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# 1

# SOLID WASTE CHARACTERISTICS, PRODUCTION, AND POTENTIAL FOR RESOURCE RECOVERY

## *HISTORICAL BACKGROUND*

The emergence of the industrial age fostered the science of economics, and prompted many leading thinkers to attempt to bring rational order to the seemingly chaotic world around them. The rationalism that resulted led to the common belief that trends could be understood—and decisions made—best on the basis of numbers. This substitution of the quantitative for the qualitative still pervades modern society and influences our entire set of attitudes toward resources and how they should be distributed. Adam Smith, through his concept of "the invisible hand," introduced an element of positive faith and optimism. However, his efforts were overshadowed by a number of pessimists—analysts who predicted continuing misery, poverty, exploitation, and class discrimination. Ricardo, with his "iron law of wages," held that wages for the working people would always remain at the poverty level, since any increase in wages would result in a commensurate increase in population, and this would once again drive wages down.

Equally pessimistic was the view held by Thomas Malthus, who in 1798 reasoned that since population growth is geometric and the increased production of food is arithmetic, a famine must result. This "law of population" was part of the "laissez-faire" school of economic liberalism, and was in great part responsible for the earned reputation of economics as a "dismal science." Malthus held that overpopulation can be prevented only by two types of checks: positive and preventive. Numbered among the former are wars, plagues, and similar disasters. Preventative checks include abstention from marriage, limitations on the number of children, and the like. Although the latter is clearly preferable, Malthus had little hope for the world, and insisted that the poor were "authors of their own poverty," simply because they failed to use the preventive checks on population growth.

This thesis was widely believed for many years and held as basic economic dogma. But as populations grew, widespread famine and deprivation was avoided, and Malthus's writings fell from favor Economists began to think of Malthus as an economic anachronism—to be studied, but only in the historical context. Technology, the new God, was able to preserve order, avert disaster, and lead us into the promised land.

This optimism was widely shared during the nineteenth and well into the twentieth century, with only a few disquieting voices. Thoreau's distrust of things technical was tolerated with bemusement as the ramblings of an ungrateful crackpot.

In the later 1950s and 1960s, a few more voices in the wilderness became audible. Paul Erlich, with his grand overstatements and predictions of doomsday, seemed strangely reminiscent of Malthus. Barry Commoner became the first *public* ecologist, and helped promote the feeling of disquiet. Slowly, through the 1960s, the public became convinced that there may indeed be something to this "doomsday" talk.

The most respected and well-publicized voice of pessimism became an interdisciplinary group of scientists at MIT. Funded by the Club of Rome, a group of concerned industrialists, this group of talented scientists and engineers developed a computer model of the world, based on projections of pollution, agricultural production, availability of natural resources, industrial production, and population. Their ambitious undertaking, led by Dennis Meadows and Jay Forrester, resulted in the publication of the final report, which indicated that even our most *optimistic* projections will eventually lead to the onset of famine, wars, and the destruction of our economic system [1]. It was, in short, a dismal outlook. Malthus would have been pleased.

The Meadows report has been criticized for inaccuracies and misinterpretations, and some of these accusations appear to be valid. Indeed, a revised model has shown an increased chance for world survival [2] and more accurate data would seem to reduce the level of pessimism.

Nevertheless, the dismal outlook of Malthus is reaffirmed by Meadows, and we are beginning to realize that our planet is finite—that it has only limited resources and living space. The scarcity of land and nonrenewable resources could indeed have the ultimate devastating effect envisioned by Malthus and now once again suggested by Meadows At the very least, the concern is real, and we should begin to seek alternative life systems in order to have more assurance that these disasters can be avoided.

One (of many) possible potentially beneficial alternatives toward global stability is to eliminate the solid wastes generated by our materialistic society which are now deposited on increasingly scarce land. The recovery of these resources from solid waste would be a positive step toward establishing a balanced world system where society is no longer dependent on extraction of scarce natural ores and fuels. It seems quite clear that society has to adapt, using less technology in some instances, more in others, in order to achieve this balance. The technology and philosophy necessary for the implementation of resource recovery is the topic of this text.

