Chapter 5

Recycling

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INTRODUCTION

Recycling is not a new phenomenon, at least not in concept. America's early settlers recycled as a matter of survival, turning corn husks into mattresses and old clothes into quilts. The materials conservation efforts so critical during World War 11 are not so distant that we have forgotten a time when used aluminum foil was carefully saved. In fact, most of us have recycled materials at some point in our lives—typically paper, aluminum, or glass.

But recycling is receiving increasing attention today as the Nation begins to grapple with the problems caused by MSW. Increased recycling is a goal for many State and local governments, private companies, and public interest groups. The topic of recycling is extremely complicated, and OTA believes it would be a disservice to oversimplify the facts. As a result, this chapter is long and detailed, but such detail is needed to understand the likely effectiveness of different recycling policy options.

Recycling actually consists of three different activities: collecting secondary materials, preparing those materials for market, and the actual recycling of the materials by manufacturing new products. The first section of this chapter briefly overviews recycling rates for different materials and presents information on collection and preparation. The second section discusses technologies and markets for individual secondary materials. The third section discusses pollutants associated with manufacturing processes that use virgin or secondary materials. The final section discusses general characteristics of commodity markets and barriers inhibiting the use of secondary materials.

How Much Do We Recycle?

It is difficult to provide accurate estimates of the amount of materials recycled in the United States because existing data for most materials are unreliable, especially in the MSW category. The lack of a consistent definition for MSW is a problem. Most observers agree that waste from residential, commercial, and industrial sectors should be counted, but what about junked automobiles, construction and demolition waste, and that portion of industrial waste that is disposed along with what is more commonly thought of as MSW?

Experts also disagree about how to account for waste from manufacturing processes, such as aluminum scrap from can-making and paper scrap from box-making. The manufacturing sector typically considers this waste as *post-consumer*. However, these portions of the scrap stream are not included in most accountings of MSW recycling—-most observers consider them to be *pre-consumer*. Actually, manufacturing wastes are more appropriately divided into three categories:

- "home scrap" produced and reused inside a production facility,
- "prompt industrial scrap*' produced in an intermediate stage of processing and returned to the basic production facility for reuse, and
- ''old scrap" (post-consumer) generated by the product's final consumer,

This assessment considers the first two categories of scrap to be pre-consumer waste; almost all of this waste is recycled as common practice in manufacturing as a way to reduce materials procurement and disposal costs. The significant issue from an MSW perspective, then, is old scrap. Unfortunate y, available statistics on recycled materials do not always provide information on all three categories of scrap. These problems are not confined to the United States (See box 5-A).

The most frequently reported estimate for a national MSW recycling rate is 10 percent (81). This does not include home and prompt industrial scrap. material recycled at the industrial and manufacturing level. This figure also does not include what modest recycling may take place at home, such as reuse of plastic containers or yard and food waste

Box 5-A—Recycling in Japan

Japan is known as a nation that recycles. Indeed, recycling has been practiced within the private sector for hundreds of years. However, the amount of MSW in Japan that is recycled is difficult to estimate for several reasons. First, neither the national government nor the private sector maintain aggregate recycling data or estimate an overall recycling rate. Second, the Japanese do not include materials that are recovered and recycled in their definition of MSW; instead they only include waste materials sent to landfills and incinerators (108,2 13).[1] This differs significantly from the definitions of MSW commonly used in the United States.

Some experts estimate that the recycling rate in Japan is around 50 percent (108,213). In contrast, OTA estimates that the rate may be as low as 26 to 39 percent, at least for materials for which data are available. Japanese officials also express varied estimates of the rate (108,180). Appendix A explains OTA's calculations and why its estimates differ from the estimate of 50 percent. The calculations indicate the great difficulties involved in estimating recycling rates.

Whether Japan recycles at a rate of 30 or 50 percent, it still sends a clear message that the United States could improve its current recycling rate of 10 percent dramatically. However, if the lower estimate proves correct it would indicate that high national recycling rates can be difficult to achieve, even in a country noted for its dependence on imports of raw materials, its homogeneous culture, and its propensity for citizen cooperation in community activities.

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[1] Most Japanese municipalities require citizens to sort MSW into two categories—combustibles for incineration (e.g., paper. food waste, and sometimes plastics) and non-combustibles for landfilling (e.g., metals, glass, and sometimes plastics). Few recycling programs are conducted by municipal, prefectural, or national governments.

comporting. In fact, no attempt has ever been made to estimate actual yard and food waste comporting.

Glass recycling has increased considerably during the 1980s because of the efforts of glass manufacturers to increase the use of cullet, or waste glass; the recovery rate for glass in 1987 was estimated to be 15 percent (223) (figure 5-1). Paper and paperboard recycling have also increased; the American Paper Institute reports a recovery rate of 28.5 percent for all waste paper (this is higher than the Franklin estimate of 22.6 percent because it includes pre-consumer waste). Aluminum recycling has also increased; according to the Aluminum Association, recovery of aluminum from MSW is now around 43 percent.

Increases in recovery of ferrous metals, plastics, and yard waste also have been occurring as more communities and businesses implement recycling programs and build processing facilities. Changes are occurring so quickly that information may be outdated even as it is reported.

Preparing Materials for Recycling

MSW can be collected in a variety of ways: as mixed wastes, with commingled recyclable, or with separated recyclable. How materials are collected affects the kind of preparation needed before recovered materials can be manufactured into new recycled products. A variety of technologies and methods are used to sort recyclable materials, remove contaminants, and prepare materials for marketing. Sometimes, this preparation takes place at centralized facilities, commonly referred to as Materials Recovery Facilities (MRFs). A MRF can help reduce separation demands on waste generators and can respond relatively quickly to changing demands of materials markets. About 12 MRFs were in operation in the United States in mid-1989, and more are planned (100).

The choices of equipment and design for a MRF depend on the types of materials being recovered, the type and degree of contamination of incoming material, the requirements of the buyers, and the disposal method for waste that is not recycled. The major influence is the type of MSW handled—mixed v. commingled v. separated. Box 5-B describes examples of materials recovery facilities.

It is difficult to compare the quality and cost of different materials recovery systems without considering a broad array of variables such as the entire MSW management system for the area served, materials recovered, and market availability. Standard methods for evaluating performance are not available. Operational experience with the more automated processes used in U.S. MRFs is also limited.

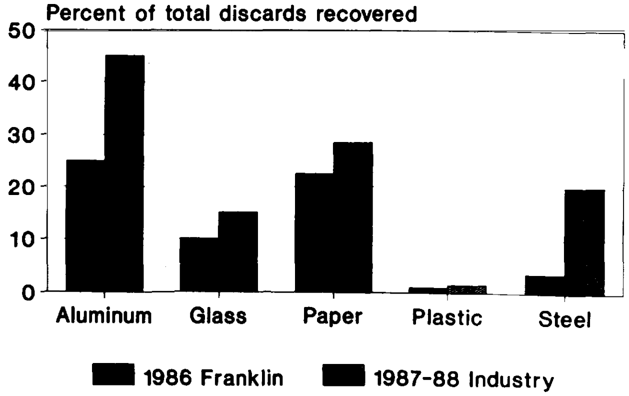
Mixed MSW

The first step in preparing mixed MSW for processing is "previewing," where oversized materials, explosive materials, and materials that could damage the equipment are removed. Various unit processes can be used to recover recyclable from unsorted raw waste. Size reduction (or shredding) reduces the volume of the waste and prepares it for the segregation step, where components of the waste stream are separated from each other. [1]Following segregation the material is sent to market using many of the same techniques used for commingled or separated recyclable. After recovering recyclable and/or compostables from raw waste, residual material is either landfilled or incinerated. In some systems the residue is processed as refuse-derived fuel (RDF) prior to incineration. Some systems only recover metals and glass for recycling (in addition to preparing compost); other systems recover plastics, different paper fractions, and batteries (box 5-B) (also see ref. 1).

Facilities that handle mixed MSW have the advantage that no change in the collection system is required. The plant manager can determine which materials to recover, depending on market conditions. Mixed waste systems have the potential to remove a high percentage of metals and other recyclable and/or noncombustible materials from the waste stream. Separation can also improve the combustion efficiency of incineration and the quality of resulting ash.

The biggest disadvantages of mixed waste facilities are the relatively high energy requirements and high maintenance costs. The use of multiple mechanical processes may also require more time to adjust equipment to the incoming waste stream. Explosion hazards can be associated with the shredding and grinding steps, but these risks can be minimized with proper design and operation. A history of poor performance at mixed waste processing plants in the 1970s has made this type of technology fairly unpopular in the United States.

Figure 5-1-MSW Recycling Rates: Estimates by Franklin Associates and Industry



NOTE: Industry estimate for paper includes pre-consumer scrap; industry estimate for steel includes a higher total for white goods, as well as ferrous scrap recovered at incinerators.

SOURCES: American Paper Institute, Paper Recycling Committee, 1987 *Annual Statistical* Summary Waste *Paper Utilization,* 2d ad. (New York, NY: July 1988); K. Copperthite, U.S. Department of Commerce, personal communication, 1988; Franklin Associates, Ltd., *Characterization of* Municipal Solid *Waste in the United States, 1960 to 2000 (Update 1988),* final report, prepared for U.S. Environmental Protection Agency (Prairie Village, KS: March 19SS); B. Meyer, Aluminum Association, personal communication, 1988; K. Smalberg, Steel Can Recycling Institute, personal communication, 1989; Society of the Plastics Industry, *Facts and Figures of the U.S. Plastics* Industry (Washington, DC: 1987); Society of the Plastics Industry, *Plastics A.D. 2000, Production and Use Through the Turn of the Century* (Washington, DC: 1987).

Refuse-derived fuel (RDF)-At many centralized facilities, the portion of the waste that is not recovered for recycling is converted into RDF. The RDF is then burned in a waste-to-energy incinerator to recover energy in the form of electricity or steam. Several kinds of RDF can be produced (including fluff, densified, and pelletized RDF), depending on the configuration of processes at a particular facility and on the specifications of RDF users.

An advantage of using RDF as a fuel, as opposed to mixed MSW, is that the properties of RDF are relatively consistent regardless of variation in MSW feedstock. Thus the incineration process can achieve

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[1] Size reduction requires a relatively high amount of energy and maintenance, thus costs are a major factor in determining the amount of size reduction. It is also a process that is difficult to do manually. Removal and segregation processes may be combined in several ways, depending on the composition of the incoming wastes and the types of materials being recovered. Several types Of technologies may be used including: air classification to separate light *from heavy fractions,* magnetic separation to remove ferrous metals, and screening to separate materials on the basis of particle size. Automated facilities to separate components of mixed waste are relatively new at the commercial level in the United States and have not as yet been proven as economical waste management methods. However, manual sorting can often substitute for automated methods, and source separation or manual methods are more effective for at least some materials (e.g., newspaper and glass).

Box 5-B—Examples of Materials Recovery Facilities

Mixed Waste Facilities

The Delaware Reclamation Plant, completed in 1983, processes solid waste and municipal sewage sludge from New Castle County, Delaware. The facility recovers ferrous metals, glass, and nonferrous metals, produces compost mixed with sewage sludge, and produces refuse-derived fuel (RDF). From the 500,000 tons of solid wastes and 60,000 tons of sewage sludge (20 percent solids) generated in the county each year, the facility produces about 130,000 tons of RDF and 250,000 tons of solid wastes. These solid wastes, which are landfilled, include ash from the RDF facility (which also accepts up to 60,000 tons of commercial waste), excess sludge, and solid wastes that have neither combustion capability nor materials recovery value (258). The facility markets the light ferrous fraction, aluminum, and a small portion of glass. Although high purity glass recovery is technically feasible, the cost of production far exceeds the current market value unless there is a nearby glass factory. The heavier ferrous fraction has no current market. The compost is used as landfill cover. Additional materials recovery prior to combustion could increase recycling and reduce the metals content of the ash.

MSW first passes through hammermills designed to shred up to 70 tons of waste per hour and equipped with explosion venting and suppression systems. After the hammermills shred the waste into 4-inch pieces, it is sent to air classifiers to separate the light from the heavy fractions. Magnets remove the ferrous material from the heavy fraction and a trommel screen separates glass. The organic matter removed in the trommel screens will eventually be sent to the humus processing section. The remaining, smaller fraction is further processed to separate the glass from the organics, paper, and plastics; the latter three also will be sent to the humus processing section. The glass fraction is crushed, screened, and reground. Then it is mixed with an amine acetate and removed through foam flotation; a magnetic separator removes fine ferrous contaminants from the glass once it has been dried. The remaining waste is sent to a secondary air classifier, where primarily nonferrous fraction is separated and sent to a trommel screen. The nonferrous material in this fraction (consisting of 60 percent aluminum) is recovered through eddy current separation (259).

The ORFA Corporation of America operates a facility in Philadelphia, Pennsylvania% that is designed to process about 90,000 tons of mixed MSW each year from the surrounding areas (182). The fully automated facility, completed in 1989, produces three products: ORFA Fiber, primarily composed of cellulose; granulate, consisting of glass, plastics, mixed sand, dust, grit, nonferrous metals and other dense substances; and ferrous metals. About 50 to 60 percent of the incoming waste becomes ORFA Fiber, about 18 percent becomes granulate, about 8 percent is ferrous metal, and the remainder is moisture and bulky waste. Uses for the Fiber include recycled paperboard, building board, kitty litter, and growing medium. Granulate is used as fill for strip mines, and ferrous metal is sold to local scrap dealers. Other ORFA facilities are planned, with expected capital costs of about $30 to $35 million for 132,000 tons per year of processing capacity. Tipping fees are expected to be about $85 per ton.

In the ORFA process, MSW is received in an enclosed tipping floor, where it is inspected for unacceptable materials such as bulky items or hazardous wastes, The MSW is then shredded and passed over a magnetic separator to remove ferrous metals. The shredded material is then screened to separate the light fraction and heavy fraction. The heavy fraction is sent to a hammer mill and the light fraction is sent to a high-speed cutting mill for further size reduction. The two fractions are then recombined. The combined fractions are dried in a natural-gas-fueled rotating drum dryer to approximately 5 percent moisture content. To reduce odor and stabilize complex organic compounds, the dried material is treated with ozone. The dry, sanitized, and stabilized material is screened and separated into coarse, medium, and fine grades before being sifted to separate the granulate from the ORFA Fiber. Coarse and medium fibers are baled and the fine fiber and granulate are stored in bins for shipment.

