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8.3 IMPLICATIONS FOR SOLID WASTE MANAGEMENT

This section addresses several aspects of the relationship between the characteristics of solid waste and the methods used to manage it. Implications for waste reduction, recycling, composting, incineration, and landfilling are included, as well as general implications for solid waste management as a whole.

MSW is abundant, unsightly, and potentially odorous; contains numerous potential pollutants; and supports both disease-causing organisms and disease-carrying organisms. Like MSW, bulky solid waste is abundant, unsightly and potentially polluting. In addition, the dry, combustible nature of some bulky waste components can pose a fire hazard. Because of these characteristics of MSW and bulky waste, a prompt, effective, and reliable system is required to isolate solid waste from people and the environment.

A beneficial use of solid waste is relatively difficult because it contains many different types of materials in a range of sizes. The only established use for unprocessed MSW is as fuel in mass-burn incinerators (see Section 10.1). Even mass-burn incinerators cannot handle unprocessed bulky waste. In the past, unprocessed bulky waste was used as fill material, but this practice is restricted today. In general, processing is required to recover useful materials from both MSW and bulky waste.

Implications for Waste Reduction

Waste reduction refers to reducing the quantity of material entering the solid waste management system. Waste reduction is distinguished from recycling, which reduces the quantity of waste requiring disposal but does not reduce the quantity of material to be managed.

Based on the composition of MSW (see Section 8.1), each of the following measures would have a significant impact on the quantity of MSW entering the solid waste management system:

- Leaving grass clippings on the lawn
- Increasing backyard composting and mulching of leaves and other yard wastes
- Selling products in bulk rather than in packages, with the consumer providing the containers
- Buying no more food than is eaten
- Substituting reusable glass containers for paper, plastic, and single-use glass containers
- Reusing shopping bags
- Placing refuse directly in refuse containers instead of using trash bags
- Using sponges and cloth hand towels in place of paper towels
- Continuing to use clothing and other products until they are worn out, rather than discarding them when they no longer look new
- Prohibiting distribution of unsolicited printed advertising

Leaving grass clippings on the lawn is becoming increasingly common because of disposal bans in some states and the development of mulching lawn mowers that cut the clippings into smaller pieces. Implementation of the other waste reduction measures on the list is unlikely in the United States because they do not conform to the prevailing standards of convenience, comfort, appearance, sanitation, and free enterprise.

Implications for Waste Processing

Fluctuations in waste generation must be considered when waste processing facilities are planned. If a facility must process the entire waste stream throughout the year, it must be sized to handle the peak generation rate. Storage of MSW for later processing is limited by concerns about odor and sanitation. Limitations on the storage of bulky waste are generally less severe, but long-term storage of combustible materials is usually restricted.

Processing systems for mixed solid waste must be capable of handling a variety of materials in a range of sizes.

Because solid waste does not flow, it must be hauled or moved by conveyor. Because objects in MSW do not readily stratify by size, screening of MSW generally requires a mixing action such as that produced by trommel screens. Abrasive materials in solid waste cause abrasive wear to handling and processing equipment. Heavy, resistant items can damage size reduction equipment. Size reduction is often required, however, because bulky items in solid waste tend to jam conveyors and other waste handling equipment.

Implications for Recovery of Useful Materials

Almost all solid waste materials can be recycled in some way if people are willing to devote enough time and money to the recycling effort. Because time and money are always limited, distinctions must be drawn between materials that are more and less difficult to recycle. Table 8.3.1 shows the compostable, combustible, and recyclable fractions of MSW. The materials listed as recyclable are those for which large-scale markets exist if the local recycling industry is well developed. The list of recyclable materials is different in different areas.

Approximately 75% of the MSW discarded in the United States is compostable or recyclable. No solid waste district of substantial size in the United States has documented a 75% rate of MSW recovery and reuse, however. Reasons for this include the following:

Some recyclable material becomes unmarketable through contamination during use.

