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

$$M = \frac{w - d}{w} \times 100, \qquad (12.2)$$

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

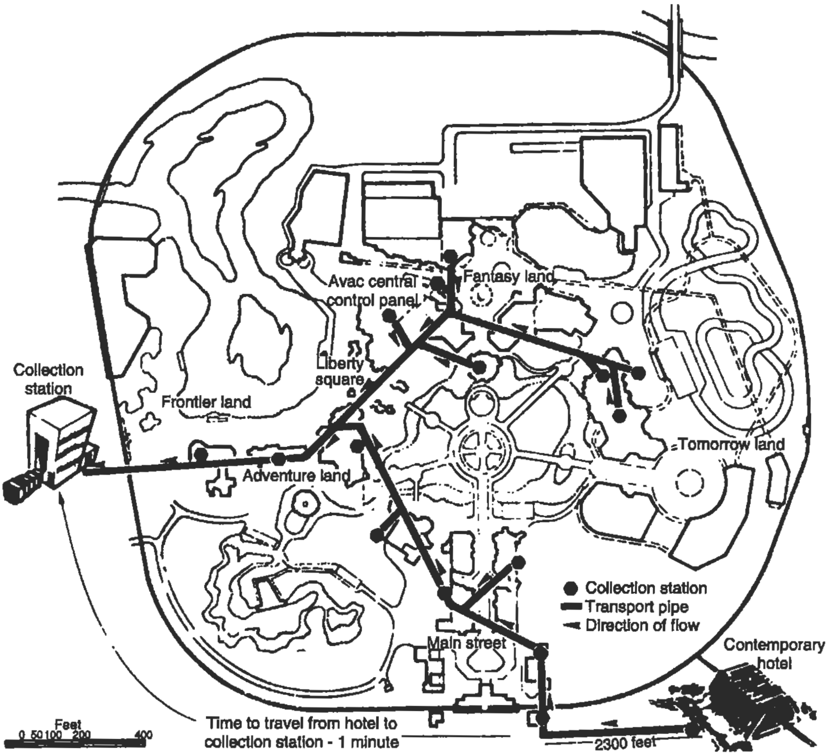

Figure 12-3. Solid waste collection system at Disney World. (Courtesy of AVAC Inc.)

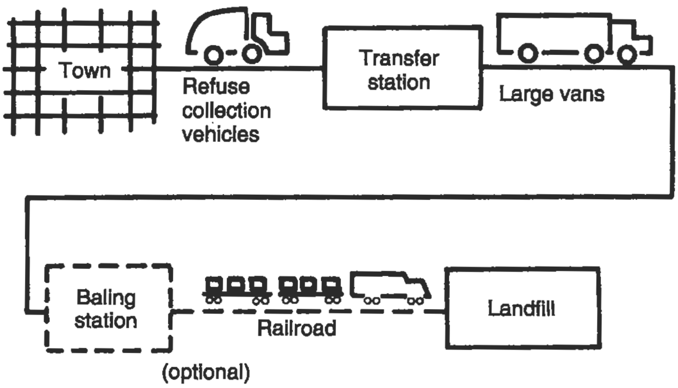

Figure 12-4. Transfer station method of solid waste collection.

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.

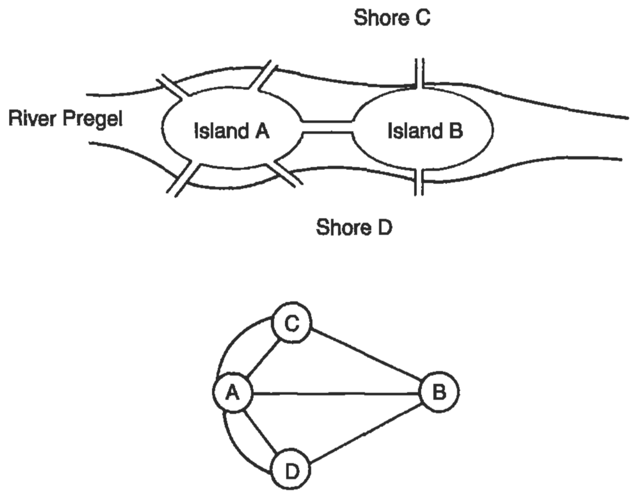

Figure 12-6. The seven bridges of Königsberg; the Euler routing problem.