## MATERIALS FLOW IN SOCIETY

### Reasons for Resource Recovery

The flow of materials in our society may be illustrated by the schematic diagram shown in Fig. 1-1. This diagram emphasizes the fact that we do not "consume" materials; we merely use them and ultimately return them, often in an altered state, to the environment. The production of useful goods for eventual use by those people called "consumers" requires an input of materials. These materials originate from one of three sources: raw materials, which are gleaned from the face of the earth and used for the manufacture of products; scrap materials produced in the manufacturing operation; and materials recovered after the product has been used. The industrial operations are not totally efficient, and thus produce some waste which must be disposed of. The resulting processed goods are sold to the users of the products, who, in turn, have three options after use: to dispose of this material; to collect the material in sufficient quantities to either use it for energy production or to recycle it back into the industrial sector; or to reuse the material for the same or a different purpose without remanufacture.

It is instructive to note that this is a closed system, with only one input and one output, emphasizing again the finite nature of our world. At steady state, the materials injected into the process must equal the materials disposal back into the environment. This process applies to the sum of all materials as well as to certain specific materials. For example, the manufacture of aluminum beverage containers involves the use of raw material—bauxite ore—which is refined to produce aluminum. The finished product—the cans—are sold to the consumers. Some of these cans are defective or for other reasons unfit for consumer use and are recycled as industrial scrap. The consumer uses the cans, and the empty

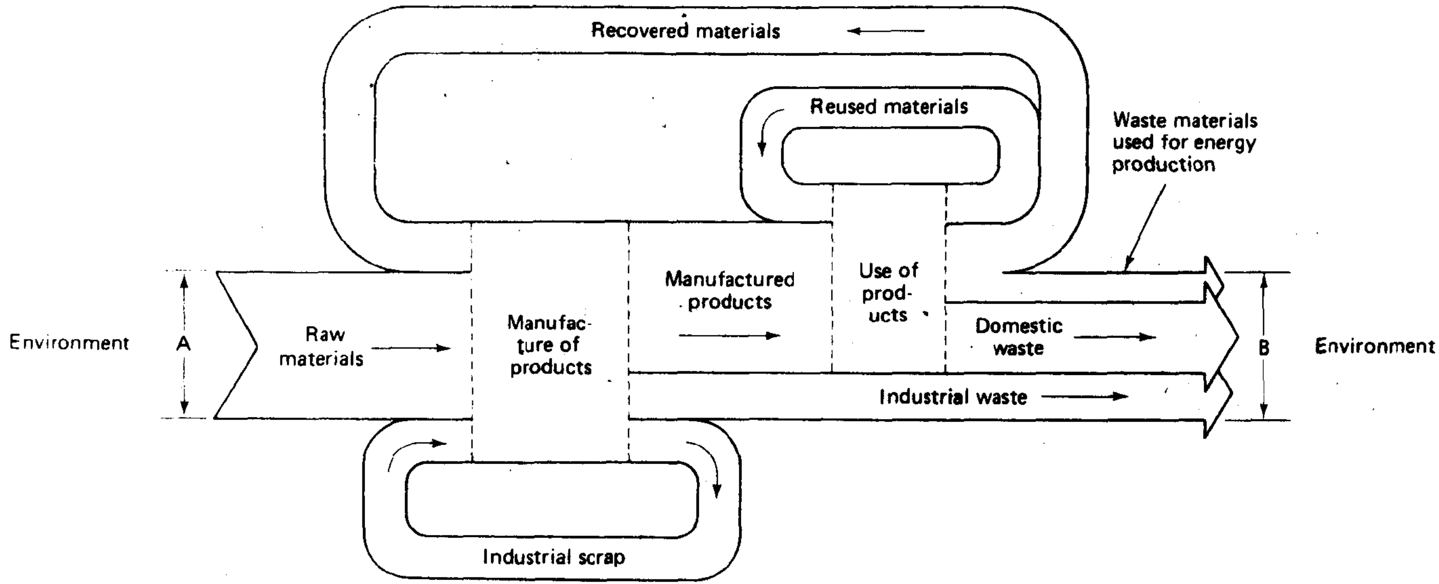


**Figure 1-1.** Flow of materials in society.

containers or other products are disposed of in the usual manner. Some of this aluminum is returned to the industrial sector (for remanufacture) and some of it might be used for other purposes in the home. The aluminum that is recovered and returned to the manufacturing process gets there only by a conscious effort by the community or other organizations which collect and recycle the material through the system. For many of the materials, this is often at a financial loss.