A significant fraction of recyclable material cannot be recovered from the consumer.

A portion of both recyclable and compostable material is lost during processing (sorting recyclable materials or removing nonrecyclable and noncompostable materials from the waste stream).

Some compostable material does not decompose enough to be included in the finished compost product and is discarded with the process residue.

TABLE 8.3.1 COMBUSTIBLE, COMPOSTABLE, AND RECYCLABLE COMPONENTS OF MSW[a]

Waste Category	*Percentage of Total*[b]
Combustible, compostable, and recyclable	22.6
Newspaper	6.8
Corrugated cardboard	8.6
Kraft paper	1.5
High-grade paper	1.7
Magazines & mail	4.0
Recyclable and combustible but not compostable	2.1
PET bottles	0.4
HDPE bottles	0.7
Polyethylene film other than trash bags	1.0
Recyclable but not compostable or combustible	7.9
Aluminum cans	0.6
Tin & bimetal food & beverage cans	1.5
Other metal[c]	1.5
Glass food and beverage containers	4.3
Compostable and combustible but not recyclable	44.7
Other paper	17.2
Yard waste	9.7
Food waste	12.0
Disposable diapers	2.5
Fines	3.3
Combustible but not compostable or recyclable	17.2
Other plastic	7.3
Wood	4.0
Textiles/rubber/leather	4.5
Other organics	1.4
Not combustible or compostable or recyclable	5.5
Other aluminum	0.4
Other metal[c]	1.8
Batteries	0.1
Other inorganics	3.2
Total recyclable[a]	32.6
Total compostable	67.3
Total combustible	86.6

[a]Materials listed as recyclable are those for which large-scale markets exist in areas where the recycling industry is well developed.

[b]Derived from Table 8.1.1. Currently recycled materials are not included.

[c]A substantial portion of this category is readily recyclable, and a substantial portion is not. Some of the material listed here as nonrecyclable can be recovered in recyclable condition by an efficient ferrous recovery system at a combustion facility.

A portion of finished MSW compost cannot be marketed and must be landfilled.

In MSW discharged from compactor trucks, most glass containers are still in one piece, and most metal cans are uncrushed. Most glass and aluminum beverage containers are in recyclable condition. Many glass food containers and steel cans are heavily contaminated with food waste, however. Some of the recyclable paper in MSW received at disposal facilities is contaminated with other materials, but 50% or more is typically in recyclable condition.

The ratio of carbon to nitrogen (C/N ratio) is an indicator of the compostability of materials. To maximize the composting rate while minimizing odor generation, a C/N ratio of 25/1 to 30/1 is considered optimum. Higher ratios reduce the composting rate, while lower ratios invite odor problems.

Table 8.3.2 shows representative C/N ratios of compostable components of MSW. Controlled composting of food waste, with a C/N ratio of 14/1, is difficult unless large quantities of another material such as yard waste (other than grass clippings) are mixed in to raise the ratio. The C/N ratio moves above the optimum level as quantities of paper are added to the mixture, however.

Paper, leaves, and woody yard waste serve as effective *bulking agents* in composting MSW, so the addition of a bulking agent such as wood chips is generally unnecessary.

The metals content of MSW is a major concern in composting because repeated application of compost to land can raise the metals concentrations in the soil to harmful levels. Compost regulations usually set maximum metals concentrations for MSW compost applied to land. Most regulations do not distinguish between different forms of a metal. For example, the lead in printing ink on a plastic bag is treated the same as the lead in glass crystal even though the lead in printing ink is more likely to be released into the environment. Similarly, the hexavalent form of chromium found in lead chromate is treated the same as the elemental chromium used to plate steel even though the hexavalent form is more toxic than the elemental form.