- 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

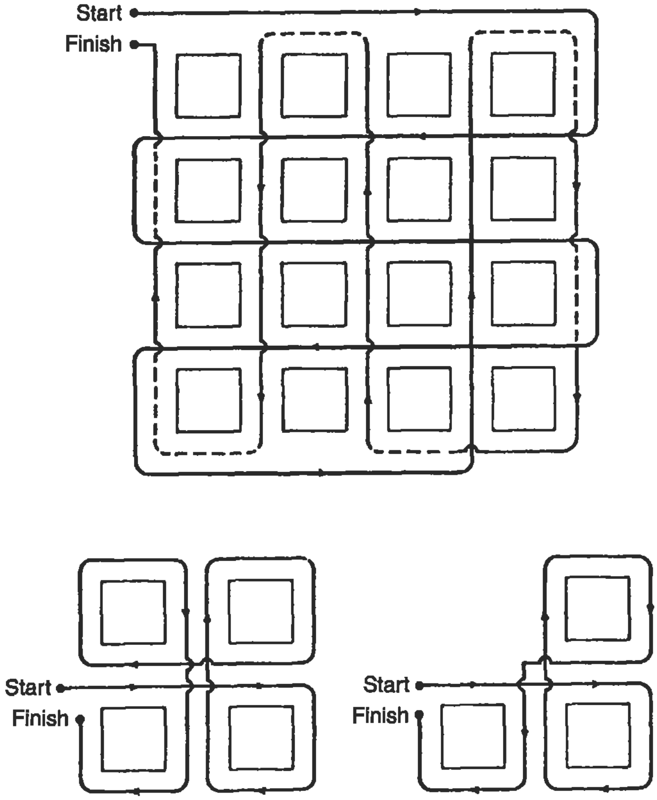

Figure 12-7. Heuristic routing examples.

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.

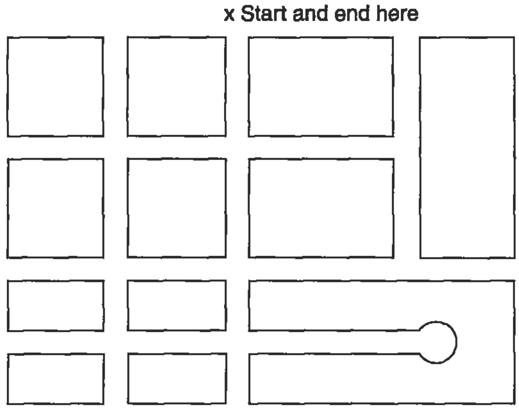

Figure 12-8. Route for Problem 12.7.

12.4 Drive along a measured stretch of road or highway and count the pieces of litter visible from the car. (Do this with one person driving and another counting!) Then walk along the same stretch and pick up the litter, counting the pieces and weighing the full bags. What percent of the litter by piece (and by weight if you have enough information) is visible from the car?

12.5 On a map of your campus or your neighborhood, develop an efficient route for refuse collection, assuming that every blockface must be collected.

12.6 Using a study hall, lecture hall, or student lounge as a laboratory, study the prevalence of litter by counting the items in the waste receptacles vs the items improperly disposed of. Vary the conditions of your laboratory in the following way (you may need cooperation from the maintenance crew):

- Day 1: normal conditions (baseline)
- Day 2: remove all waste receptacles except one
- Day 3: add additional receptacles (more than normal).

If possible, do several experiments with different numbers of receptacles. Plot the percent of material properly disposed of vs the number of receptacles, and discuss the implications.

12.7 Using heuristic routing, develop an efficient route for the map shown in Fig. 12-8 if (a) both sides of the street are to be collected together or (b) one side of the street is collected at a time.