Commingled Recyclables Facility

The Monmouth Recycling Corporation operates a facility in Long Branch, New Jersey that handles 70 percent of the containers recycled by the county, including glass, aluminum, and ferrous cans (216). The company has been in the recycling business since 1978, first as a buy-back operation for non-ferrous metals. It gradually expanded into glass in 1982 using manual separation of colors and contaminants, and in 1988 it began a commingled materials processing line.

Trucks are weighed before they dump their loads into a receiving pit. Materials are then pushed with a loader onto a conveyor where they are separated by several automated and manual steps. The conveyors pass over a magnet to remove ferrous metals; aluminum cans are removed by hand and dropped through a chute where they are automatically flattened and blown into a van for transport. Several people pick different colors of glass from the remaining materials and drop them in different hoppers where they move by conveyors to a primary crusher, pass under another magnet, through a secondary crusher and then through a vibrating screen. The system generates color-separated glass cullet with minor paper contamination.

Separated Recyclables Facility

Recycle *America,* a subsidiary of Waste Management, Inc., began operating a materials processing center in San Jose, California, in 1986. Residents of the city separates metal cans, glass bottles, and newspaper into three bins. The materials are loaded separately into different compartments of route trucks. Trucks arrive at a computerized scale and successively dump the different materials, allowing compilation of data on the tonnages of different materials collected on each route. Newspaper processing involves baling the materials. Glass is broken as it is initially unloaded, then it is moved by conveyor to allow manual removal of contaminants. The glass is then dropped again into containers for shipping. By this method the glass is compacted, without the use of a crusher, from 300 to 1,000 pounds per cubic yard. Metal cans are separated into ferrous metal and aluminum as the materials pass through a series of magnets. About 20 percent of the steel cans are discarded because labels have not been removed. The cans are then baled for shipment.

New *England CRInc (NECRInc)* operates a facility in Billerica Massachusetts, that collects plastic, glass, steel, and aluminum beverage containers. The containers are separated, baled, and shipped to secondary aluminum smelters, glass manufacturers, etc. The company also operates two other similar facilities, two curbside recycling programs, and several drop-off programs around New England. It recently expanded its operations into Rhode Island, where it operates a facility that handles separated and commingled materials from a curbside collection program (newspaper is separated, while glass, plastic, and metal containers are commingled).

more thorough combustion and produce energy more efficiently. Among the disadvantages are the large amount of processing and energy needed to produce the fuel.

Commingled Recyclable

Technologies to separate commingled recyclable depend on the particular materials that are included in the mix. Some systems handle only glass and metal containers (box 5-B), while other facilities also sort paper and plastic. A combination of manual and automatic systems are usually used. Many of these same technologies are applicable to the segregation step for mixed waste.

The advantages of commingled collection are that some separation is already done and thus the amount of contamination that must be dealt with is reduced. Items that could pose a health hazard to workers are excluded (e.g., disposable diapers). One disadvantage of commingled collection is that it requires a different collection system than for the rest of MSW and is highly dependent on public participation (ch. **2).**

Separated Recyclable

Even when recyclable are separated at curbside, some preparation of materials often is necessary to meet the needs of buyers. Thus, prepared materials often command a higher price than materials that would be delivered directly to market. Technologies to handle separated recyclable include automated or manual methods to remove contaminants as well as baling, shredding, or grinding equipment.

One advantage of processing separated recyclable is that much of the labor of sorting materials has already been done, and the equipment required is generally very simple. Equipment may include scales, **conveyors,** and balers, as well as other unit processes for separating materials such as magnets for **separating** ferrous and nonferrous metals.

A disadvantage of separated collection is that it. like commingled collection, requires a different collection system and is highly dependent on public participation. Specialized collection equipment (e.g., compartmentalized collection vehicles) is often needed.

RECYCLING: TECHNOLOGIES, MARKETS, RISKS

Recycling technologies vary considerably depending on the secondary material and the intended end product. For example, technologies to recycle used oil vary depending on whether the oil is intended to be reprocessed for use as fuel or re-refined and used again as a lubricant. This section provides an overview of technologies and markets for secondary materials-paper and paperboard products, glass, aluminum, batteries, iron and steel, tires, oil, plastics, and compost.

Paper and Paperboard Products

Paper and paperboard products account for a larger fraction of MSW than any other single category of material. An estimated 64.7 million short tons of paper and paperboard were used **and discarded** as MSW in the United States in 1986 (81).[2] If this figure is correct, paper and paperboard would account for 41 percent by weight of gross discards (ch. 3).

According to Franklin Associates (81), 14.6 million tons of paper and paperboard were recovered from MSW in 1986. By comparison, the American Paper Institute reports waste paper recovery in 1986 at 22.1 million tons (9). The difference between the two estimates is caused by how each accounts for pre-consumer waste (i.e., prompt industrial scrap) that is collected routinely by fabricators and shipped to paper mills for use in the papermaking process.

In 1987, total waste paper recovery (including pre-consumer waste) in the United States reached an all-time high of 24 million tons, a recovery rate of 28.5 percent (9). For comparison, total recovery of waste paper was only 12.6 million tons in 1970, a recovery rate of 22.4 percent. Recovery, and subsequent use, has shown a similar increase worldwide.

Recovered waste paper, or secondary fiber, is used to produce new paper products, construction materials, and miscellaneous products such as animal bedding, insulation, and cushioning. Growth in demand for these products worldwide has caused heightened demand for secondary fiber. Consumption of secondary fiber in the United States increased from 12.0 million tons in 1970 to 19.2 million tons in 1987, and exports increased from 0.4 million tons to 4.4 million tons over the same period.

In the United States, paper and paperboard mills are the major consumers of secondary fiber, accounting for 94 percent of the total in 1987 (9). OTA's evaluation of opportunities for increased paper recycling therefore begins with a description of trends in the U.S. paper and paperboard industry.

Structure, Conduct, and Performance of the Paper Industry

The paper industry is international and relatively competitive. The United States, with its abundant forest resources and low-cost production facilities, plays a major role in the world paper industry. Of the 238 million tons of paper and paperboard produced worldwide in 1987, the United States accounted for 74.4 million tons, or 31 percent (199).

Statistics alone, however, do not give a complete picture of U.S. standing internationally because many large U.S. paper companies own forest resources, pulp and paper mill capacity, and converting operations abroad (200).[3] The United States is headquarters for 26 of the world's largest 100 pulp and paper companies (in terms of 1987 sales from pulp, paper, and converting operations only). Of the 10 largest, 8 are U.S. companies. Total 1987 sales for the 100 largest companies amounted to $125.4 billion, of which U.S. companies accounted for 43.7 percent (200). Japanese companies accounted for the second largest share-14.8 percent.

The paper and allied products industry is scattered throughout the country, with establishments located in every State. The largest concentration of production is in the South, which accounts for about 35 percent of total production, by value. The North Central region and the Northeast account for about 25 percent each.

The regional distribution of the industry parallels that of domestic forest resources-the paper indus-

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[2] One short ton equals 2,000 pounds. In this report, all references to tons refer to short tons unless otherwise noted.

[3] Converting operations refer to plants that transform paper and paperboard into products such as boxes or envelopes.

try locates its mills close to the major source of raw materials. As a result, many paper mills are in remote locations, where forestry and paper industries are the major employers.

According to the 1982 *Census of Manufactures* (242), the industry consists primarily of large establishments. Nearly half of all the U.S. paper and paperboard mills are directly associated with a pulp mill. These integrated mills accounted for the bulk of paper and paperboard shipments. In 1982, the value of shipments from integrated mills amounted to $23.0 billion, or 75 percent of total mill shipments.

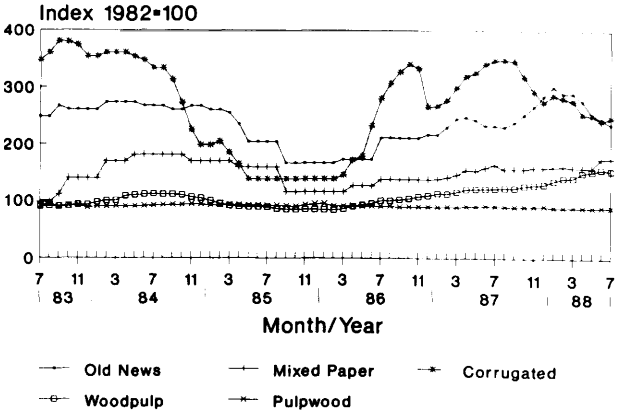
The paper industry generally keeps pace with the overall level of U.S. industrial production and exhibits relative stability. During the last recession, the industry's overall rate of decline was equal to or less than the average for all industries. Capacity utilization for most segments of the paper industry generally remains above 90 percent.

The **annual** average producer price indices for various paper products closely follow the index for all finished goods, but they are slightly more volatile. With the exception of wood pulp, all producer prices reported for paper products have increased by more than 50 percent since 1977 (250). The producer price index for wood pulp has fallen somewhat below the others and has exhibited greater volatility, particularly since 1981.

Data on monthly average paper product prices may be more meaningful, however. Beginning in July 1983, monthly data show that prices for waste paper are considerably more volatile than those for wood pulp (figure 5-2). This kind of relationship is typical of secondary materials.

The increased prices of paper products have benefited the industry. As recently as 1984, the profitability of the paper industry lagged well behind the rest of the economy. Over the last few years, however, the profitability of the paper industry has risen substantially, owing in part to cost-cutting measures, higher capacity utilization rates, and increased competitiveness associated with the decline in the value of the dollar (40,41) Despite this improvement, the industry's long-term returns-on-equity rates continue to be low relative to those for U.S. industry in general (3).

Figure 5-2—Producer Price Indexes: Waste Paper, Woodpulp, and Pulpwood



SOURCE: U.S. Department of Labor, Bureau of Labor Statistics, "Producer Price Indexes" (Washington, DC: January 1983-August 1988).

U.S. foreign trade in paper and allied products is substantial; in 1986, U.S. exports were valued at $4.9 billion, and imports at $7.8 billion. Of U.S. exports, wood pulp and paperboard accounted for the largest share (35 and 25 percent, respectively). Major destinations for U.S. paper product exports in 1986 were Japan, Canada, Mexico, and West Germany (225). Newsprint is by far the major product, accounting for 47 percent of total imports of paper-related products in 1986; wood pulp and printing and writing paper also account for significant shares (21 and 11 percent, respectively). Major sources of imports are Canada (accounting for 75 percent), Finland, West Germany, and Mexico (225).

The Use of Secondary Fiber in Production of Paper and Paperboard Products

The major grades of waste paper traded include old newspapers (ONP), old corrugated containers (OCC), mixed grades, pulp substitutes, and high grade de-inking.[4] The total amount of waste paper used and the proportion of each grade making up the total vary considerably by type of final paper product. For some paper products, waste paper is

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[4] The Paper Stock Institute, a division of the Institute of Scrap Recycling Industries, Inc., identifies 49 standard grades and 31 specialty grades of waste paper, but statistics are not collected on that basis (185).

used in conjunction, and sometimes competes directly, with wood pulp. In some instances, the paper product is made from 100 percent waste paper.

Consumption of secondary fiber, or waste paper, in the production of *all* grades of paper and paperboard increased in the United States from 12.0 million tons in 1970 to 19.5 million tons in 1987. By weight, about 25 percent of the fiber raw material used to make paper and paperboard in the United States consists of secondary fiber.

The regional distribution of paper mills that consume waste paper differs somewhat from that of virgin paper mills, reflecting the comparative economics of raw materials transportation. Secondary fiber mills often are located to take advantage of the largest sources of waste paper-converting plants and large population centers. The five largest waste paper consuming States in 1986 were Wisconsin, California, Ohio, Michigan, and Pennsylvania (243).

Technologies of Recycled and Virgin Papermaking

Once it is received at a mill, waste paper is normally prepared or repulped by mixing it with water and beating it with a hydrapulper. This process mechanically separates the fibers from foreign materials and forms a fiber and water slurry. Plastics and any remaining foreign materials are filtered out of the slurry, which is then thickened. If de-inking is required, the pulp is diluted and sent to a series of flotation cells where the pulp is aerated so the ink migrates to the surface as a foam. This foam is often removed using a vacuum (70).[5] In some processes, de-inking is aided with the use of heat and chemical ink dispersants, detergents, solvents, or defoamers. Additional cleaning may be required to remove contaminants. The de-inked stock, about 4 percent fiber and 96 percent water, can then be used to form paper sheets, although some fiber refining or blending may be required. In some instances, the pulp must be bleached with chlorine gas, chlorine dioxide, sodium hypochlorite, hydrogen peroxide, oxygen, or other chemicals prior to papermaking (241). The use of coated waste papers results in the production of large amounts of sludge, which can amount to as much as 30 percent of the input by weight (3). This sludge then becomes industrial waste.

Pulping wood can be accomplished by mechanical or chemical methods.[6] Mechanical pulping involves grinding logs or wood chips, adding water to form a slurry, filtering, and cleaning. Sometimes the wood is heated or soaked in a chemical liquor to soften the fibers prior to grinding. In chemical pulping, which is used to make pulp for higher quality products, wood chips are cooked in chemical solutions containing caustic soda and sodium sulfide or sulfites of calcium, magnesium, ammonia, or sodium. The cooking process dissolves the lignin, which binds the fibers together. After cooking, the pulp is washed, then diluted, screened, and cleaned. The pulp can then be bleached. Often, pulps from a variety of woods are blended to attain specific qualities required for different products. The same equipment can be used for making paper both from wood pulp and from secondary fiber pulp.

The major difference between the costs of making virgin and recycled paper is in the pulping and stock preparation stages. Industry representatives generally agree that the capital cost of expanding papermaking capacity is estimated to average about $150,000 per ton of daily capacity if waste paper is used and about $500,000 to $1 million if wood is used. The cost of building anew mill is considerably greater than the cost of expanding an existing mill. For example, building a new mill for recycled paperboard can cost 50 percent more and take twice as long than expanding an existing mill. The cost differential for the fiber itself is much less important in the comparative economics of virgin versus secondary fiber than this capital cost differential.

Comparative Energy Consumption**-Recycled** fiber can be used to make various paper and paperboard products. Each product, however, has unique limitations on the amount of recycled fiber that can be used, and each one is produced by manufacturing processes that can differ in the amount of energy used.

For some paper products, using waste paper may require less energy than producing paper fromvirgin timber. These savings can result from reduced

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[5] Waste paper is de-inked for most tissue and writing papers, but not for most paperboard products.