The interaction of the materials flow with the "environment" is at the input of raw materials and the deposition of wastes. In Fig. 1-1 these two interfaces are denoted by the letter "A" for raw materials and by the letter "B" for the materials returned to the environment.

It can be argued that both A and B should be as large as possible since there are many benefits to be gained by increasing these values. For example, a large quantity of raw materials injected into the manufacturing process represents a high rate of employment in the raw materials industry, which can have a residual effect of creating cheaper raw materials and thus reducing the cost of manufacturing.

A large B component is also beneficial in the sense that the waste disposal industry (which includes people as diverse as the local trash collector and the president of a large firm that manufactures heavy equipment for landfills) has a key interest in the quantity of materials that people dispose of. Thus a large B component would mean more jobs in this industry.

However, large A and B components also have detrimental effects. In the first place, a large raw material input means that great quantities of nonreplenishable raw materials are extracted (often using something less than environmentally sensitive methods, as exemplified by the present method of strip mining). Similarly, large quantities of waste can have a significant detrimental effect, in that wide land areas are being used for disposal of the waste, or that burning the waste in incinerators can result in serious air pollution problems in local situations.

A high rate of raw material extraction can eventually lead to a problem in the depletion of natural resources. At the present time in the United States we have already exhausted our domestic supplies of some nonreplenishable materials, such as copper, zinc, and tin, and are importing a substantial fraction of these materials [3]. It is obvious that if the rest of the world were to attain the standard of living that the developed nations have at the present, the raw materials supply would not be adequate to meet the demand. Our present life-style is based on obtaining these materials from concentrated sources (ores), and in using them we are distributing the products over a wide land area. Such a distribution obviously makes recovery and reuse difficult.

Finally, the question of national security for each country is predicated on the nation's ability to obtain reliable supplies of raw materials. We already have seen the problems that can be created by relying on other countries for such necessities as oil. There is little doubt that cartels will be developed by nations that have large deposits of other nonreplenishable materials, and that in the future the cost of such products as aluminum, tin, and rubber will increase substantially.

There is thus ample justification for reducing the wastes disposed of into the environment to the smallest quantities practical and we should clearly try to redesign our economic system to achieve this end.

### *Methods of Decreasing Raw Material Use and the Production of Waste Quantities*

It is clear from Fig. 1-1 that if the system is in steady state, the input must equal the output. Hence a reduction of either A or B necessarily results in a concomitant reduction in the other. In other words, it is possible to attack the problem in two ways.

Looking first at the A component, a reduction in raw materials demand could be achieved by increasing the amount of industrial scrap reprocessed, by decreasing the amount of manufactured goods, or by increasing the amount of recovered materials from the postconsumer waste stream. Increasing industrial scrap would involve increasing either "home scrap" (waste material reused within an industrial plant) or "prompt industrial scrap" (clean, segregated industrial waste material used immediately by another company). But scrap represents inefficiency, and an ultimate goal of industry is to produce as little scrap as possible. Clearly, decreasing the demand for raw materials will require one of the other two approaches.

The second possibility for achieving a low use of raw materials is to decrease the amount of manufactured goods. This will necessitate a redesign of products in such a way as to use less material and less energy. The quantity of material used for manufactured goods might be reduced as a result of increased raw material cost, or it can be mandated by the government. Under the name "waste reduction," the federal government has evaluated several methods of legislating a lower rate of material use. Taxes on excessive packaging, a package charge (e.g., 1 cent/lb), mandatory longer life of manufactured products, and other options have been considered.

The third possibility is to increase the recovery of materials. If this is accomplished, the total amount of consumer goods produced and the amount of goods manufactured by industry need not be reduced, but it would be possible to reduce the raw materials input to this system and concurrently to reduce the amount of materials destined for disposal. This strategy seems not only feasible but economically, politically, and practically attractive.

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Looking at the other end of Fig. 1-1, the disposal fraction, it is clear that the only two methods of reducing the quantity of materials to be disposed of is to increase the recovery and/or the reuse component, or to increase the use of waste for the production of energy. As defined in the figure, a reused product is one that the consumer can put to some other or to repeated use without the product going back to the manufacturer. On the other hand, the recovery of a material involves the remanufacture or processing of that material by industry. Both increased reuse and recovery will result in decreased raw material use. Increased use of waste for energy production will, on the other hand, only reduce the disposal quantities and will only indirectly affect raw material extraction.