Chapter 13

Solid Waste Disposal

Disposal of solid wastes is defined as placement of the waste so that it no longer impacts society or the environment. The wastes are either assimilated so that they can no longer be identified in the environment, as by incineration to ash, or they are hidden well enough so that they cannot be readily found. Solid waste may also be processed so that some of its components may be recovered, and used again for a beneficial purpose. Collection, disposal, and recovery are all part of the total solid waste management system, and this chapter is devoted to disposal.

DISPOSAL OF UNPROCESSED REFUSE IN SANITARY LANDFILLS

The only two realistic options for disposal are in the oceans and on land. Because the environmental damage done by ocean disposal is now understood, the United States prohibits such disposal by federal law, and many developed nations are following suit. This chapter is therefore devoted to a discussion of land disposal.

Until the mid-1970s, a solid waste disposal facilities was usually a *dump* in the United States and a *tip* (as in "tipping") in Great Britain. The operation of a dump was simple and inexpensive: trucks were simply directed to empty loads at the proper spot on the dump site. The piled-up volume was often reduced by setting the refuse on fire, thereby prolonging the life of the dump. Rodents, odor, insects, air pollution, and the dangers posed by open fires all became recognized as serious public health and aesthetic problems, and an alternative method of refuse disposal was sought. Larger communities frequently selected incineration as the alternative, but smaller towns could not afford the capital investment required and opted for land disposal.

The term *sanitary landfill* was first used for the method of disposal employed in the burial of waste ammunition and other material after World War II, and the concept of burying refuse was used by several Midwestern communities. The sanitary landfill differs markedly from open dumps: open dumps are simply places to deposit wastes, but sanitary landfills are engineered operations, designed and operated according to acceptable standards (Fig. 13-1).

Sanitary landfilling is the compaction of refuse in a lined pit and covering of the compacted refuse with an earthen cover. Typically, refuse is unloaded, compacted with bulldozers, and covered with compacted soil. The landfill is built up in units called *cells* (Fig. 13-2). The daily cover is between 6 and 12 in. thick depending on

Figure 13-1. The sanitary landfill.

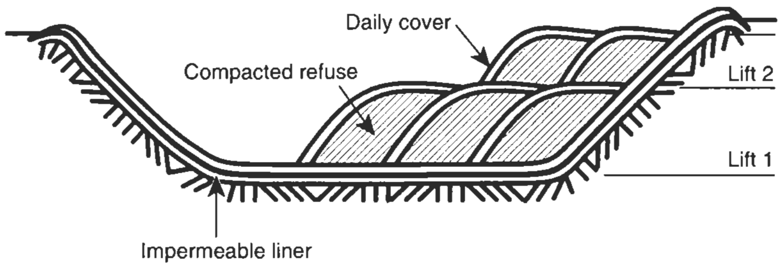

Figure 13-2. Arrangement of cells in an area-method landfill.

soil composition (Fig. 13-3), and a final cover at least 2 ft thick is used to close the landfill. A landfill continues to subside after closure, so that permanent structures cannot be built on-site without special foundations. Closed landfills have potential uses as golf courses, playgrounds, tennis courts, winter recreation, or parks and greenbelts. The sanitary landfilling operation involves numerous stages, including siting, design, operation, and closing.

Siting Landfills

Siting of landfills is rapidly becoming the most difficult stage of the process since few people wish to have landfills in their neighborhoods. In addition to public acceptability, considerations include:

- *Drainage*: Rapid runoff will lessen mosquito problems, but proximity to streams or well supplies may result in water pollution.

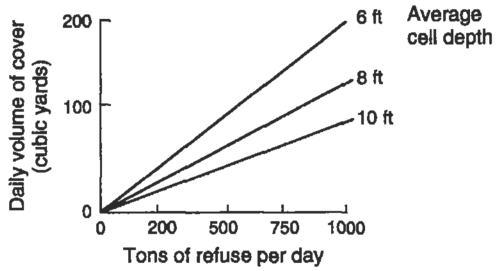

Figure 13-3. Daily volume of cover versus refuse disposal rate.