[6] According to API, U.S. woodpulp capacity is broken down as follows: 80 percent chemical, 10 percent semichemical, 10 percent mechanical (8).

energy demands in the process of making paper from waste paper and a reduced need to harvest and transport timber. They can be offset, however, by the energy needed to collect, transport, and de-ink the waste paper.

Estimates of the energy saved using waste paper vary greatly, however, and should be viewed with caution. In virgin papermaking, many process byproducts (e.g., lignin, bark, wood waste) are used to generate energy in the production process, thus reducing the need for purchased fuel. These types of byproducts are not produced in recycled papermaking. Many estimates of comparative energy consumption in papermaking do not account for this aspect of fuel use. Recycled paper and board often require more fossil fuel than virgin products.

Generalizations about relative energy consumption in virgin and recycled papermaking are difficult to make given the conflicting conclusions made by various studies of the subject. One study (99) estimated that most paper products require less energy to produce using recycled fiber than virgin fiber, but that most paperboard products require more energy if produced using recycled fiber (table 5-1). Data for tissue production from table 5-1 indicate a savings of 57 percent, while another study estimated savings of 41 percent (195). In contrast, Renard (206) reported a net energy loss of about 1 percent for the production of tissue from recycled fiber.

Other studies also address the total direct energy cost of using de-inked newspaper to produce new newsprint; these direct costs included electricity, heating water, and the introduction of inorganic additives (NaOH and NaOCl), but excluded the energy used to produce raw inputs (206). One study estimated direct savings of about 23 percent, or about 6.3 million Btu/ton. A more conservative study, however, concluded that using de-inked stock saved about 2.7 to 4.1 million Btu/ton, depending on the type of virgin pulp used.

In contrast, an analysis of primary versus secondary fiber use in linerboard production showed a net increase in energy cost when secondary fiber is used. According to one study (113), "increased use of secondary fiber as opposed to increased kraft pulping capacity leads to reduced steam and electrical process-energy requirements per unit product but to slightly increased energy costs per unit product, " based on using coal as an auxiliary fuel to replace wood residue fuel generated in primary fiber pulping.

An alternative approach to recycling waste paper is to recover the energy value in collected waste paper by using it as a fuel supplement. However, one analysis of wastepaper used as a coal supplement in electric powerplants or to generate steam at paper plants found that recycling (with an optimum allocation of waste paper to efficient recycling options) was more energy efficient (99). In fact, that same analysis concludes that "the most energy efficient strategy of making paper is to increase the amount of source-separation and recycling (compared to the alternatives of burning or landfilling). The next most energy efficient use of scrap is to burn it for energy production and the least efficient is to land-fill it" (99).

Markets for Waste Paper, by Product Category

Every paper product that uses waste paper exhibits its unique market characteristics. The major categories of products described here include the paper grades (fine printing and writing paper, newsprint, tissue, and packaging and industrial paper), the paperboard grades (unbleached kraft, semichemical, bleached paperboard, and recycled paperboard), and building paper and board.[7]

***Fine Printing and Writing Papers*—In 1987,** U.S. mills produced 20.7 million tons of printing, writing, and related papers for use in publishing and office products (e.g., books, brochures, magazines, stationery, copy papers, accounting forms). Although most printing and writing paper is made from virgin fiber, about 1,375,000 tons of wastepaper was used, for a waste paper **utilization rate** of about 6.6 percent (see figure 5-3).[8] About 74 percent of this waste paper was pulp substitutes, or cuttings from converting plants. The remainder consisted mainly of post-consumer high grade de-inking paper (e.g.,

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[7] The use of waste paper for non-paper products is not described because reliable data are not available; these products include cellulose insulation, molded products (e.g., egg cartons and flower pots), cushioning material for packaging, animal bedding, and mulch.

[8] Utilization rate refers to the portion of waste paper used in total domestic production of the grade(s) under discussion.

Table 5-l-Estimated Energy Used To Produce Paper and Paperboard Products
(In million Btu per ton produced)

Product	From 100°/0 virgin wood	From mixed recycled paper		% change due to recycling
	Energy use	Minimum virgin fiber content	Energy use	
Paper products				
Newsprint	44.33	00/0	34.76	-21.6
Printing paper	67.72	16%	43.43	-35.9
Packaging paper	47.07	70%	43.48	-7.6
Tissue paper	68.52	00/0	29.46	-57.0
Paperboard products				
Liner board	14.46	75%	36.28	+1 50.9
Corrugated board	37.22	0%	36.28	-2.5
Box board	25.97	0%	36.25	+39.6
Food service board	29.19	100%	N/A	—
Other paper board	17.65	O%	36.32	+105.8
Construction board	31.71	65%	32.24	+1 .7

SOURCE: T. Gunn and B. Hannon, “Energy Conservation and Recycling in the Paper Industry,” *Resources and Energy* 5:243-260, 1983.

computer printout, tabulating cards, white ledger and forms).

Only a few printing and writing paper mills can de-ink waste paper and/or produce new paper that contains at least 50 percent waste paper. In 1983, 174 printing and writing paper mills with 18.6 million tons of capacity were operating in the United States, but only 12 mills had de-inking facilities (6). By 1988, mill capacity had increased to 22.7 million tons, but only 9 mills had de-inking facilities (one of which was not operating). A total of 18 mills, however, had the ability to produce printing and writing paper containing at least 50 percent waste paper; these mills had the combined capacity to produce about 1 million tons annually, or about 5 percent of the total (82).[9]

The majority of printing and writing paper mills are large, integrated world-class mills that use 600-ton-per-day papermaking machines. However, most mills that predominantly use waste paper as furnish-’ secondary paper” mills—are smaller, older, and less efficient, typically using 70-ton-per-day machines. The secondary paper mills have been successful in producing high-quality recycled printing and writing paper that is comparable to virgin paper because they use very high-quality secondary fiber. According to paper industry representatives, however, they can compete with the large integrated mills only because they can use lower cost secondary fiber.

Concerns have been expressed about the future supply and price of high-quality secondary fiber. Increased exports and increased competition from other types of paper mills (especially tissue) have driven up the price of some secondary fiber, making many grades economically marginal for the secondary paper mills. Since most of the highest quality waste paper appears to be collected already, a future increase in supply will be limited to increases in the rate of production of waste paper as a byproduct at converting plants. As a result, secondary paper mill representatives express reluctance to build new mills to produce more recycled printing and writing paper. One representative noted that just two new 600-ton-per-day paper machines (i.e., state-of-the-art technology) could consume the available annual supply of pulp substitutes.

This view is not held by all, however. During 1988, the Korean-owned Mi-Ho Paper Co. announced that it would build a new recycled printing and writing paper mill in St. Josephs, Missouri, that would use primarily secondary fiber. The business plan for the mill identifies reliable sources for the waste paper and also has most of the production

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[9] The remainder of the 1,257,000 tons of waste paper consumed at printing and writing paper mills was presumably consumed in mills producing paper containing less than 50 percent waste paper.

earmarked for export. The capacity of the mill has not been reported, but it is expected to cost about $60 million to build, including land, insurance, and financing costs. The success of this venture will not be apparent for years to come, and many industry sources in the United States are skeptical.

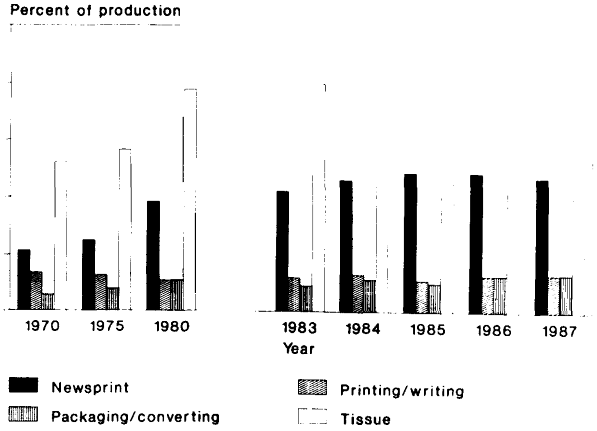
In addition, some expansion of current recycled printing and writing paper capacity has occurred recently. One mill announced a 25-ton-per-day expansion at a cost of about $15 million (or about $600,000 per ton of daily capacity).

Therefore, the major barriers to increased use of secondary fiber in printing and writing paper appear to be supply of high-quality secondary fiber, technological constraints in the papermaking process, and high standards on the part of the consumer. Improvements in de-inking technology are required to allow the use of lower quality waste paper, such as that collected in office paper recycling programs. The industry is conducting some research in this area, but prospects for success are unknown. Additional research also is needed to improve the removal of contaminants (e.g., sticky adhesives and plastics), improve fiber treatment or refining, and find commercially viable ways to reduce or handle the low-solid sludge generated when recycling printing paper that has a thin clay coat. Some technology in use in Europe does allow the production of printing and writing paper from lower grade waste paper, but its quality is allegedly lower than U.S. standards for printing and writing paper. This paper, which can be called "adequate for the purpose" grade, is being produced in the Federal Republic of Germany, for instance, at a rate of about 140,000 tons per year (235). OTA is not aware of any imports of this type of paper into the United States.

Newsprint—Newsprint mills in the United States produced 5.8 million tons of newsprint in 1987. About 23 percent, or 1.4 million tons, was made from waste paper, virtually all old newspapers (ONP) (figure 5-3). Total U.S. production supplied less than half of total U.S. demand for newsprint, and 8.9 million tons of newsprint were imported in 1987, primarily from Canada.

In 1987, U.S. capacity to produce newsprint was about 5.9 million tons (8). The seven recycled newsprint mills in operation in 1987 had total annual capacity of 1.5 million tons (84). Most of these mills are located very close to sources of secondary fiber-major metropolitan areas-to minimize transportation costs.

Figure 5-~Waste Paper Utilization Rate, By Paper Product



SOURCE" American Paper Institute, "Waste Paper Utilization in Paper and Paperboard Manufacture" (New York, NY: individual yearly reports for 1970 through 1987); Paper Recycling Committee, 1987 *Statistics of Paper, Paperboard & Wood Pulp* (New York, NY: August 1987).

After 4 years of virtually no growth, the North American newsprint industry has embarked on a period of expansion. Within the next few years, 9 new newsprint machines, each with a capacity of 200,000 tons per year, will come on-line; 7 of these machines are in Canada. Most of this new capacity will use virgin fiber, mainly because the new machines are additions to current plants rather than developments at new sites. Most mills are located close to sources of wood pulp, so it is unlikely that it would be cost-effective to transport large amounts of ONP a longer distance to be used as furnish instead. This could change, however. For example, a new facility being built at a mill in Quebec will use ONP, magazines, and other forms of waste paper to produce newsprint pulp (47).

The major barriers to increased use of waste paper in newsprint appear to be lack of markets and higher levels of contaminants found in new supplies of ONP. Given current expansion plans, further increases in capacity would likely result in an overall reduction in the industry's capacity utilization rate. Of course, given the large volume of U.S. imports of newsprint, some of that displacement could occur in Canadian (or other foreign source) mills. Unless restrictions were placed on imports, however, there would be no assurance that U.S. capacity utilization would not be affected.[10]

Sufficient additional supply of ONP does exist to furnish new recycled newsprint capacity. It has been estimated that at least 700,000 to 800,000 tons of ONP would be available in the Northeast alone (123). However, questions exist as to the quality of the additional supply, particularly that generated by mandatory source separation programs. Garden State Paper, for example, has reported difficulty with contamination in ONP recovered from New Jersey's mandatory recycling program (123).

Finally, market volatility is an additional barrier to capacity expansion. Many analysts predict that the world supply of newsprint will outpace demand by 1990. With the possibility of recession increasing, the industry may see further investment in new machines as too risky.

Tissue—Tissue grade paper includes toilet and facial tissue, napkins, toweling, diapers, wipes, and other sanitary papers. U.S. mills produced 5.3 million tons of tissue in 1987. Approximately 2.4 million tons of secondary fiber was used to produce tissue, for a utilization rate of 44 percent. This is a significant increase from just over 25 percent waste paper utilization in 1970 (figure 5-3). All grades of waste paper are used to make tissue products, with high grade de-inking and pulp substitutes contributing the largest share-almost 75 percent. The lower grades, mostly post-consumer waste, generally are used to make industrial toweling and wipes for the ''away-from-home' market.

Tissue production capacity in the United States has expanded steadily over the last decade, to about 5.8 million tons in 1988, and additional expansion is expected. An estimated 20 to 40 tissue mills make tissue products with about 25 percent recycled content or more (84). Highly proprietary technology has allowed some tissue mills to increase their consumption of de-inking grades of waste paper. Unfortunately, the potential to further increase consumption of lower grades of waste paper cannot be determined quantitatively. However, tissue producers do not appear concerned by the possibility of reduced supplies of pulp substitutes, perhaps indicating a future tendency to rely less on these high grade fibers. Because most tissue products made with post-consumer waste paper are the coarser, ''away-from-home' variety, increased use of such waste in tissue paper production depends to some extent on consumer preference. In blind tests on product quality and performance, consumers invariably pick the virgin product because it is whiter and softer (3). Whether consumers can accept a coarser product for home use is unknown.

Kraft andPacka@”ngPaper-in 1987, U.S. mills produced 5.1 million tons of unbleached kraft and bleached packaging and industrial papers, mostly for making shipping bags and wrapping. *1 The waste paper utilization rate in producing these papers has averaged about 5 percent over the last decade (figure 5-3), with pulp substitutes and OCC being the major grades of wastepaper used. Much of this waste paper is pre-consumer waste. According to the API (7), high grade secondary fibers from waste clippings at bag-making plants were the primary source of waste paper because packaging papers require high strength. Lower grade fibers and fibers recycled more than once do not exhibit the necessary strength characteristics .12 Therefore, the use of waste paper in these products is not expected to increase.

Production of kraft papers, the largest share of this category, has declined over the last few years. The major market for these papers is grocery and merchandise bags, which have been losing about 5 percent of the market per year to plastics (197). Bans on plastic shopping bags, which have been implemented in several localities, could lead to increased domestic production of kraft papers.

Unbleached Kraft Paperboard—Production of unbleached kraft paperboard in the United States in 1987 amounted to 18.5 million tons. About 1.9 million tons of secondary fibers, mainly OCC and box plant clippings, were used to make products in

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[10] Increased pressure is also being placed on Canadian newsprint mills to use more ONP. It appears likely that some displacement will occur there as a result of Canada's own recycling programs.

[11] Kraft paper, produced by a modified sulfate pulping process, is a relativelycoarse paper with high strength characteristics. Unbleached grades are used primarily for packaging and wrapping; bleached kraft can be used to make many grades of paper including tissues and printing and line papers.