In summary, it thus seems reasonable that the feasible options for achieving reduced material use and waste generation is by

1. Waste reduction.
2. Increased recovery.
3. Increased reuse.

The following paragraphs are devoted to a discussion of each of these potential methods of achieving reduction of solid waste and the use of natural resources.

### Waste reduction

The savings in material use due to waste reduction programs could be significant. For example, an 80% shift to refillable beer and soft drink containers, which would have 18 trips to the bottling plant and back, is not unreasonable under the Oregon-type bottle legislation. Better automobile tires, which would last 100,000 to 130,000 km (60,000 to 80,000 mi), instead of the present 30,000 km (20,000 mi), certainly seem to be in the future. In almost all cases, products can be redesigned to produce a 10 to 15% increase in their life, at very minimal cost.

If just those three goals were achieved (refillable beverage containers, better tires, and longer product life), a reduction of 18 million tonnes* (20 million tons) of postconsumer waste, or a 15% reduction in the 1985 projected waste generation figures, is possible [4].

Waste reduction can be achieved in two basic ways: (1) reduction in the amount of material used per product without sacrificing the utility of that product and/or (2) increasing the lifetime of a product.

The reduction in material use per product can probably be achieved most readily by redesigning some of the packaging that is presently used in the marketing operation. For example, a drawn and ironed steel can result in a savings of about 25 to 30% in materials over the common seamed tin can. Redesign of the automobile to reduce by 5% the steel presently used

*"Tons" in this text means 2000 lb, and "tonnes" means 1000 kg.

would result in about 315,000 tonnes (350,000 tons) of steel saved annually.

The car can also be used as an example of what would occur if longer life is achieved. The average life of a passenger car in the United States is about 10 years (much less than in other countries). The average weight of a car is about 1800 kg (4000 lb) and increasing the life by only 2 years, to an expected life of about 12 years by the year 1990, will achieve a savings of about 5.4 million tonnes (6 million tons) of steel, 135,000 tonnes (150,000 tons) of aluminum, and 135,000 tonnes (150,000 tons) of zinc.

It should be reemphasized that such reductions and changes in product materials and design will undoubtedly produce some economic ramifications. Such rules and regulations, if enacted, must be drawn up with the full knowledge that economic repercussions will result.

**Reuse**

At the present time, many of our products are reused in the home without much thought being given to ethical considerations. These products simply have utility and value for more than one purpose. For example, paper bags obtained in the supermarket are often used to pack refuse for transport from the house to the trash can. Newspapers are rolled up to make fireplace logs, and coffee cans are used to hold nails. All of these are examples of reuse. Unfortunately, none of these secondary uses has much economic impact on the total quantities of raw material used by our society.

By contrast, the use of refillable beverage containers would constitute a major form of reuse. At the present time in the United States, there are about 60 billion beer and soft drink containers sold annually. This translates into about 8 million tonnes (9 million tons) of solid waste, or about 8% of the solid waste stream. More important perhaps is the fact that these products account for a large fraction of our visible litter.

The advisability of an Oregon-type bottle law is still hotly debated. The bottling industries are vehemently against it, because such a law would force changes in their bottling and distributing strategies. Most environmental groups, as well as the EPA, are in favor of such legislation.

**Materials recovery**

Many of the components of municipal solid waste can be recovered and recycled for subsequent use, the most important being paper, steel, aluminum, and glass.

About 54 million tonnes (60 million tons) of paper enter the solid waste stream annually, and only about 15% of this is recovered. It is estimated that about 27 million tonnes (30 million tons) per year could be recovered economically from the solid waste stream without the use of new and advanced technology.

In 1973, about 3.6 million tonnes (4 million tons) of steel cans were generated in urban areas of the United States, and only about 2% of those cans were recovered. Even with the new basic oxygen furnaces which require rather pure charges and can tolerate only limited amounts of recovered steel, the steel industry could still absorb about 3 million tons of scrap steel per year.

Aluminum is another material that is ideally suited for recycling. About 0.9 million tonnes (1 million tons) of aluminum enters the solid waste stream annually, 50% of this being cans and 30% being foil. Only about 4% of our aluminum is presently being recovered, although some aluminum can recycling operations have achieved 15 to 20% recovery in certain urban areas.