- *Wind*: It is preferable that the landfill be downwind from any nearby community.
- *Distance from collection.*
- *Size*: A small site with limited capacity is generally not acceptable since finding a new site entails considerable difficulty.
- *Rainfall patterns*: The production of leachate from the landfill is influenced by the weather.
- *Soil type*: Can the soil be excavated and used as cover?
- *Depth of the water table*: The bottom of the landfill must be substantially above the highest expected groundwater elevation.
- *Treatment of leachate*: The landfill must be proximate to wastewater treatment facilities.
- *Proximity to airports*: All landfills attract birds to some extent, and are therefore not compatible with airport siting.
- *Ultimate use*: Can the area be used for private or public use after the landfilling operation is complete?

Although daily cover helps to limit disease vectors, a working landfill still has a marked and widespread odor during the working day. The working face of the landfill must remain uncovered while refuse is added and compacted. Wind can pick material up from the working face, and the open refuse attracts feeding flocks of birds. These birds are both a nuisance and a hazard to low-flying aircraft using nearby airports. Odor from the working face and the truck traffic to and from the landfill make a sanitary landfill an undesirable neighbor to nearby communities.

Early sanitary landfills were often indistinguishable from dumps, thereby enhancing the "bad neighbor" image. In recent years, as more landfills have been operated properly, it has even been possible to enhance property values with a closed landfill site, since such a site must remain open space. Acceptable operation and eventual enhancement of the property are understandably difficult to explain to a community.

Design of Landfills

Modern landfills are designed facilities, much like water or wastewater treatment plants. The landfill design must include methods for the recovery and treatment of the leachate produced by the decomposing refuse, and the venting or use of the landfill gas. Full plans for landfill operation must be approved by the appropriate state governmental agencies before construction can begin.

Since landfills are generally in pits, the soil characteristics are of importance. Areas with high groundwater would not be acceptable, as would high bedrock formations. The management of rainwater during landfilling operations as well as when the landfill is closed must be part of the design.

Operation of Landfills

The landfill operation is actually a biological method of waste treatment. Municipal refuse deposited as a fill is anything but inert. In the absence of oxygen, anaerobic decomposition steadily degrades the organic material to more stable forms. This process is very slow and may still be going on as long as 25 years after the landfill closes.

The liquid produced during decomposition, as well as water that seeps through the groundcover and works its way out of the refuse, is known as *leachate*. This liquid, though relatively small in volume, contains pollutants in high concentration. Table 13-1 shows typical leachate composition. Should leachate escape the landfill, its effects on the environment may be severe. In a number of instances, leachate has polluted nearby wells to a degree that they ceased to be sources of potable water.

The amount of leachate produced by a landfill is difficult to predict. The only available method is water balance: the water entering a landfill must equal the water flowing out of the landfill, or leachate. The total water entering the top soil layer is

$$C = P(1 - R) - S - E, \tag{13.1}$$

where

C = total percolation into the top soil layer (mm),
P = precipitation (mm),

Table 13-1. Typical Sanitary Landfill Leachate Composition

Component	Typical value
BOD_5	20,000 mg/L
COD	30,000 mg/L
Ammonia nitrogen	500 mg/L
Chloride	2,000 mg/L
Total iron	500 mg/L
Zinc	50 mg/L
Lead	2 mg/L
Total polychlorinated biphenyl (PCB) residue	1.5 μg/L
pH	6.0

Table 13-2. Percolation in Three Landfills[a]

Location	Precipitation, P (mm)	Runoff coefficient, R	Evapotranspiration, E (mm)	Percolation, C (mm)
Cincinnati	1025	0.15	568	213
Orlando	1342	0.07	1172	70
Los Angeles	378	0.12	334	0

[a] D. G. Tenn, K. J. Haney, and T. V. Degeare, *Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites* (U.S. Environmental Protection Agency, OSWMP, SW-168, Washington, DC 1975).