[12] In the process of recycling paper, the wood fibers are broken and shortened, thus reducing their strength.

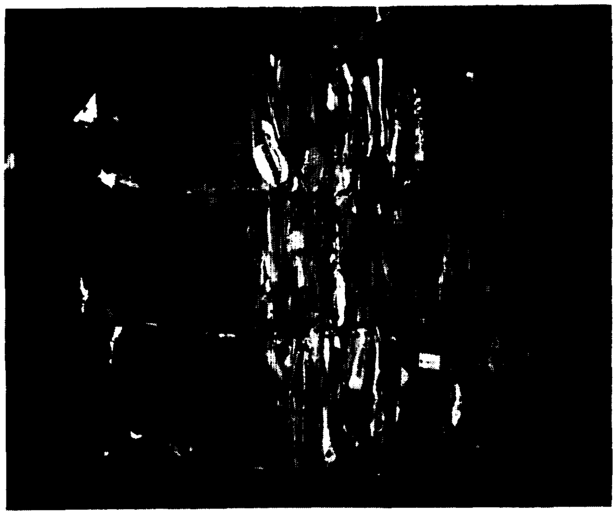


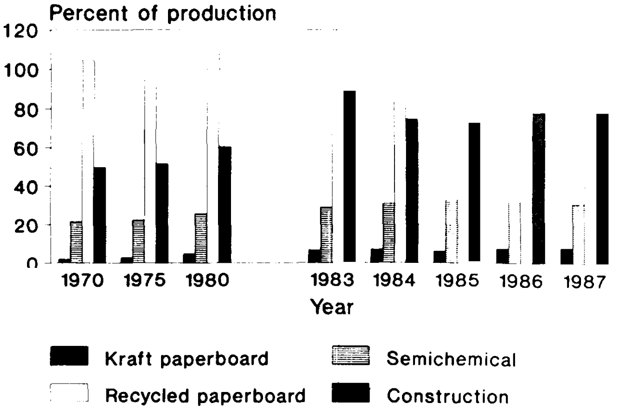
Photo credit: W. Johnson

Old corrugated cardboard typically is compacted and baled before being shipped to paper mills for recycling.

this category, for a waste paper utilization rate of 10 percent (figure 5-4). Most unbleached kraft paperboard is produced in the form of linerboard, which is used as the facing material in corrugated boxes and solid fiber boxes. The remainder is used to make folding cartons and other products. Demand for these products has remained strong in recent years, and linerboard in particular is expected to continue in high demand stimulated by projected strong growth in industrial production--corrugated containers are the most widely accepted shipping container.

Expansion of the use of secondary fibers in these mills is limited primarily by performance requiremerits. *3 Increased use of secondary fibers reduces the strength of the final product, thus limiting the amount of such fiber that can be used in linerboard mills. Some research is underway to enhance the strength of board made from OCC (e.g., using heat and higher pressure in board production, press drying in papermaking, separation of the linerboard from the weaker medium, and enhancement with chemical additives). However, additional research and development is needed (1 14). Box-makers continue to prefer virgin products because of their strength and durability; they often are specifically requested by customers abroad, where they are valued as inputs to recycling processes.

Figure 5-4--Waste Paper Utilization Rate, By Paperboard Product



SOURCE: American Paper Institute, "Waste Paper Utilization in Paper and Paperboard Manufacture" (New York, NY: individual yearly reports for 1970 through 1987); Paper Recycling Committee, *1987 Statistics of Paper, Paperboard & Wood Pulp* (New York, NY: August 1987).

One analysis indicated that favorable economics exist to increase the use of secondary fiber in the production of unbleached kraft linerboard (113). According to that study, the major economic advantage of secondary fiber is the relatively low capital cost. It is estimated that a 700-ton-per-day expansion at an existing linerboard mill would cost only $15.1 million for the secondary fiber process, compared with $113.7 million for the kraft pulping process (113).

Semichemical Paperboard—In 1987, U.S. mills produced 5.6 million tons of semichemical paperboard, primarily for use as corrugating medium (the center component or fluting material of corrugated boxboard). The waste paper utilization rate for this product has been about 32 percent over the last few years, an increase from only about 21 percent in 1970 (figure 5-4). Nearly all of the secondary fiber used to make semichemical paperboard consists of OCC.

Production of semichemical paperboard has increased steadily, but is expected to level off (199). Technically, more secondary fiber could be used in the production of corrugated boxes (and is used to

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[13] Corrugated boxes are required t. meet certain requirements for burst strength and sometimes stacking or compression strength as determined by standard industry tests.

make recycled paperboard for corrugated boxes). Many Asian mills are reported to use much larger proportions (if not 100 percent) of secondary fiber in their corrugated boxes. However, these boxes are of a much lower quality than those made in the United States, and limitations exist as a result of U.S. legal and technical shipping requirements. It is possible that these requirements could be changed to accommodate the use of more recycled fiber if greater care were used in shipping.

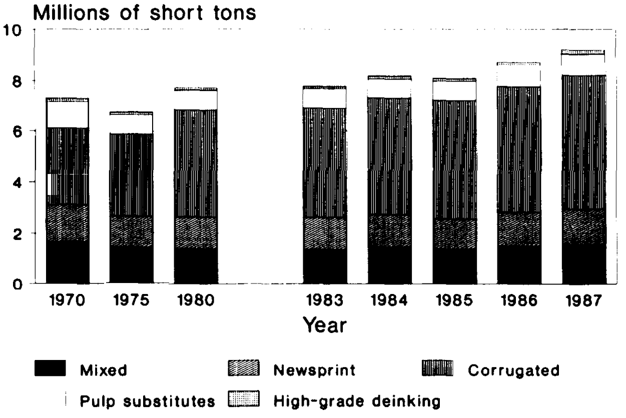
Semichemical paperboard production generally follows the same trend as kraft linerboard, the other major component of corrugated boxboard; demand is closely tied to industrial production.

Bleached Paperboard--Bleached paperboard is produced almost exclusively from virgin fiber. It is used primarily in sanitary packaging, such as milk cartons, and food service items, such as cups and plates, where it must meet very strict requirements. In 1987, 4.3 million tons of bleached paperboard were produced in the United States. Increased use of secondary fiber is unlikely in these products.

Recycled Paperboard-Almost half of all waste paper used in the United States is consumed in recycled paperboard. In 1987, 9.2 million tons of waste paper were used to make 8.6 million tons of recycled paperboard, a 100 percent recycled product (figure 5-4).[14] All grades of waste paper are used in the production of recycled paperboard, with OCC showing the largest increase (figure 5-5).

Recycled paperboard products include test liner, corrugating medium, filler chipboard for solid fiber boxes, folding cartons, rigid boxes, gypsum wallboard, paper tubes and drums, panelboard, set up boxes, tablet backing, and miscellaneous other products (8). Recycled paperboard has become more popular as industries attempt to lower costs. However, only slight increases in production capacity are expected to 1990.

Figure 5-5-Waste Paper Use in Recycled Paperboard, By Grade



SOURCE: American Paper Institute, Paper Recycling Committee, 1987 *Annual Statistical Summary Waste Paper Utilization,* 2d ed. (New York, *NY:* July 1988).

Recycled paperboard continues to have strong competition from plastics and virgin paperboard. Major portions of the paperboard market were lost in recent years when diaper manufacturers converted packaging from folding cartons to plastic bags and when liquid detergent in plastic bottles began to replace cartoned granules. In higher priced consumer products, where packaging accounts for a very small share of cost, manufacturers are reluctant to use recycled paperboard because the consumer may associate it with an inferior product. Strength and printability are generally the same for recycled and virgin paperboard, but recycled paperboard is used where lower quality is acceptable (114,264). **Thus, consumer preference appears to play an important limiting role in the increased use of recycled paperboard.** Some industry representatives, however, contend that sanitary and health considerations are the primary factor, followed by weight, economic, and performance considerations.

Construction Paper and Board-Production of construction paper and board in the United States declined from about 3 million tons in 1970 to 1.2 million tons in 1987. About 900,000 tons of waste paper of all grades were used to make construction paper and board in 1987 (figure 5-4). Products in this category include roofing, siding, wallboard, and insulation board. These markets have suffered competition from other materials, such as fiberglass, which is expected to continue.

Waste Paper Exports

The United States is the world's largest exporter of wastepaper, and exports of U.S. waste paper have increased tremendously (figure 5-6). Concurrently, the importance of the export market for U.S. waste

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[14] The process of repulping and cleaning the waste paper results in Some shrinkage.

paper dealers also has grown. In 1970, only 3 percent of the waste paper recovered in the United States was exported, By 1987, exports had grown to 18 percent of recovery (9).

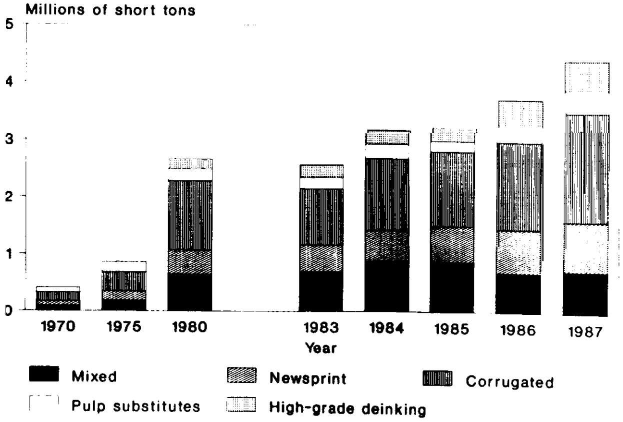
Major Markets—According to the Department of Commerce, more than half of U.S. waste paper exports in 1987 was destined for the industrializing countries of the Far East, particularly the Republic of Korea and Taiwan. Since 1970, U.S. exports to that region have increased fifteen-fold, a growth factor far greater than that exhibited by any other region. Mexico is also a large importer of U.S. waste paper, accounting for 18 percent of total U.S. exports in 1987.

The three largest consumers (i.e., Taiwan, Korea, and Mexico) accounted for 59 percent of total U.S. exports in 1987 (225), These countries have expanded papermaking capacity significantly in the last decade, based heavily on imported raw materials, particularly secondary fibers. Low labor costs have allowed them to import lower grade waste paper and sort it by hand for use in their paper mills. Their mills are relatively new and efficient, using technology imported from industrialized countries. Most of the paper produced in Taiwan and Korea is used internally, both for direct consumption and for packaging consumer goods for export.

The Japanese paper industry also consumes a large amount of secondary fiber, amounting to as much as 50 percent of total furnish. Japan accounted for 15 percent of U.S. waste paper exports in 1987.

The European market is expected to decrease in importance for U.S. exporters. U.S. waste paper exports to Europe declined from 402,800 tons in 1985 to 351,200 tons in 1986, as European recovery rates increased to supply their demand. In fact, waste paper markets in Europe experienced a glut in 1986, despite very strong performance by the European paper industry. This situation was particularly marked in West Germany, where mandatory collection of waste paper resulted in an oversupply of lower grades throughout the region and dampened prices considerably (202). Paper stock prices for the lower grades fell by 60 to 80 percent during the year (86). Increased West German exports to Korea and Taiwan have alleviated the European oversupply situation somewhat, but some concerns have been raised about the future ability of the Far East market to absorb the increased supply of low grade waste. Overall, the potential for future increases in U.S. waste paper exports to Europe seems low.

Figure 5-6—U.S. Exports of Waste Paper, By Grade



SOURCE: American Paper Institute, Paper Recycling Committee, *1987 Annual Statistical Summary Waste Paper Utilization*, 2d ed. (New York, NY: July 1988).

Grades Exported--About 40 percent of U.S. exports of waste paper is OCC, which is in high demand because it is made from strong softwood fibers. Mixed paper and ONP each account for about 20 percent, with the remaining 20 percent split between pulp substitutes and high grade de-inking. These proportions have remained relatively constant over the last decade, with variations of about 5 percentage points (figure 5-6). For each grade, exports are equivalent to 20 to 30 percent of domestic consumption. Pulp substitutes, the highest valued waste paper, are the exception to this, with exports equivalent to only about 10 percent of domestic consumption.

Export demand for most grades of waste paper is expected to remain strong. Exports of most grades increased from 1986 to 1987 by more than 10 percent. Only mixed waste showed a lower growth rate, reportedly because of increased contamination from materials such as plastics and metals (203).

Although export demand is strong, increased supplies from States that recently have implemented recycling programs is reported to have reduced export prices. In the Northeast, where waste paper is a major export, prices for OCC and ONP declined in mid-1988 when New Jersey and other States increased their recycling. Although other factors may

Photo credit: R. Guttman

The United States is the world's largest exporter of waste paper. In 1987, 18 percent of the waste paper recovered in the United States was exported, with over half going to the industrializing countries of the Far East.

have contributed to the downward pressure on prices, by late 1988 some localities were having to pay waste paper dealers to take ONP. Waste paper export prices on the west coast also were affected to some extent, particularly since transportation costs there have risen (205).

The Glass Industry

About 11 million tons of glass containers are produced each year in the United States (52). According to industry sources, between 20 and 25 percent of each new glass container is produced from cullet, or waste glass. Of this, 50 to 55 percent is post-consumer cullet and the remainder is home scrap.[15] On that basis, the amount of cullet used in production would be 2.5 million tons, of which 1.3 million tons would be post-consumer cullet.

Glass discards were estimated to account for about 8 percent of MSW in 1986, or about 12.9 million tons. An estimated 90 percent of the glass was in the form of containers. With about 1.3 million tons of cullet being recycled, this would represent a post-consumer glass recycling rate of 10 percent in 1986; the rate for 1988 is somewhat higher, at about 15 percent.

It is difficult to compare glass recycling rates in other countries. Most glass bottles in Europe and Japan are refillable. In the Netherlands, for example, over 90 percent of retail soft drink and beer sales are in returnable bottles, as required by law (194). In Japan, 66 percent of all bottles are collected and reused an average of three times; beer and some sake bottles are reused an average of 20 times (106).

The data on international glass recycling are conflicting. One study indicated that glass recycling rates for Europe, Japan, and the United States ranged from 10 to 53 percent, with Japan having a rate of only 17 percent (194). However, a 1983 survey in Japan indicated that about 54 percent of empty bottles and 52 percent of cullet were recovered (106). In Switzerland, enough glass was recycled in

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[15] This is an estimate for 1986, used to be consistent with the rest of the statistics in this chapter; for 1987-88, 25 percent of each new container is cullet, 60 percent of which is post-consumer.