Glass is potentially an ideal material for recycling because it is clean and can be reprocessed many times without a loss in its structural strength or other attributes. However, purity specifications and color standards are stringent, and reprocessed glass requires approximately the same amount of energy as glass made from raw materials. Of the 13 million tons of glass that are discarded annually, only about 3% is presently recovered.

### Energy recovery

The potential for energy recovery from solid waste is significant. For example, in 1975, 122 million tonnes (135 million tons) of waste was generated, 70% of which was combustible, yielding a heat value equal to about 500,000 barrels of oil per day. Recognizing that much of the waste generated in rural areas is not economically recoverable, the combustible materials from Standard Metropolitan Statistical Areas would still result in over 400,000 barrels of oil per day equivalent. This translates to about 10% of all the coal used by the utilities and 5% of all the coal used in the United States.*

## SOLID WASTE QUANTITIES AND CHARACTERISTICS

### *Definitions*

A great deal of confusion exists in the definition of "solid waste," and this leads directly to disagreements on the estimated quantities and composition of solid waste. There are both gross and subtle differences in the

*While it is convenient to translate Btus into barrels of oil, this is not realistic. The production of the Btu from refuse requires a certain amount of effort and expenditure of energy. Second, the refuse cannot be used in all of the many ways that oil can, and thus it cannot be a one-to-one substitution. This is discussed later in the text.

types and sources of such material, and indeed a question as to what is and is not "solid."

This text is devoted mainly to the recovery of resources from *postconsumer solid waste*, defined as the waste generated in private households, office buildings, and commercial and service establishments. Excluded are the wastes disposed of either into the sewerage system or directly into the atmosphere. This definition also eliminates many other types of solid wastes, including those resulting from mining, agricultural, and industrial processing. In these cases, not only is it often difficult to define what is and is not a "waste" (e.g., manure in a pasture vs. feedlot), but it is often meaningless to attempt to define "solid" (e.g., drums of waste pesticide or lubricating oil). Thus, although it is readily conceded that these wastes represent very real problems, we have chosen in this text to emphasize the waste materials typically collected by municipalities from homes and commercial establishments.

When solid waste generation sampling and composition studies are conducted and reported, it is also commonly assumed that the data do not include junked automobiles, street sweepings (including leaves), and sewage sludges, although all of these could well be included by the foregoing definition. In the vernacular, we are most interested in "what the garbage truck takes away."

The postconsumer solid waste thus defined is commonly referred to as *municipal solid waste*, or MSW. Municipal solid waste is comprised of a number of distinct categories of materials which have professionally accepted definitions:

*Refuse*—all MSW as transported from a home or commercial establishment, and comprising *garbage*—food waste (exclusively); *rubbish*—paper, cans, bottles, and so on; and *ash*—residue of coal burning.

*Trash*—tree limbs, leaves, and bulky items (refrigerators, large boxes, etc.).

Often some part of the trash is collected with the refuse, while in other communities the trash is either transported by the homeowners or is removed by special pickup. Whether some fraction of the trash is counted in the overall sampling survey has a large bearing on the outcome. For example, a solid waste sampling study for Honolulu yielded a surprisingly high organic fraction of over 85%. In that instance, all of the garden waste (mangoes, palm leaves, etc.) are picked up by the refuse truck, and this fraction can be as high as 30% by weight of the total load. The high organic fraction in Honolulu is thus readily understandable. In some communities, garden wastes may be counted as part of the refuse during one study, and not counted in another, thus yielding wide discrepancies of what is produced as MSW.

In this text, we define MSW as containing garden waste which is normally placed in the refuse can and collected with the remainder of the refuse. MSW as defined here does not, however, contain tree limbs, white goods and other bulky items collected separately.

Solid waste quantities should always be expressed in terms of weight, not volume, since the latter varies with compaction.

### *Solid Waste Generation*

The quantities of MSW generated can be estimated in one of three ways:

Input analysis.

Secondary data.

Output analysis.

Input analysis is based on data from published industry production statistics. For example, it is estimated by the Glass Containers Manufacturers Institute [5] that the annual production of glass containers is about 9,000,000 tonnes (10,000,000 tons). Of this about 270,000 tonnes (300,000 tons) was recovered and did not enter the waste stream [6], resulting in about 9,350,000 tonnes (9,700,000 tons) of waste glass containers. Other glass products entering the waste stream are estimated at 997,000 tonnes (1,100,000 tons) per year [7]. The total tonnage of waste glass is thus approximately 9,800,000 tonnes (10,800,000 tons) per year.

