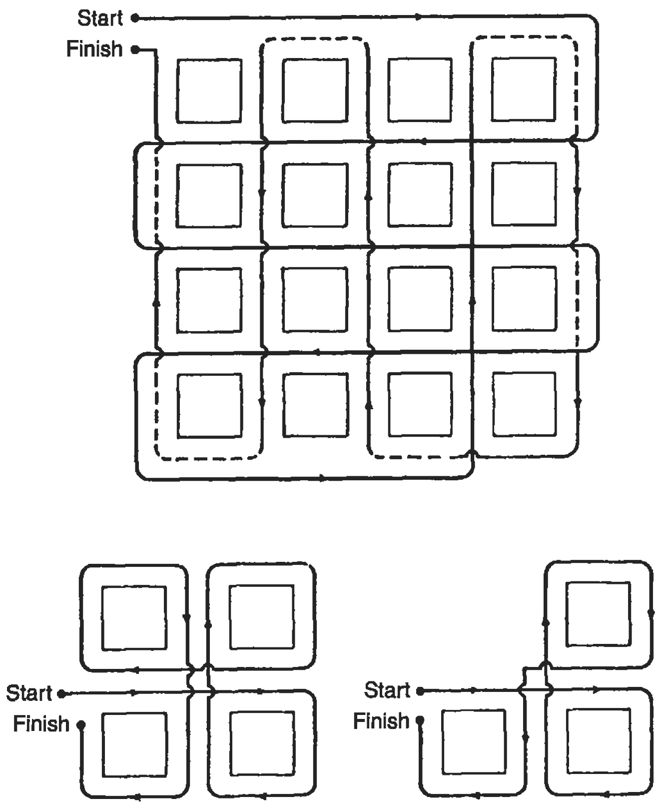

Figure 12-7. Heuristic routing examples.

residential development of land that was once forested or agricultural and changes in forest management practices have resulted in increases in forest and grass fires, and ultimately have led to a complete prohibition of backyard burning in almost all communities. Spontaneous dump fires and the spread of disease from dumps led to the prohibition of open dumps after 1980, in conformance with the Resource Conservation and Recovery Act (RCRA) of 1976. The sanitary landfill has become the most common method of disposal, because it is reasonably inexpensive and is considered relatively environmentally sound.

Unfortunately, landfilling is not the ultimate solution to the solid waste disposal problem. Although modern landfills are constructed so as to minimize adverse effects on the environment, experience has shown that they are not fail-safe. Moreover, the cost of landfilling is increasing rapidly, as land becomes scarce and refuse must be transported further and further from where it is generated. Rising public "environmental consciousness" is making waste processing and reclamation of waste material and energy appear increasingly attractive. Options for resource recovery are discussed further in Chap. 14.

LITTER

Litter is unsightly, a breeding ground for rats and other rodents, and hazardous to wildlife. Deer and fish, attracted to aluminum can pop-tops, ingest them and die in agony. Plastic sandwich bags are mistaken for jellyfish by tortoises, and birds strangle themselves in the plastic rings from six-packs.

Anti-litter campaigns and attempts to increase public awareness have been ongoing for many years. Bottle manufacturers and bottlers encourage voluntary bottle return. The popularity of "Adopt-a-road" programs has also sharply increased littering awareness, and has the potential to reduce roadside litter.

Restrictive beverage container legislation is a more drastic assault on litter. The Oregon "Bottle Law" prohibits pop-top cans and discourages the use of nonreturnable glass beverage bottles. The law operates by placing an artificial deposit value on all carbonated beverage containers so that it is in the user's interest to bring them back to the retailer for a deposit. The retailer in turn must recover the money from the manufacturer and sends all of the bottles back to the bottling company. The bottling company must now either discard these bottles, send them back to the bottle manufacturer, or refill them. In any case, it becomes more efficient for the manufacturer to either refill or recover the bottles rather than to throw them away. The beverage industry is thus forced to rely more heavily on returnable containers, reducing the one-way containers such as steel cans or plastic bottles. Such a process saves money, materials, and energy, and has the added effect of reducing litter.

CONCLUSION

The solid waste problem has three facets: source, collection, and disposal. The first is perhaps the most difficult. A "new economy" of reduced waste, increased longevity instead of planned obsolescence, and thriftier use of natural resources is needed. Collection and disposal of refuse are discussed in the next chapter.

PROBLEMS

12.1 Walk along a stretch of road and collect the litter in two bags, one for beverage containers only and one of everything else. Calculate: (a) the number of items per mile, (b) the number of beverage containers per mile, (c) weight of litter per mile, (d) weight of beverage containers per mile, (e) percent of beverage containers by weight, and (f) percent of beverage containers by count. If you are working for the bottle manufacturers, would you report your data as (e) or (f)? Why?

12.2 How would a tax on natural resource withdrawal affect the economy of solid waste management?

12.3 What effect do the following have on the quantity and composition of MSW: (a) garbage grinders, (b) home compactors, (c) nonreturnable beverage containers, and (d) a newspaper strike? Make quantitative estimates of the effects.