1986 to satisfy 75 percent of the raw material needs of the glass packaging industry. About 30 percent of West Germany's waste glass is collected, mostly in outdoor collection centers (1 15). In Sweden, glass recovery is only about 15 percent, even though more than 200 municipalities provide facilities fix glass recycling (230).

Technologies of Virgin and Recycled Glassmaking

Glass can be manufactured entirely from virgin materials-primarily from silica sand, and other materials such as feldspar, limestone, and natural soda ash. In addition to making containers, silica sand is used to make flat glass, safety glass, pressed and blown glass, fiberglass, optical glass, and industrial glass. The largest end use for silica sand is containers, which consumed 69 percent of the silica sand produced in the United States in 1986 (246).

To improve melting efficiency in a glassmaking furnace, it is desirable to have at least 8 to 10 percent cullet in the furnace charge, with 25 percent cullet the most common mix. Varying the mixture of cullet and virgin material affects the chemical processes in the furnace, and can require changing the furnace temperature. Because of chemical differences, container cullet generally cannot be used to make most types of glass other than new containers and fiberglass.

Although cullet itself is 100 percent recyclable (one pound of cullet makes one pound of new glass), limitations exist on the amount of cullet that can be used as furnace feed. In general, glass produced from cullet must meet strict buyer specifications on quality and color (table 5-2). Color separation processes, however, usually are not 100 percent efficient, so that strict color specifications can act as a constraint to using large amounts of cullet.

It also is difficult to make glass entirely from cullet because cullet lacks ‘‘fining” agents that are needed to reduce bubbles in the glass. Little documentation is available on the amounts of cullet that can be used at various U.S. glassmaking facilities. One study of a European glassmaking facility indicated that, under good conditions, a maximum of about *70* percent cullet can be used in the glassmaking process to make flint glass (57). Higher mixes are possible, especially for colored glass (206), and industry representatives contend that mixes of 80 percent or more are common (160). One glass manufacturer in Connecticut reportedly produced new container glass using 100 percent cullet for an extended period several years ago, but the highest level attained recently at that facility was 68 percent for making green glass. That same manufacturer reported that the biggest constraint to using more cullet was the difficulty in obtaining high-quality cullet from local suppliers (89).

Table 5-2--Specifications for Furnace-Ready Cullet

- **Only glass container glass is acceptable**
- **Permissible color mix levels-**
  - ***Flint glass***
    - ***95-1 00%* flint; O-5% amber; O-1% green; O-5% other colors**
  - ***Amber glass***
    - ***90-100%* amber; 0-10% flint; O-10% green; 0-5% other colors**
  - ***Green glass***
    - **80-100%. green; O-20% amber; O-1O% flint or Georgia green; 0-5% other colors**
- **Glass must be free of any refractory materials. Grounds for rejection include:**
  - **-presence of pottery, porcelain, china, dinnerware, brick, tile, clay, and so forth, larger than 1 inch.**
  - **-presence of more than one paticle of any of above materials larger than 1/8 inch, but less than 1 inch in a 200-pound sample.**
  - **-presence of more than two grains of quartzite, sandstone, or sand pebbles larger than U.S. 16 mesh per 10 pounds of sample.**
  - **—any day particles larger than U.S. 20 mesh or more than 50 particles larger than U.S. 30 mesh per 10 pounds of sample.**
  - **-any alumina silicate refractory heavy minersls larger than U.S. 30 mesh or more than 10 grains larger than U.S. 40 mesh per 10 pounds of sample.**
  - **-presence of zircon, cassiterite, chrome, or similar refractory particles larger than U.S. 60 mesh.**
- **Glass must be free of metallic fragments and objects, dirt, gravel, limestone chips, asphalt, concrete, and excessive amounts of paper, cardboard, wrap, plastics, etc.**
- **Large amounts of excessively decorated glass must be kept separate.**

SOURCE: Brockway, Inc., "Specifications for Furnace-Ready Cullet," unpublished manuscript (undated).

***Energy Consumption*-To** manufcture glass, four separate steps are used: melting, refining and conditioning, forming, and annealing. Energy is required to perform each step. In addition, energy is consumed in mining and transporting sand and other virgin materials. Mining and transporting can account for about 16 percent of total energy use when making glass from a mix of 15 percent cullet and the remainder virgin materials (table 5-3).

Table 5-3-Energy Consumption Associated With Manufacturing Glass (using 15% cullet)

Manufacturing component	Energy (million Btu/ton)	Percentage of total energy
Materials energy		
Glass sand	0.50	3.2%
Feldspar	0.11	0.70/0
Limestone	0.02	0.1%
Natural soda ash	1.85	12.1%
Subtotal	2,48	16.4%
Process energy		
Melting	7.6	49.7%
Refining & conditioning	1.5	9.80/o
Forming	1.3	8.50/o
Post-forming	1,3	8.5%
Handling	1.1	7.1%
Subtotal	12.8	83.60/0
Total energy	15.3	100.0?!0

SOURCE: ML. Renard, A *Review of Comparative Energy Use in Materials Potentially Recoverable From MSW,* National Center for Resource Recovery, prepared for the U.S. Department of Energy, Office of Renewable Energy, DOE/CS/20167/12, March 1982.

The use of cullet produces energy savings because the heat required to melt cullet is only about one-half to two-thirds that required to melt virgin raw materials (206). In addition, increased use of cullet saves energy because fewer inorganic additives need to be mined. For example, soda ash accounts for 75 percent of the energy used in providing virgin materials and 12 percent of the total energy cost. These energy savings are offset some by the energy required to collect, beneficiate (i.e., remove contaminants such as aluminum), and transport the cullet. If 100 percent cullet is used, the total energy savings in processing amounts to about 15 percent, and an additional 16 percent is saved by avoiding mining and transportation of virgin materials (table 5-3) (206).

Markets for Glass Products

The production of glass items experienced a severe downturn during the recession of the early 1980s. Shipments of glass containers declined 16 percent from 1980 to 1985, primarily as a result of competition from aluminum and plastics. Although glass shipments increased in 1986, they again dropped in 1987. The industry has the potential to increase shipments, however, over the long term. Glass is competitive with other container materials because of the high-quality image it imparts to a product, its microwaveability, and its recyclability (52).

Because the unit price of silica sand is relatively low, cullet prices must remain low to compete. Nevertheless, average prices for industrial sand have increased over the past few years, reflecting higher mining costs (245) and increased demand. Although the potential supply of silica sand is large, land use restrictions and zoning regulations may limit its availability locally, especially in urban and industrialized areas. Restrictions on the availability of virgin materials could bode well for increased use of cullet in glass production in some areas. Current glassmaking technology would allow a substantial increase in cullet use.

Several non-glass markets for cullet exist, including ceramics, abrasives, industrial compounds, fillers, and glassphalt.[16] Initial processing of the cullet may be more important in some of these end uses than it is for glassmaking (236).

Consistently high quality and assured supplies of cullet are essential for all glass end-use products so manufacturers can control the mixture of cullet and virgin materials and produce new glass that consistently meets buyer specifications. **Therefore, the ability to increase the proportion of cullet in most end uses will be determined by improvements in the collection and beneficiation processes.**

The need to produce a consistent color glass for buyers limits the amount of color mixing that can be tolerated. Since two-thirds of the glass made in the United States is clear and only about one-tenth is green, color separation is an extremely important factor in increasing the use of cullet in glassmaking.

An adequate mechanical color separation technology has yet to be developed. Curbside collection of color separated glass containers usually results in higher quality cullet for glassmaking than that from glass separated at centralized processing facilities, where color separation is more difficult to control because of breakage.

Beneficiation removes contaminants (e.g., pieces of aluminum) from the cullet and crushes the cullet to a size suitable for the furnace. By 1989, at least 27

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[16] Glassphalt is a product made with asphalt and glass.

beneficiation facilities, costing between $500,000 and $1 million each, will be on-line at U.S. glass container manufacturing plants. Newer facilities are significantly better at removing small pieces of aluminum (from neck rings and caps) in the cullet, thus allowing for larger proportions of cullet in the furnace feed (89). With increases in community collection of glass containers, glassmakers may build additional beneficiation facilities to assure consistent quality of the cullet supply.

Glass manufacturers in the United States have indicated a commitment to increasing the use of cullet in glass containers. In addition to those firms building new beneficiation facilities, at least one manufacturer has offered low interest loans to communities to build multi-material buy-back centers and help increase cullet supplies (236). Glass manufacturers feel that publicizing the image of glass as a recyclable material is an important factor in increasing consumption.

One end use where quality is less important is asphalt. Crushed glass can replace as much as 30 percent of the stone and sand used in a conventional asphalt mix (272).[17] Within this range, the product is of comparative strength and lower cost, taking into account revenues obtained for accepting the waste glass. Processing of glass to be used in asphalt requires only removing metal, plastic, and labels. The potential for cullet use in asphalt could be tremendous: the Nation uses approximately 1 billion tons of asphalt each year. The low cost of sand and gravel, however, limits the revenue potential of this market for cullet, especially compared with glassmaking. Therefore, cullet is usually used in asphalt only when the quality is low or the distance to a glass plant is great.[18]

Fiberglass manufacturers also have considered the use of post-consumer cullet. The Mineral Insulation Manufacturers Association, however, reports that tests of mixed post-consumer cullet in fiberglass resulted in serious melting difficulties. These difficulties were caused by a variety of contaminants in the cullet, including organic matter, plastics, metals, and non-container glass (152). The manufacture of fiberglass, like glass containers, is subject to strict raw materials specifications. Although fiberglass manufacturers could use glass cullet in their process, it would need to meet standards at least as strict as those for cullet use in glassmaking and additional expenditures would be required for storage silos and materials handling equipment. Therefore, the near-term potential for post-consumer cullet use in fiberglass manufacturing on a national basis is relatively low.

The Aluminum Industry

Although aluminum comprises only about 1 percent by weight of MSW (about 1.8 million tons), its relatively high economic value can make it an important component of recycling programs. About 76 to 79 percent of the aluminum in MSW consists of aluminum cans, or used beverage containers (UBCs). The remainder consists of other aluminum packaging, such as foil and semi-rigid containers, discarded appliances, lawn furniture, and other items.

Aluminum can recycling has increased during the last two decades because of increased demand for aluminum, concerns about litter, the effects of deposit laws, and increases in energy prices (primary aluminum production is very energy-intensive). The aluminum that is diverted from MSW in the United States is almost totally used beverage containers. In 1988, 77.9 billion aluminum beverage cans were shipped and 42.5 billion cans weighing about 752,500 tons were recovered, representing an aluminum can recovery rate of about 55 percent (4). In terms of all aluminum discarded in MSW, this represents a 43 percent recovery rate—virtually all achieved through private collection efforts.[19]

Estimates of recovery rates in Europe and Japan for all aluminum in MSW (not just UBCs) range from 18 to 40 percent, with the highest rates in the Netherlands, Italy, West Germany, and Japan (194). These rates are lower than the U.S. rate, in Dart

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[17] The Asphalt Institute believes that 20 percent may be a more realistic maximum, because of the lower bonding properties of glass relative to stone.

[18] New York City uses cullet that cannot be sold for glassmaking in its asphalt plant to substitute for up to 20 percent of the sand and gravel. It pays $10 per con for the sand and gravel. The quality of the glassphalt is comparable to regular asphalt (28). In addition, a test glassphalt road in Baltimore has held up well in urban traffic for the last 5 years (10,210).

[19] Franklin (81) reported a recovery rate of 25 percent for aluminum from MSW for 1986. The discrepancy between their estimate and that of the Aluminum Association is at least partly because Franklin estimated that less than 1/2 of the aluminum in MSW is in the form of UBCS (81).

because the use of aluminum beverage cans is lower in Europe and Japan. In Japan, estimates of recovery are between 25 and 32 percent for all aluminum (167,194) and about 40 percent for UBCs (49). Sweden has a deposit system on aluminum cans (ch. 8) and has achieved over 70 percent recovery (230,231).

In the United States, the recovered scrap metal is either returned to the domestic aluminum industry to be recycled into semifabricated products (e.g., can sheet) or castings, used as an oxidizing agent in steelmaking, or is exported. UBCs make up a substantial portion of this scrap. Of the UBCs diverted from MSW, 93 percent is used directly by can sheet manufacturers in the production of new can sheet. The Aluminum Association estimates that in 1988 713,000 tons of UBCs were consumed in domestic production of aluminum mill products and other uses and about 35,500 tons were exported.[20]

The production of secondary aluminum from post-consumer or old scrap by both primary and secondary producers in 1988 was 1,152,000 short tons (247). UBCs provided 60 percent of the raw material for this production, with the remainder coming from shredded auto parts and other old scrap such as old aluminum siding. This scrap material generally is bought and sold through a well-developed aluminum scrap dealers network.[21] Aluminum recovered from old scrap accounted for 20 percent of apparent U.S. consumption of aluminum in 1988, while net imports accounted for 7 percent (248).

Aluminum is imported in ingot and mill product forms primarily from Canada, with additional amounts from Japan, Venezuela, Brazil, and many other countries. Despite these imports, the United States has long been and continues to be the largest producer of primary aluminum in the world, as well as the world's largest market for aluminum products.

In 1989, 10 companies were making can sheet in the United States, and they were the major consumers of aluminum UBC scrap diverted from MSW. The majority of the UBC scrap is processed and melted directly by the can stock producer. In some cases, the material is shipped to another location, usually a secondary smelter, where it is melted and then returned to the can stock producer for final processing into new can sheet. More than 50 secondary aluminum producers are in operation in the United States.

The raw material for the primary aluminum producers is alumina, a refined product of bauxite. Only three sites in the United States refine bauxite into alumina. Small amounts of bauxite are imported—primarily from Guinea, Jamaica, and Australia-for making alumina in the United States, but most U.S. producers import alumina directly. Alumina is imported primarily from Australia, Jamaica, and Suriname. In many cases, U.S. aluminum companies own shares of bauxite and alumina operations in these exporting countries. Costs for transporting bauxite and alumina to the United States range from about $3/metric ton (Guinea to U.S. Gulf coast) to almost $20/metric ton (Australia to U.S. east coast) (249). One benefit of recycling aluminum is that it helps reduce dependence on foreign sources for raw materials.

Energy Consumption

Aluminum recycling has a natural economic impetus because of the high electrical energy costs associated with producing primary aluminum. The soaring energy costs in the 1970s further enhanced the energy conservation benefits. The recovery of aluminum from scrap saves about 90 to 95 percent of the energy required to produce the same product from alumina (195,206).