Similar analyses yield national tonnages for other materials. The 1975 values recently published by EPA are shown in Table 1-1. The last line in the table indicates an annual national solid waste production of 115 million tonnes (128 million tons) or on a personal level, a contribution of about 1.6 kg/capita/day (3.5 lb/capita/day). The table has two total columns, "as generated" and "as disposed." The difference between the two columns is moisture transfer during storage and transport of the mixed refuse. Newsprint, for example, has in its original condition about 7% moisture, but absorbs considerable moisture from garbage and other sources, yielding an average moisture content of 23% after the moisture transfer has taken place.

The input method of estimating solid waste generation is applicable to national data (or for isolated areas), where the input figures can be readily obtained from highly specialized agencies which routinely collect and publish industry-wide data. This system also allows for regular updates of waste generation estimates due to low-cost data gathering. Further, since the data collected by the same institutions include future projections, it is possible to estimate future solid waste generation. Using such a method, the EPA has projected the growth in solid waste generation as shown in Table 1-2.

TABLE 1-1

**Generation of Municipal Solid Waste in the United States,[a] (1973)**

| | Product category (millions of tons, as-generated wet weight)[b] | | | | | | | Totals | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | As-generated wet weight[b] | | As-disposed wet weight[c] | |
| *Material category* | *Newspapers, books, magazines* | *Containers, packaging* | *Major household appliances* | *Furniture, furnishings* | *Clothing, footwear* | *Food products* | *Other products* | *Millions of tons* | *Percent* | *Millions of tons* | *Percent* |
| Paper | 9.8 | 19.1 | tr. | tr. | — | — | 8.3 | 37.2 | 29.0 | 44.9 | 34.9 |
| Glass | — | 12.2 | 0.1 | tr. | — | — | 1.0 | 13.3 | 10.4 | 13.5 | 10.5 |
| Metals | | 5.9 | 2.1 | 0.1 | | | 4.0 | 12.1 | 9.6 | 12.6 | 9.8 |
| Ferrous | — | (5.2) | (1.8) | (0.1) | — | — | (3.7) | (10.8) | (8.6) | | |
| Aluminum | — | (0.7) | (0.1) | tr. | — | — | (0.1) | (0.9) | (0.7) | | |
| Other nonferrous | — | — | (0.2) | tr. | — | — | (0.2) | (0.4) | (0.3) | | |
| Plastics | — | 2.7 | 0.1 | 0.1 | tr. | — | 1.5 | 4.4 | 3.4 | 4.9 | 3.8 |
| Rubber and leather | — | tr. | tr. | tr. | 0.7 | — | 2.6 | 3.3 | 2.6 | 3.4 | 2.6 |
| Textiles | — | 0.1 | tr. | 0.6 | 0.5 | — | 0.9 | 2.1 | 1.6 | 2.2 | 1.7 |
| Wood | — | 1.8 | tr. | 2.6 | — | — | 0.5 | 4.9 | 3.8 | 4.9 | 3.8 |
| Total nonfood product waste | 9.8 | 41.7 | 2.3 | 3.4 | 1.2 | — | 18.9 | 77.5 | 60.5 | 86.5 | 67.3 |
| Food waste | — | — | — | — | — | 22.8 | — | 22.8 | 17.8 | 19.1 | 14.9 |
| Total product waste | 9.8 | 41.7 | 2.3 | 3.4 | 1.2 | 22.8 | 18.9 | 100.3 | 78.3 | 105.6 | 82.2 |
| Yard waste | | | | | | | | 26.0 | 20.2 | 20.9 | 16.3 |
| Miscellaneous inorganics | | | | | | | | 1.9 | 1.5 | 2.0 | 1.6 |
| Grand total | | | | | | | | 128.2 | 100.0 | 128.5 | 100.0 |

[a] *Net solid waste disposal defined as net residual material after accounting for recycled materials diverted from waste stream.*

[b] *"As-generated" weight basis refers to an assumed normal moisture content of material in its final use prior to discard, for example: paper at an "air-dry" 7% moisture; glass and metals at 0%. Total waste, including food and yard categories, estimated at 26% moisture.*

[c] *"As-disposed" basis assumes moisture transfer among materials in collection and storage, but no net addition or loss of moisture for the aggregate of materials.*

*Source: Ref. 8.*

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