TABLE 8.3.2 REPRESENTATIVE C/N RATIOS OF COMPOSTABLE COMPONENTS OF MSW

Waste Category	*C/N Ratio*
Yard waste	29/1
Grass clippings	17/1
Leaves	61/1
Other yard waste	31/1
Food waste	14/1
Paper	119/1
Newspaper	149/1
Corrugated & kraft	165/1
High-grade paper	248/1
Magazines & mail	131/1
Other paper	85/1
Disposable diapers	95/1
Fines	23/1

Note: Derived from Table 8.1.4.

Two extensive, recent studies of metals in individual components of MSW yielded contradictory results. A study in Cape May County, New Jersey found toxic metals concentrated in the noncompostable components of MSW (Camp Dresser & McKee Inc. 1991; Rugg and Hanna 1992). A study in Burnaby, British Columbia, however, found higher metals concentrations in the compostable components of MSW than were found in Cape May (see Table 8.1.6) (Rigo, Chandler, and Sawell 1993).

Disposable diapers are listed as compostable in Table 8.3.1 despite their plastic covers. The majority of the weight of disposable diapers is from the urine, feces, and treated cellulose inside the cover, all of which is compostable. Note, however, that most people wrap used diapers into a ball with the plastic cover on the outside, using the waist tapes to keep the ball from unraveling. Vigorous size reduction is required to prepare these diaper balls for composting.

Wood is biodegradable but does not degrade rapidly enough to be considered compostable. The same is true of cotton and wool fabrics, included in the textiles/rubber/leather category in Table 8.3.1.

Implications for Incineration and Energy Recovery

The heat value of MSW (4800–5400 Btu/lb) is lower than that of traditional fuels such as wood (5400–7200 Btu/lb), coal (7000–15,000 Btu/lb), and liquid or gaseous petroleum products (18,000–24,000 Btu/lb) (Camp Dresser & McKee 1991, 1992a,b; Niessen 1995). The heat value of MSW is sufficient, however, to sustain combustion without the use of supplementary fuel.

Heat value is an important parameter in the design or procurement of solid waste combustion facilities because each facility has the capacity to process heat at a certain rate. The greater the heat value of a unit mass of waste, the smaller the total mass of waste the facility can process.

The ash and moisture content of MSW is high compared to that of other fuels. Most of the ash is contained in relatively large objects that do not become suspended in the flue gas (Niessen 1995). Ash handling is a major consideration at MSW combustion facilities.

Because of its high ash and moisture content and low density, MSW has low *energy density* (heat content per unit volume) (Niessen 1995). Therefore, MSW combustion facilities must be designed to process large volumes of material.

The effect of recycling programs on the heat value of MSW is not well documented. Numerous attempts have been made to project the impact of recycling based on the measured heat values of individual MSW components (for example, see Camp Dresser & McKee [1992a]). Little reliable data exist, however, that document the effect of known levels of recycling on the waste received at operating combustion facilities.

A reasonable assumption is that recycling materials with below-average heat values raises the heat value of the remaining waste, while recycling materials with above-average heat values reduces the heat value of the remaining waste. The removal of recyclable metal and glass containers increases heat value (and reduces ash content), while the recovery of plastics for recycling reduces heat value. The removal of paper for recycling also reduces heat value. Because recycled paper has a low moisture content, its heat value is 30% to 40% higher than that of MSW as a whole.

The increase in heat value caused by recycling glass and metal is probably greater than the reduction caused by recycling paper. Because plastics are generally recycled in small quantities, the reduction in heat value caused by their removal is relatively small. The most likely overall effect of recycling is a small increase in heat value and a decrease in ash content.

Sulfur in MSW is significant because sulfur oxides (SO_x) have negative effects and corrode natural and manmade materials. SO_x combines with oxygen and water to form sulfuric acid. A solid waste combustion facility must maintain stack temperatures above the dew point of sulfuric acid to prevent corrosion of the stack. Niessen (1995) provides additional information.

Like sulfur, chlorine has both health effects and corrosive effects. Combustion converts organic (insoluble) chlorine to hydrochloric acid (HCl). Because HCl is highly soluble in water, it contributes to corrosion of metal surfaces both inside and outside the facility (Niessen 1995).