In the United States, electricity can account for up to 50 percent of the total cost of producing aluminum from virgin raw materials (155). For 1988, estimates of the U.S. Bureau of Mines show that the average electricity cost for U.S. aluminum smelters is 19.5 cents per pound of aluminum, compared with the total smelting cost of 59.1 cents. Energy also is required to mine, beneficiate, and transport raw materials such as alumina, aluminum fluoride, cryolite, calcinated petroleum coke, and electrode

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[20] The Bureau of Mines' statistics on aluminum differ somewhat from those reported by the Aluminum Association, because of differences in accounting methods, definitions, and reporting procedures.

[21] The aluminum industry, like the paper industry, recycles a significant amount of scrap generated in the production of intermediate aluminum products (prompt industrial scrap); this scrap is not included in the statistics reported here. In 1988, 1.21 million tons of new scrap was consumed by the aluminum industry, according to the Bureau of Mines (247).

pitch. Smelting, however, is the most energy-intensive step in the process. The cost of smelting accounts for 85 percent of the total cost to produce aluminum in the United States.

In contrast, when aluminum is recovered from scrap the electrolysis step is eliminated, thus saving energy. In addition, none of the mining and beneficiation steps are required. Energy is required, however, to collect and transport the scrap. Estimates of energy consumption during secondary production range from 8.7 to 11.3 million Btu/ton, including the energy used for shredding and transportation (206).

Technologies of Aluminum Production

Bauxite, the ore from which alumina is made, is refined by dissolving it in a strong alkali solution, from which aluminum trihydrate is extracted to produce alumina, an oxide of aluminum. Primary aluminum production begins at the smelting stage, in which the alumina is dissolved in a large pot containing a molten bath of cryolite, and electrolysis is used to recover 99.7 percent pure aluminum. The aluminum is then alloyed with various elements to produce the qualities desired for specific end uses. This alloying stage is critical for most uses of aluminum.

In secondary aluminum production, scrap aluminum is melted in a furnace, to which alloying elements are added as needed, and subsequently cast into ingots or other aluminum products. New scrap is easy to recycle because the alloys are known and the user can readily separate it by alloy. Aluminum UBC scrap, a combination of similar alloys, is also easily reused, usually by melting and reforming it into new sheet stock. General] y, the only other material added to the furnace during melting of UBC scrap is primary aluminum, to provide the proper alloy and specifications for the final end-use product.

The presence of mixed alloys that may be found in different discarded aluminum products can pose a problem in the secondary production process. It is essential to control the alloy mix to meet strict product specifications.

The primary aluminum industry, in addition to being energy-intensive, is also capital-intensive. The Bureau of Mines (249) estimates that the world average cost to build a new aluminum smelter would range from $3,000 to $4,000 per metric ton of capacity. Consolidated Aluminum Corp.. however, announced the construction of an aluminum recycling facility in the United States in September 1988. The facility will have the annual capacity to produce about 45,000 metric tons of aluminum for a capital cost of $15 million, or about $330 per metric ton of capacity (204).

Markets for Aluminum

The United States is not only the largest aluminum producer, it is also the world's largest market for aluminum, consuming about one-fourth of the world's primary production in 1988. Aluminum industry shipments in the United States exceeded 8.2 million tons in 1988. By market, containers and packaging accounted for the largest share (27 percent) of shipments. Following in importance were transportation (21 percent), building and construction (18 percent), electrical (9 percent), consumer durables (8 percent), and other domestic uses (6 percent).[22] Exports represented 11 percent of U.S. industry shipments in 1988.

Most aluminum produced at secondary smelters is consumed in foundries to produce castings, and a smaller portion is used in steel mills as a deoxidizer. Because of the alloys used to make can sheet, UBC scrap is usually used by can-stock producers to make new can sheet (although other alloys can be produced by additional processing).

Sheet for beverage and food cans constitutes the largest share of the aluminum container and packaging sector, accounting for 82 percent of total shipments in 1988. The remainder consists mainly of foil for semi-rigid food containers, packaging, and consumer foil use. Shipments of aluminum sheet for cans increased from 925,500 tons in 1976 to 1,849,000 tons in 1988, mostly by displacing competing steel and glass, primarily for beer and soft drink cans. Aluminum cans now account for just over half of the entire beverage container market, but 95 percent of the beverage can subset of the market, compared with only about 5 percent of the food can market. Glass retains about one-quarter of the beverage container market, plastic nearly one-fifth,

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[22] Market breakdowns provided by the Aluminum Association (4).

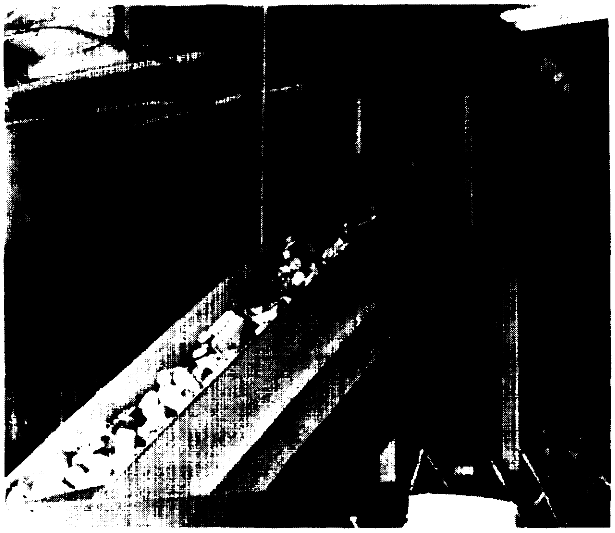

Photo credit: Office of Technology Assessment

Used beverage containers made from aluminum, shown here just before being compacted and baled for shipping, are recycled at a relatively high rate because of aluminum's high economic value.

and steel cans less than one-twentieth. Although the number of aluminum beverage cans has increased, cans now weigh less so total weight has dropped from 0.69 ounces per can in 1976 to 0.57 ounces per can in 1988.

Demand for aluminum beverage containers is expected to remain strong, because beverage manufacturers and retailers find aluminum a cost-effective packaging material. Growth in aluminum's container market share, however, is expected to slow (168). Some increased competition may also come from plastic, depending on the plastic industry's success in increasing the recycling and recyclability of their products.

Because all new primary aluminum production capacity is being constructed in countries with low electricity costs compared to the United States, U.S. aluminum producers will place increased emphasis on aluminum recycling. This will be particularly important if acid rain legislation is passed.[23] **As a result, post-consumer scrap can be expected to maintain its attraction for aluminum producers in the United States into the foreseeable future. In summary, the major barriers to increased recycling of aluminum from MSW are in the collection and transportation networks, the methods of segregating different forms of aluminum scrap, and the technologies for removing contaminants, such as food and dirt, from the scrap prior to melting.**

Batteries

Two general types of batteries can be present in MSW—household (or dry cell) batteries and lead-acid automotive batteries. Recycling of these batteries is discussed here, while efforts to reduce the amount of potentially toxic substances in them (e.g., mercury) are discussed in chapter 4.

Household Batteries

Over **2** billion household batteries of all shapes and sizes are sold each year in the United States (153). Batteries can be classified into seven types: carbon/zinc (or LeClanche), alkaline or alkaline/manganese, mercury or mercuric oxide, silver oxide, zinc/air, nickel/cadmium, and lithium. Household batteries are a concern in the MSW system because many contain mercury or other potentially toxic metals (e.g., cadmium, nickel, silver). Some contain lithium, a metal that is reactive in the presence of water (140,153). These metals serve various purposes in the batteries. Mercury (mercuric oxide), for example, is used as a positive electrode in hearing aid batteries. It also is used to coat zinc electrodes, to prevent production of a gas that reduces battery performance, and to reduce electrical impedance and allow zinc to produce electricity more easily (16).

The amount of mercury in batteries has declined substantially in recent years (173) (ch. 4). The industry is now using proprietary substitutes, at least in part, for the mercury coating on zinc electrodes. Mercuric oxide batteries also are slowly being replaced by zinc/air batteries; between 1981 and 1987, the market share for mercuric oxide batteries declined from 72 to 58 percent, while the market share for zinc/air batteries increased from 14 to 40 percent. Zinc/air batteries, however, are sensitive to humidity and to fluctuations in oxygen availability,

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[23] About one-half of U.S. aluminum production capacity is supplied with power from utilities that would be affected by acid rain legislation (44). Depending on what legislative provisions are enacted, power rates to smelters could rise by 12 percent. As a result, costs could rise by an estimated 2.5 to 4.0 cents per pound for most aluminum smelters and by as much as 7,7 cents per pound for those in Ohio and West Virginia (19).

two constraints that do not plague mercuric oxide batteries.

Separate collection of household batteries occurs to a limited extent in Japan, the United States, and several European countries (box **5-C).** Batteries can be separated by hand (based on size, shape, weight) at households, retail outlets, or drop-off centers, and then sent to a refinery for processing. Batteries also can be segregated to some extent from mixed MSW at centralized processing facilities. Rechargeable batteries that are built directly into appliances, however, may be difficult to remove and collect.

Several collection programs exist in the United States (226), including the New Hampshire/Vermont Solid Waste Program; the Environmental Action Coalition's program in New York City; the Household Hazardous Waste Project in Missouri; and programs in Bellingham, Washington, and Hennepin County, Minnesota. In general, batteries are collected in retail stores where new batteries are sold. The New Hampshire/Vermont program collected 9 tons of batteries from April 1987 through November 1988. The American Watchmakers Institute also has been collecting button batteries and using proceeds from their sale to fund scholarships for teaching watchmaking.

At least two organizations-the American Association of Retired Persons and the National Capital Poison Center--oppose legislative proposals to encourage collecting button batteries because of fears that children might ingest more batteries. They also fear costs of hearing aid batteries would increase (139,150). One suggestion is that States and the battery industry need to jointly sponsor research on the health and environmental risks associated with different management options and on the development of new processing technologies (1 34).

In theory, collected batteries can be processed to recover the metals. To recover mercury, for example, batteries can be heated to about 1,200° F to open them up and volatilize the mercury, which is then cooled, condensed, and refined (234). The steel casings of the batteries then can be removed and the remaining silver and zinc can be dissolved with hydrochloric acid. This precipitates salver chloride, which is then reduced to silver powder (234). The remaining portion can be ground up, and some of the ferrous metals can be recovered with magnets.

In the United States, collected batteries are sent to at least two commercial processing facilities. At the Mercury Refining Co. (Mereco) in New York, mercuric and silver oxide batteries are processed to recover mercury and silver (153,1 54). Nickel/cadmium batteries are marketed to facilities in Europe. Lithium batteries are sent to a company in Buffalo, New York, that treats the lithium to make it less reactive and then sends the batteries to hazardous waste landfills. Mereco also takes carbon/zinc, zinc/air, and alkaline batteries; until technologies for processing these are economical, however, it is cheaper to send them to a hazardous waste landfill. The Environmental Pacific Corp. in Oregon takes in all batteries (67,260). The company either recovers metals itself or sells the batteries to smelters for metals recovery. Residues from processing are sent to smelters or hazardous waste facilities for further treatment.

Lead-Acid Automotive Batteries

About 75 million lead-acid automotive batteries reach the end of their useful lives each year in the United States; by 1990, this number is expected to reach 80 million (133). These batteries are of particular concern because all automotive batteries contain lead and sulfuric acid, which pose potential environmental and health risks when landfilled or incinerated.

Historically, used auto batteries have been collected and recycled for their lead content, as well as for the plastic casings. (About half of a battery's weight, 18 to 19 pounds on average, is lead.) Recently, however, several factors reduced the recycling rate for auto batteries and increased the prospects that some may be ending up in MSW landfills.

Recovery of auto batteries is not mandated in most States, so the primary motivation for collection is profit from the sale of the lead.[24] The price for this scrap lead depends on the price of unwrought lead and the cost of processing scrap lead into usable forms. After 1979, lead prices dropped precipitously

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[24] Rhode Island placed a $5 charge in lieu of trade on all vehicle batteries; Minnesota, Pennsylvania, Florida, and Wyoming all have legislation requiring that retailers who sell batteries accept spent batteries; and California has regulations governing the management of lead-acid storage batteries.

Box S-C—Household Battery Management in Europe and Japan

Collection and Recycling in Europe

Battery collection programs have been initiated in at least 11 European countries. Some are run by industry and/or trade associations, and some by municipalities (137,183). In the Netherlands, for example, mercuric oxide batteries have been collected since 1978, and most communities now have depots for batteries (14,122).

The presence of collection systems, however, does not mean that batteries are recycled. In the Netherlands and Denmark, batteries are stored temporarily, sent to a manufacturer for reprocessing, or exported to West or East Germany, where they are put in salt mines or landfilled with industrial wastes (115,137). This is partly because recycling plants designed for batteries have not demonstrated long-term economic success. Two plants in France and one in Sweden were unable to operate profitably on the basis of recovering mercury alone. Several institutes are conducting research on sorting and processing technologies (e.g., 256,257).

The European Community Commission

In *1987, the* European Community Commission issued a proposal that called for labeling batteries, collection of used batteries, and prohibitions on the marketing of certain batteries. The proposal also called for a 70 percent reduction in mercury in batteries (85 percent for alkaline/manganese batteries), replacement of mercury batteries by zinc air and lithium batteries, and deposit systems (69). The battery industry, which previously agreed to reduce mercury in alkaline/manganese batteries by 85 percent, estimates that the mercury in batteries discarded in Europe will decline by 86 percent between 1985 and 1992 (69).

Household Battery Management in Sweden

The Swedish Environmental Protection Board, concerned about consumption of mercury from fish by children and pregnant women, estimated that up to one-third of background levels of mercury during the late 1970s and early 1980s came from incineration of batteries (106). Incineration of wastes in general was estimated to account for 55 percent of known mercury emissions in Sweden in 1985 (138,174). However, mercury also comes from anthropogenic emissions from continental Europe and from natural emissions (e.g., geothermal areas) (138).

In 1983 the government began a voluntary collection program that encouraged the 27 cities with incinerators to collect batteries (14,15,106,1 15,174). By 1987, the government's goal of collecting 75 percent of mercury oxide, alkaline, and nickel/cadmium batteries had not been met, so it expanded the effort into a nationwide voluntary program, including extensive education and the placement of collection receptacles at offices and public areas. The educational campaigns and management of collected batteries are funded with a surcharge on all mercury oxide, alkaline, and nickel/cadmium batteries. The government is studying mandatory deposit systems, and in 1989 it banned all alkaline batteries containing over 0.025 percent mercury, effective in 1990 (137).