R = runoff coefficient,
S = storage (mm), and
E = evapotranspiration (mm).

The percolation for three typical landfills is shown in Table 13–2.

Using these figures it is possible to predict when landfills produce leachate. Clearly, Los Angeles landfills may virtually never produce leachate. Leaching through a 7.5-m (25-ft) deep landfill in Orlando, FL, might take 15 years, while a 20-m (65-ft) deep landfill in Cincinnati can produce leachate after only 11 years. Leachate production depends on rainfall patterns as well as on total amount of precipitation. The figures given for Cincinnati and Orlando are typical of the "summer thunderstorm" climate that exists in most of the United States. The Pacific Northwest (west of the Pacific Coast Range) has a maritime climate, in which rainfall is spread more evenly through the year. Seattle landfills produce leachate at approximately twice the rate of Cincinnati landfills, although the annual rainfall amount is approximately the same.

Gas is a second by-product of a landfill. Since landfills are anaerobic biological reactors, they produce CH_4 and CO_2. Gas production occurs in four distinct stages, as illustrated in Fig. 13-4. The first stage is aerobic and may last from a few days to several months, during which time aerobic organisms are active and affect the decomposition. As the organisms use up the available oxygen, the landfill enters the second stage, at which anaerobic decomposition begins, but at which methane-forming organisms have not yet become productive. During the second stage, the acid formers cause a buildup of CO_2. The length of this stage varies with environmental conditions. The third stage is the anaerobic methane production stage, during which the percentage of CH_4 progressively increases, as does the landfill interior temperature to about 55°C (130°F). The final, steady-state condition occurs when the fractions of CO_2 and CH_4 are about equal, and microbial activity has stabilized. The amount of methane produced from a landfill may be estimated using the semi-empirical relationship (Chian 1977)

$$\begin{aligned} &CH_aO_bN_c + \left(\tfrac{1}{4}\right)(4 - a - 2b + 3c)H_2O \\ &\quad \rightarrow \tfrac{1}{8}[4 - a + 2b + 3c]CO_2 + (4 + a - 2b - 3c)CH_4. \end{aligned} \tag{13.2}$$

Equation (13.2) is useful only if the chemical composition of the waste is known.

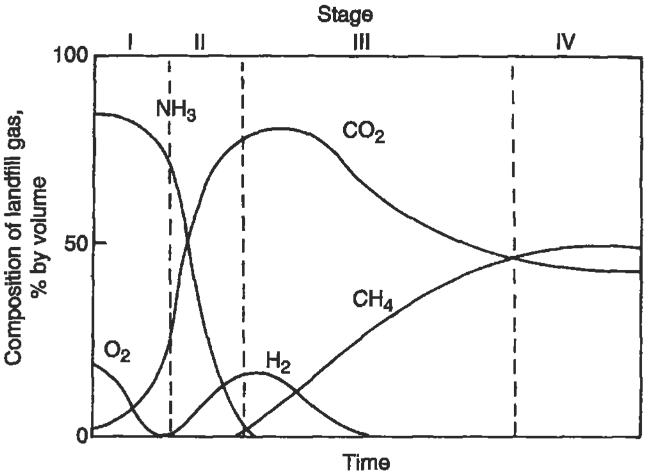

Figure 13-4. States in the decomposition of organic matter in landfills.

The rate of gas production from sanitary landfills may be controlled by varying the particle size of the refuse by shredding before placing the refuse in the landfill, and by changing the moisture content. Gas production may be minimized with the combination of low moisture, large particle size, and high density. Unwanted gas migration may be prevented by installing escape vents in the landfill. These vents, called "tiki torches," are kept lit and the gas is burned off as it is formed. Improper venting may lead to dangerous accumulation of methane. In 1986, a dozen homes near the Midway Landfill in Seattle were evacuated because potentially explosive quantities of methane had leaked through underground fissures into the basements. Venting of the accumulated gas, so that the occupants could return to their homes, took three weeks.