Chlorine is a component of additional regulated compounds including dioxins and furans. Trace concentrations of dioxins and furans can be present in the waste or can be formed during combustion. Niessen (1995) provides additional discussion.

Oxides of nitrogen (NO_x) form during the combustion of solid waste, both from nitrogen in the waste and in the air. NO_x reacts with other substances in the atmosphere to form ozone and other compounds that reduce visibility and irritate the eyes (Niessen 1995).

Emissions of SO_x, NO_x, chlorine compounds, and hydrocarbons are regulated and must be controlled (see Section 10.1 and Niessen [1995]). Emissions of hydrocarbons and chlorine compounds other than HCl can generally be controlled by optimization of the combustion process. Maintaining complete control of the combustion of material as varied as MSW is difficult, however, so small quantities of hydrocarbons and complex chlorine compounds are emitted from time to time.

Combustion cannot destroy metals. Assuming that a combustion facility is designed with no discharge of the water used to quench the combustion ash, the toxic metals in the waste end up in the ash or are emitted into the air. Regulations limit the emission of toxic metals.

The tendency of a metal to be emitted from a combustion facility is a function of many factors such as:

- The volatility of the metal
- The chemical form of the metal
- The degree to which the metal is bound in other materials, especially noncombustible materials
- The degree to which the metal is captured by the air pollution control system

Emissions of a metal from a solid waste combustion facility cannot be predicted based on the abundance of the metal in the waste.

Mercury is the most volatile of the metals of concern, and a substantial portion of the mercury in MSW escapes capture by the air pollution control systems at MSW combustion facilities. The quantity of mercury in MSW has declined rapidly in recent years because battery manufacturers have eliminated most of the mercury in alkaline and carbon–zinc batteries. One cannot assume that a reduction in the quantity of mercury in batteries proportionately reduces the quantity emitted from MSW combustion facilities, however.

All but a small fraction of each metal other than mercury becomes part of the ash residue either because it never enters the facility stack or because it is captured by the air pollution control system. The environmental significance of a metal in combustion ash residue depends primarily on its leachability and the toxicity of its leachable forms. A portion of the ash residue from some MSW combustion facilities is regulated as hazardous waste because of the tendency of a toxic metal (usually lead or cadmium) to leach from the ash under the test conditions specified by the U.S. EPA.

Niessen (1995) and Chandler & Associates, Ltd. et al. (1993) provide additional information on the implications of solid waste characteristics with combustion as a disposal method. Niessen provides a comprehensive treatise on waste combustion from the perspective of an environmental engineer. The final report of Chandler & Associates, Ltd. et al. provides a detailed study of the relationships among metals concentrations in individual components of MSW, metals concentrations in stack emissions, and metals concentrations in various components of ash residue at a single MSW combustion facility.

Implications for Landfilling

The greater the density of the waste in a landfill, the more tons of waste can be disposed in the landfill. The density of waste in a landfill can be increased in a variety of ways, including the following:

- Using compacting equipment specifically designed for the purpose (Surprenant and Lemke 1994)

- Spreading the incoming waste in thinner layers prior to compaction (Surprenant and Lemke 1994)
- Shredding bulky, irregular materials such as lumber prior to landfilling

Because solid waste contains toxic materials (see Section 8.1), landfills must have impermeable liners and systems to collect water that has been in contact with the waste (leachate). The liner must be resistant to damage from any substance in the waste, including solvents. The first lift (layer) of waste placed on the liner must be free of large, sharp objects that could puncture the liner. For this reason, bulky waste is typically excluded from the first lift.

To some extent, the moisture content of waste placed in a landfill influences the quantity of the leachate generated. In most cases, however, a more important factor is the quantity of the precipitation that falls on the waste before an impermeable cap is placed over it.

For additional information, see Section 10.5.

—F. Mack Rugg

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