Some collected carbon/zinc batteries are sent to ordinary landfills in Sweden (sometimes to separate areas at the landfills) (137,173). All other batteries are sent to the SAKAB Mercury Distillation Demonstration Plant. Almost 300 tons of batteries are now in storage at SAKAB. Nickel/cadmium batteries are sorted and sent to another facility for recovery of the nickel and cadmium.

The SAKAB Demonstration Plant was built to test the feasibility of recovering mercury from batteries; mercury oxide batteries were used because of their high concentrations of mercury (106). The plant handled 100 kilograms per day. It is not operating now because it was not commercially viable at that size; the parent company, however, is still interested in developing the facility (137). Concerns were expressed that manual sorting would increase health risks for workers (14,1 5).

The effect of collecting batteries on the levels of mercury in incinerator emissions is not clear. Three years after the collection program began, the amount of mercury emitted from the Stockholm incinerator reportedly had declined 80 percent, to a total of 150 kilograms in 1986 (106). The pollution controls at the facility also were upgraded at this time, however, so it is impossible to determine how battery collection affected emissions.

West Germany: Voluntary Agreement

In 1987, the German government and a trade association representing the electrical industries reached a voluntary agreement regarding batteries (87,93). Manufacturers and importers agreed to reduce mercury levels in alkaline/manganese batteries from current levels of 0.5 percent by weight to 0.15 percent by 1990, with an option to reduce the level to less than 0.10 percent by 1995. Manufacturers also agreed to accept returned button batteries (e.g., from watch-makers and camera shops), although there is some confusion about whether other batteries must also be collected.

If the number of returned batteries is deemed insufficient, the government could impose a mandatory deposit on the sale of new household batteries (ch. 8). The Federal Environmental Agency is concerned that after the minimum mercury concentration per alkaline/manganese battery is attained, the total level in all batteries will increase again as the market share of these batteries increases.

If the European Community Commission proposal is adopted, then this more stringent German agreement might be dropped because it would interfere with trade within the European Community.

Collection and Recycling in Japan

Past experience with Minamata disease, a debilitating human disease caused by mercury consumption, makes mercury a major issue in Japan (106). In the early 1980s, the government reached an agreement with manufacturers to reduce the amount of mercury in batteries by five-sixths between 1983 and 1986. Two household battery collection programs also were established. About three-fourths of Japanese municipalities collect cylinder-shaped batteries, while battery manufacturers collect button-shaped batteries at retail stores. However, collection rates have been low (9 percent by weight of cylinder-shaped batteries and 27 percent by number of button-shaped batteries) and did not increase during 1987 and 1988 (179). As of 1985, over 750 municipalities simply stored cylinder-shaped batteries, 47 mixed them with concrete and landfilled the material, and about 550 sent them to a processing facility located at Itomuka, on the northern island of Hokkaido. Button-shaped batteries also were shipped to Itomuka.

The Itomuka facility is a demonstration mercury recycling plant that began operating in October 1985. It is a joint venture between the Clean Japan Center (CJC), Mitsui Metals Engineering Company, and Nomura Kosan Company (50,109). Participating municipalities pay transportation costs and a tipping fee to cover operating costs. The plant's purpose is to demonstrate the technical and economic feasibility of recycling mercury-containing wastes—mostly batteries, but also fluorescent lamps, thermometers, and mirrors (109). The plant can handle 20 tons per day. Batteries are separated by size and shape, and then a proprietary process separates cylinder-shaped batteries by weight. Thermal treatment and recovery techniques are used to separate metals (e.g., volatilization, distillation, and condensation of mercury; magnetic recovery of ferrous materials). Gas emissions are treated with a wet scrubber and electrostatic precipitator (109). Wastewater is evaporated until salts are crystallized out, then recirculated instead of being discharged. OTA was unable to obtain data on air emissions.

The plant processed an estimated 7 percent of the household batteries used in Japan annually, recovering mercury, zinc and manganese (in combination), and iron. Problems have occurred with the condition of incoming batteries, fluctuations in supply, and the battery dismantling process (50). As of November 1988, the facility was operating at a loss (179). In particular, the zinc residues (consisting of zinc, manganese, and other materials), which make up 54 percent by weight of the incoming batteries, are not being marketed because the price of zinc had fallen too low. The arrangement with the CJC is scheduled to end in August 1989.

Whether these collection efforts have had any effect on mercury levels in remaining MSW is unclear. A more important factor may be the significant decline in mercury used in household batteries.

from more than 50 cents to about 18 cents per pound. As a result, many scrap dealers could not realize a profit from the collection and sale of discarded automotive batteries.

In addition to low prices, the costs of collecting and processing batteries increased as a result of environmental regulations. For secondary smelters,[25] operating costs of full compliance with environmental regulations existing in 1988 were estimated at 6.8 cents (in 1987 dollars) per pound of refined lead produced (118).[26] Also, as of January 1985, EPA designated spent lead-acid batteries as a hazardous waste under RCRA. Costs associated with RCRA compliance can range from $100,000 to $200,000 per processing facility. Many scrap collectors and dealers refused to continue handling batteries for fear of incurring liability under Superfund.

The specter of increasing costs, ever-increasing regulation, and low lead prices caused a significant reduction in the number of people willing to

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[25] Secondary lead smelters are the facilities that reprocess the lead from spent batteries

[26] Environmental regulations considered include those for particulates, water, and health and safety. The particulates standard of 1.5 micrograms per cubic meter of lead in ambient air was used in the calculation.

participate in battery recycling. This caused a reduction of U.S. secondary lead smelting capacity from 1.4 million tons per year in 1980 to 882,000 tons per year in 1986.

On the other hand, in 1987 about 1.25 million tons of lead were consumed in the United States. Automotive batteries are the largest end-use, accounting for more than three-quarters of total consumption. Most of the demand is supplied by domestic smelters, and about two-thirds of this is from secondary smelters, despite the reduction in secondary smelting capacity. In 1987, 725,000 tons of lead were produced at secondary smelters from old scrap (about 90 percent from batteries), while 412,000 tons of lead were produced at primary facilities.[27] Significant quantities of lead are also imported, principally from Canada and Mexico, amounting to about 15 to 20 percent of U.S. consumption. The United States also imports some batteries for the replacement market and as original equipment in imported autos and exports about 2.5 to 3 million new batteries per year.

What happens to the unrecovered batteries has not been documented. Between 1980 and 1986, an estimated 98 million batteries containing 900,000 tons of lead went unrecovered (1 84). Some probably are being discarded in MSW, some are being stored in garages or elsewhere, and some may have been exported as scrap and toll smelted in Mexico.[28]

Recycling rates for auto batteries are difficult to calculate. In 1965, the recycling rate was estimated to have reached a peak of 96.6 percent (201). In the early 1980s, the estimated rate dropped sharply to a low of about 57 to 66 percent. Recycling rates then began to rise again, reaching an estimated 80 percent or more between 1984 and 1986 (128,269).[29]

At a 1986 rate of 80 percent, a reported 556,200 tons of lead was recovered from discarded batteries, representing 44 percent of total U.S. lead consumption. Obviously, auto batteries are a very important source of lead, despite a relatively large lead reserve base.[30]

The amount of unrecovered batteries may have decreased during 1987 and 1988, as a result of increases in lead prices and high demand (figure 5-7). Average annual lead prices increased from 19 cents per pound in 1985 to 36 cents per pound in 1987, as demand increased by 90,000 tons (248).[31] Corresponding lead recovery from batteries increased from 542,800 tons in 1985 and 556,200 tons in 1986 to 648,900 tons in 1987. Some portion of this increase is very likely to have come from ' 'inventoried" batteries stored in garages and basements, so recycling rates calculated using historical methods could be misleading. The increase could also be attributable to the enhanced efforts of secondary smelters and battery manufacturers to collect and recover discarded batteries to help reduce the public's concern about batteries entering landfills. Recovery rates for 1987 are estimated at about 82 to 83 percent (133,184).

Continued increases in battery recycling may be evidenced by a rise in the utilization of secondary smelter capacity from 76 percent in 1986 to 83 percent in 1987. Concern exists about the adequacy of secondary smelter capacity, however. Some analysts worry about the allegedly poor financial condition of some firms operating the smelters. About 110,000 tons of existing secondary capacity will probably be lost if more stringent water protection regulations are enacted. However, planned expansions will increase capacity to about 1 million tons by the early 1990s. Because battery manufacturers view secondary smelters as an important component of the battery consumption chain, they are interested in expanding U.S. capacity to recover lead from discarded batteries.

To this end, certain battery manufacturers have approached the two major primary lead producers, Doe Run and Asarco, about refitting currently closed primary smelters to process battery scrap. Prefeasi-

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[27] An additional 58,000 tons or so of lead were produced from purchased new scrap, including drosses (this is in addition to home scrap).

[28] Some secondary smelters have agreements with landfill operators to accept lead-acid batteries that do reach the landfill, but the extent to which this occurs is unknown (143).

[29] One study (201) estimated a rate of 69.5 percent in 1985, but another analyst (269) speculated that this lower estimate was based on data which have since been revised.

[30] According to the Bureau of Mines, the United States accounts for nearly 20 percent of the world's lead reserve base.

[31] Although 36 cents was the posted price in 1987, analysts believe that producers were offering substantial discounts to consumers.

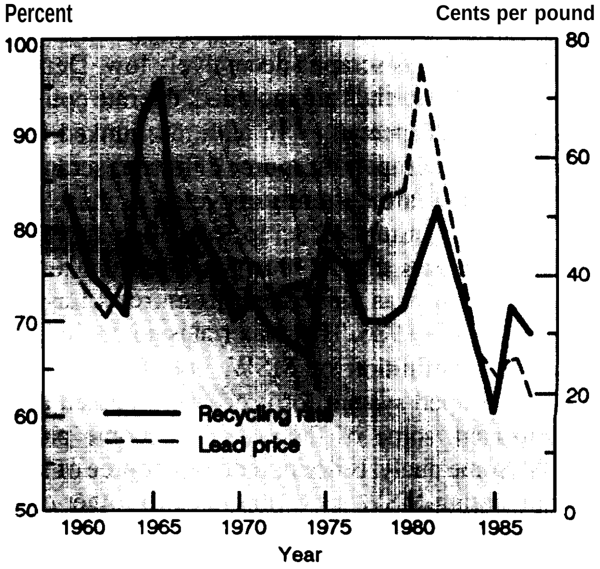
bility studies were conducted in 1988 on converting the Buick smelter in Missouri, which has capacity to process 140,000 tons per year of primary lead. The decision has been made to retrofit Buick to accept battery scrap, but the work is not expected to be completed until mid-1990. Similar retrofits are being considered for primary smelters in Glover, Missouri; East Helena, Montana; Omaha, Nebraska; and El Paso, Texas.

Another avenue for discarded batteries is the export market. Despite EPA's designation of spent batteries as hazardous waste, the United States is exporting this lead scrap to Brazil, Taiwan, and Canada.[32] In 1986, about 65,000 tons of scrap batteries were exported. Some of this scrap is used to produce new batteries that compete with U.S. producers.

The proliferation of discount battery outlets has increased the incidence of home battery replacement. Because the home mechanic may not be aware that spent batteries can be returned and recycled, there is a greater chance that they will not enter the collection chain. Unless the home mechanic is educated or otherwise induced to return the spent battery to the retailer or a collection center, batteries will continue to elude the recycling process.

In all member counties of the Organization for Economic Cooperation and Development (OECD), consumers can trade in old automotive batteries for a discount off the purchase of a new battery (183). The trade-in discount essentially amounts to a deposit that is refunded when a new battery is purchased. Statistics on recycling rates in all OECD countries are not available. The Association of European Accumulator Manufacturers estimated the average European battery recycling rate at about 80 percent in 1986-87; the rate for the Federal Republic of Germany was estimated at 75 percent in 1986 (85). In comparison, normal battery recycling rates in Japan have been estimated as nearing 100 percent (1 12). It is interesting to note, however, that when lead prices declined in 1986, Japanese recovery rates dropped to about 90 percent. It is likely that spent batteries were stockpiled for later sale at higher prices.

Figure 5-7-Battery Recycling Rates and Lead Prices



SOURCE: Putnam, Hayes & Bartlett, Inc., "The Impacts of Lead Industry Economies and Hazardous Waste Regulations on Lead-Acid Battery Recycling: Revision and Update," prepared for Office of Policy Analysis, U.S. Environmental Protection Agency (Washington, DC: September 1987).

Iron and Steel Scrap

The amount of ferrous (iron-based) scrap in MSW was estimated to be 11.0 million tons in 1986, or 7.0 percent of total gross discards (81). About one-fourth (2.8 million tons) of the ferrous scrap fraction consisted of steel packaging such as food and beverage cans. Another one-fourth (2.8 million tons) consisted of major appliances (i.e., "white goods"), and the remainder was products such as small appliances, toys, tools, and furniture. Serious questions have been raised about the accuracy of these estimates, particularly concerning the kinds of products included in the definition of MSW (ch. 3). Industry representatives contend that these estimates seriously understate the amount of ferrous material in MSW by excluding junked automobiles, office equipment, and worn out fixtures from commercial and institutional establishments.

According to the Franklin estimates, only about 400,000 tons of ferrous scrap were recovered from

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[32] Spent batteries that are shipped for recycling do not require a manifest for domestic shipments (see 40 CFR 266.80). and thus are not subject to the RCRA requirement in Sec. 3017 for bilateral agreements for the export of hazardous waste.

MSW in 1986, a recovery rate of only 3.6 percent. Most of this consisted of packaging (100,000 tons) and white goods. A recovery rate of only 3.6 percent for MSW ferrous scrap is deceptively low. Depending on what materials are included, the rate could be higher than 20 percent.[33] In addition, junked automobiles are an important source of ferrous scrap, and large amounts are currently recycled in the United States. The Institute of Scrap Recycling Industries (ISRI) estimates that as much as 8 million tons of ferrous scrap was generated from recycling old automobiles in 1986. This material is not included in Franklin's definition of MSW, but if the current, well-developed system for processing junked autos deteriorated, some of them could become part of MSW. Some analysts do include this source of scrap in calculating MSW recycling rates for other countries (e.g., for Japan; see appendix).

Reported recovery rates for ferrous scrap from MSW in other countries vary greatly, ranging from 9 percent in China to more than 40 percent in Belgium and Luxembourg; countries with more iron ore reserves tend to have lower rates (167). How much of these amounts refer to industrial scrap, however, is unknown.