Since landfills produce considerable quantities of methane, landfill gas can be burned to produce electric power. Alternatively, the gas can be cleaned of CO_2 and other contaminants and used as pipeline gas. Such cleaning is both expensive and troublesome. The most reasonable use of landfill gas is to burn it as is in some industrial application like brickmaking.

Closure and Ultimate Use of Landfills

Municipal landfills must be closed according to state and federal regulations. Such closure includes the permanent control of leachate as well as gas, and the placement of an impermeable cap. The cost of closure is very high and must be incorporated in the tipping fee during the life of the landfill. This is one of the primary factors responsible for the dramatic increase in landfill tipping fees.

Figure 13-5. A motel built on a landfill that experienced differential settling.

Biological aspects of landfills as well as the structural properties of compacted refuse limit the ultimate uses of landfills. Landfills settle unevenly, and it is generally suggested that nothing at all be constructed on a landfill for at least two years after closure, and that no large permanent structures ever be built. With poor initial compaction, about 50% settling can be expected in the first five years. The owners of the motel shown in Fig. 13-5 learned this the hard way.

Landfills should never be disturbed. Disturbance may cause structural problems, and trapped gases can present a hazard. Buildings constructed on landfills should have spread footings (large concrete slabs) as foundations, although some have been constructed on pilings that extend through the fill onto rock or some other strong material.

VOLUME REDUCTION BEFORE DISPOSAL

Refuse is bulky and does not compact easily, so that volume requirements of landfills are significant. Where land is expensive, the costs of landfilling may be high. Accordingly, various ways to reduce refuse volume have been found effective.

In the right circumstances, burning of refuse in waste-to-energy facilties (discussed in the next chapter) is an effective treatment of municipal solid waste. Burning reduces the volume of waste by a factor of 10 to 20, and the ash is both more stable and more compactable than the refuse itself.

Pyrolysis is combustion in the absence of oxygen. The residues of pyrolysis, combustible gas, tar, and charcoal, have economic value but have not yet found acceptance as a raw material. The tar contains water that must be removed; the charcoal is full of glass and metal that must be separated. These separations render the by-products too expensive to be competitive. Pyrolysis reduces the volume considerably, produces a stable end product, and has few air pollution problems. On a large scale, such as for some of our larger cities, pyrolysis as a method of volume reduction has significant advantages over incineration. Pyrolysis may also be used for sludge disposal, thus solving two major solid waste problems for a community. Such systems, however, remain to be proven in full-scale operation.

Another method of volume reduction is baling. Solid waste is compressed into desk-sized blocks that can then be handled with fork lifts and stacked in the landfill depression. Because of the high density of the refuse (on the order of 2000 lb/yd^3), the rate of decomposition is slow and odor is reduced. Baled refuse does not therefore require daily cover, further saving landfill space. Local and state regulations may, however, require baled refuse landfills to provide daily cover, which substantially reduces the cost advantages of baling.

CONCLUSION

This chapter begins by defining the objective of solid waste disposal as the placement of solid waste so that it no longer impacts society or the environment. At one time, this was fairly easy to achieve: dumping solid waste over city walls was quite adequate. In modern civilization, however, this is no longer possible, and adequate disposal is becoming increasingly difficult.

The disposal methods discussed in this chapter are only partial solutions to the solid waste problem. Another solution would be to redefine solid waste as a resource and use it to produce usable goods. This idea is explored in the next chapter.

PROBLEMS

13.1 Suppose that the municipal garbage collectors in a town of 10,000 go on strike, and as a gesture to the community, your college or university decides to accept all city refuse temporarily and pile it on the football field. If all the people dumped refuse into the stadium, how many days must the strike continue before the stadium is filled to 1 yard deep? Assume the density of the refuse as 300 lb/yd^3, and assume the dimensions of the stadium as 120 yards long and 100 yards wide.

13.2 If a town has a population of 100,000, what is the daily production of wastepaper?

13.3 What would be some environmental impacts and effects of depositing dewatered (but sloppy wet) sludge from a wastewater treatment plant into a sanitary landfill?