The Franklin estimate of 400,000 tons of ferrous scrap recovered from MSW in the United States is a relatively insignificant portion of the total ferrous scrap consumed in the United States. The total amount of ferrous scrap recovered from all sources in the United States amounted to about 66 million tons in 1986. Almost three-quarters of that total was consumed by the steel industry, one-quarter was consumed by the ferrous castings industry, and a small portion was consumed in uses such as copper precipitation and ferroalloys production. In addition, 12 million tons of ferrous scrap were exported in 1986, principally to the Republic of Korea, Japan, Turkey, Spain, and Taiwan (36).

Technologies for Using Ferrous Scrap in Steelmaking

Some of the ferrous scrap recovered from MSW is prepared for shipping by baling-the scrap is flattened and packaged to produce bales that weigh around 75 to **80** pounds per cubic foot. The density and packaging of the scrap influence the transportation costs and consequently the economics of recycling. Transportation cost is an extremely important factor in the recycling of ferrous scrap because the scrap has a relatively low value per ton.

In the past, scrap was melted primarily at mills owned by large integrated steel companies (i.e., those owning iron ore mines, ore pelletizing operations, coke ovens, blast furnaces, steelmaking furnaces, and steel fabricating plants). These mills melt the scrap material in blast furnaces along with iron ore and coke to produce hot metal. Scrap is also used in basic oxygen or open-hearth steelmaking furnaces along with hot metal to produce raw steel.

Electric arc furnaces (EAFs), developed around the turn of the century, are seeing increased use as a result of advances in the technology during the last 20 years. Modem EAFs reduced the time needed to produce a ton of steel from 180 to 70 minutes and reduced the electricity consumption from 630 kwh per ton to 430 kWh per ton (63). The reduced electricity consumption makes raw steel production by melting scrap in EAFs considerably more economical (approximately 25 percent) than by the iron ore-blast furnace-basic oxygen furnace route (124). EAFs use virtually 100 percent scrap to make steel. About 60 percent of all the ferrous scrap now consumed in the United States is melted in EAFs.

The improvements in EAF technology have nurtured the rise of "minimills.' Minimills use relatively small EAFs (100,000 tons per year capacity for a minimill operation v. 2 million tons per year for an integrated producer) to produce certain steel products. These mills are not integrated, and because they are not dependent on iron ore supplies they can be located away from traditional steelmaking loca-

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[33] Franklin does not estimate the recovery of white goods separately. However, if all of the remaining 300,000 tons of ferrous scrap recovered were white goods, then the implied recovery rate for white goods would be only about 11 percent. However, the steel industry estimates that 75 percent of white goods are collected separately and routinely delivered to auto shredders for processing (219). This would mean that 2.1 million tons of white goods were recovered, plus the 100,000 tons of packaging estimated by Franklin to have been recovered, as well as an additional 100,000 tons of miscellaneous ferrous scrap recovered from separation at waste-to-energy plants, as estimated by the steel industry. This total of 2.3 million tons of ferrous scrap represents a 21 percent recovery rate.

tions. This flexibility has helped improve productivity and lower costs; minimills can produce their products for about 15 percent less than integrated steel producers (158). The largest advantage enjoyed by the minimills, however, is in the capital cost of building a mill. The Bureau of Mines (37,245) estimates the capital cost per annual ton of raw steel capacity is less than $400 for EAF production from scrap v. $1000 for the iron ore-blast furnace-basic oxygen furnace route.

***Detinning*-The** major source of **post-consumer** scrap steel from MSW is "tin cans, " which are actually steel with a light tin coating intended to prevent rusting. However, the tin is generally considered an undesirable contaminant in steelmaking, so these cans must be detinned (as well as cleaned of other contaminants such as glass and aluminum). In the detinning process, the tin is removed either chemically or electrolytically. Tin residues typically cannot exceed 0.05 percent if the can is to be remelted into steel.

Energy Savings—Estimating current energy savings associated with producing steel from scrap v. iron ore is difficult because the relevant data are mostly from studies performed in the 1970s. The estimates presented here are averages of a mix of steelmaking processes; the mix is based on data from the 1970s and is not representative of present industry conditions.

Energy savings associated with producing raw steel from scrap v. ore were estimated to average around 75 percent, based on the 1970s data for an EAF using 100 percent scrap (206). However, the savings for the production of finished steel were estimated to be lower, about 45 percent. The energy used to mine and process the ore was estimated to be about 3 percent of the total energy cost to produce finished steel. When the total amount of energy required to mine, beneficiate, transport, and process both ore and scrap was included, the savings from using scrap were estimated to be between 47 and 59 percent (206).

More recent data indicate that energy requirements in the steel industry declined by about 16 percent from 1972 to 1981. At least some of this decrease can be attributed to the increased use of EAFs. Also, further energy efficiencies have been gained. In 1983, the total energy required to produce a ton of raw steel amounted to 21.7 million Btus, down from 25.7 million Btu in 1973 (245). Energy from coal amounts to about half of the total, and EAFs use most of their energy in the form of electricity and natural gas.

Overall Use of Scrap

Scrap is an important raw material to the steel industry. In 1986, U.S. steel mills consumed 49.7 million tons of scrap and 44.3 million tons of new pig iron (made from iron ore) to produce 81.6 million tons of raw steel. Franklin estimates that only 0.4 million tons of the ferrous scrap consumed to produce raw steel in 1986 was recovered from MSW.[34] Almost all of the scrap consumed was obtained from sources other than MSW—about 40 percent from home scrap; 40 percent from old scrap; and 20 percent from prompt industrial scrap. The old and prompt industrial scrap are purchased from brokers, dealers, and company-owned plants.

Several trends have caused an increase in the importance of purchased obsolete and prompt industrial scrap. The first is the growing use of EAFs by minimills. EAF capacity in the United States has grown from 23 percent of the total in 1978 to 36 percent in 1988. Over 200 EAFs are in operation in the United States, and they produced 27 million tons of carbon steel in 1987.

The second factor causing increased demand for scrap is the use of continuous casting, which now accounts for about 60 percent of raw steel production (36). Continuous casting reduces the generation of home scrap, compared with that of traditional ingot casting, and increases the yield from about 75 to 88 percent. Because a certain amount of scrap is used in basic oxygen steelmaking processes for temperature control, the advent of this technology has increased the demand for purchased scrap. These changes can be seen by comparing the consumption of purchased scrap and home scrap with the production of raw steel, steel mill products, and steel castings. In 1982, 24 million tons of home scrap and 24 million tons of purchased scrap were consumed to produce steel mill products and castings. In 1987, despite an increase in raw steel and castings production, use of

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[34] The steel industry estimates that 2.3 million tons of ferrous scrap were recovered from MSW (see footnote 33).

home scrap declined to 20 million tons but use of purchased scrap increased to 38 million tons (36).

Potential Markets for MSW Ferrous Scrap

Because much of the ferrous scrap in MSW (as defined in this study) is in the form of tin-plated steel cans, the detinning industry is an important potential market. Detinners are primarily interested in recovering tin, but they also increase the value of the remaining steel in the process. Detinners can sell the clean ferrous scrap to steel mills at prices set for relatively high-quality scrap. Small amounts also are sold to copper producers in the southwest, who use the scrap to precipitate copper from copper sulfate solutions. This market may decline as new copper recovery technologies are developed.

In 1986, about 550,000 tons of tin-plate scrap was processed to recover about 1,250 tons of tin. Most of this processed scrap was pre-consumer—tin plate scrap from can manufacturers and rejected tin plate from tin plate producers. Only a small amount consisted of post-consumer can scrap from MSW.

Detinning capacity is limited and confined mainly to the Midwest. Other plants are located in Maryland, Texas, Arizona, Utah, California, and Washington. The limited availability of detinning facilities is one reason why most MSW recycling programs do not include tin cans. However, detinning capacity is expanding (186). The construction of two new detinning plants was announced in 1988--one in New Brunswick, New Jersey, and one in Houston, Texas (266). The detinning industry has indicated an interest in processing increased amounts of post-consumer can scrap.

Small amounts of tin can scrap can also be used directly to produce lower grade steel products, such as reinforcing bar.[35] It is not known what portion of recovered steel cans is used in this manner, however. In 1988, 19 integrated steel mills announced that they were willing to purchase post-consumer tin cans for direct use in their furnaces (129). Because the steel mills can accept bales of scrap that are more dense than those that detinners can accept, the mills could have a transportation cost advantage. However, as of early 1989, the prices the steel mills were willing to pay for tin cans did not provide enough incentive for recyclers to collect the material in large quantities.

The steel industry has also indicated a willingness to accept bimetal cans (steel body and aluminum top). Until recently, the 150,000 tons of post-consumer bimetal beverage cans discarded each year have had a relatively small market-in 1986 only about 5 percent were recycled. However, evidence of increased bimetal can recycling rates by steel mills is not available, and some observers remain skeptical about the potential for this market (187).

Steel producers, primarily in the eastern United States, have initiated a public relations campaign to promote recycling of both tin-plated and bimetal cans. Major steelmaker formed the Steel Can Recycling Institute to promote this type of recycling.

The steel industry has placed less focus on other ferrous components of MSW. Generally, these materials can be shredded or baled and sold to steel mills or exported through scrap processors or brokers. The quality of the scrap is very important in determining price and locating a purchaser. Scrap from alloys formed by blending rare metals is difficult to market, because few products are able to tolerate such contamination. The United States has never faced a severe shortage of ferrous scrap, and it has been estimated that 800 million tons of ferrous scrap (probably lower grade) have been stored in the last 30 years because of lack of demand (36).

In 1986, domestic steel mills and ferrous foundries purchased 42 million tons of ferrous scrap, while export markets purchased an additional 12 million tons. In 1987, total domestic purchases increased to 48 million tons, while exports dropped to 11 million tons. Ultimately, the potential market for ferrous scrap depends on the worldwide demand for steel, which was strong in 1987 and 1988. In the United States alone, raw steel production is relatively high, responding to strong demand in the home market (and voluntary restraint agreements on imports). U.S. capacity utilization was 79 percent in 1987, compared with just 64 percent in 1986. As an indirect result of this strong demand for steel, the Bureau of Mines' composite price for No. 1 heavy melting scrap increased from $72 per metric ton in

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[35] Tin causes embrittlement of the steel, which is intolerable in the higher grade steel products. in general, the quantity of non-detinned scrap that can be used depends on the overall tin content of scrap used and the specifications of the end product.

1986 to $84 per metric ton in 1987 and to $114 per metric ton in July 1988. Planned capacity expansions abroad, however, will put downward pressure on these prices, and the steel market in general, in the long term.

Special Problem Materials

Steel *Drums-Fifty-five* gallon steel drums are another source of ferrous scrap. However, mills have refused to accept these drums based on fears about the potential presence of hazardous wastes and potential liabilities under Superfund (97). To counter this, ISRI proposed that drum suppliers certify that the drums are clean and indemnify the recyclers against the possible liability associated with handling the drums. According to ISRI, this has worked fairly well and has created an incentive for suppliers to ensure that drums are clean before they are delivered to the recyclers.

Some small supplier companies that cannot afford to indemnify recyclers have chosen to contract with drum reconditioning firms to clean the drums, either for reuse or disposal. The reconditioners act as intermediaries between the drum suppliers and the recyclers. They accept the drums, which have been certified to be free of RCRA-regulated hazardous waste, clean the drums, and send them to scrap processors. Steel mills apparently are willing to accept drums from scrap processors that follow these procedures.

White Goods—The term ‘‘white goods’ refers to large appliances such as refrigerators, washers, and dryers. They typically contain large amounts of steel and are a traditional source of ferrous scrap. They are discarded at an estimated rate of about 2.8 million tons per year (81). Recovery rates were discussed above.

Recycling of discarded appliances usually begins with shredding, which helps separate metallic from non-metallic materials (e.g., rubber, glass, plastic, and dirt). Scrap dealers typically shred white goods using the same equipment used for automobiles. State-of-the-art shredders can separate the discards into ferrous metals, nonferrous metals, and nonmetallic waste. Once shredded, the scrap is sent to processors where stainless steel and nonferrous metals are recovered, to steel mills where it is melted into new steel or steel alloy products, or to foundries where it is melted into new castings products.

The major environmental problem associated with recycling white goods is that polychlorinated biphenyls (PCBs) are present in the electrical capacitors of some appliances produced or repaired prior to 1979. When these appliances are shredded, the capacitors are crushed and leak PCB-contaminated oil over the shredder fluff (i.e., the nonmetallic waste produced when the appliances are shredded).

EPA clarified its policy on PCB-contaminated fluff in a letter to ISRI on July 18, 1988. EPA stated that the Toxic Substances Control Act (TSCA) rules that regulate waste contaminated with PCBs at concentrations of 50 ppm or more (40 CFR 761 .60) are applicable to shredder fluff. These regulations require that PCB-contaminated waste be disposed at a landfill, incinerator, or ‘alternative method which can achieve. . .no unreasonable risk, ’ in compliance with standards in the regulation.

This action immediately reduced the number of scrap handlers willing to accept white goods and caused others to accept them only under restrictive conditions. ISRI, for example, recommended that its members stop handling and processing appliances or fluorescent lighting fixtures unless they were evaluated prior to processing to be sure that PCBs are not present (116). In response to ISRI’s advisory, EPA issued a press release indicating that it did not believe that many pre-1979 appliances still exist in the waste stream, and therefore they should not pose a problem for scrap processors.

In Connecticut, the Department of Environmental Protection formally notified landfill operators, scrap dealers, and municipalities that shredding old appliances is illegal, unless the electrical capacitors that contain PCBs are removed. This, in turn, has led some scrap dealers to notify municipalities that they will no longer accept appliances without some means of guaranteeing that they do not contain PCBs. Some Connecticut towns have developed programs to remove electrical capacitors that contain PCBs from appliances prior to shredding and to ship the capacitors out of state at a cost of about $500 to $700 per barrel, or about $2 per capacitor.

The presence of chlorofluorocarbons (CFCs) in refrigeration systems could pose similar regulatory problems for scrap processors. CFCs contribute to the depletion of stratospheric ozone, and recycling of white goods containing CFCs may be regulated in the future. According to ISRI, data are not available indicating either the amount of CFCs that typically remain in non-operational refrigerators or air-conditioners when they are delivered for recycling or the potential for release of CFCs during processing.

Tires

Between 200 and 250 million waste tires are discarded annually in the United States. Once discarded, they can provide breeding habitat for rats and mosquitoes and present a serious fire threat (94). In 1983, for example, a scrap tire fire in Winchester, Virginia, smoldered for months and produced 250,000 gallons of an oil-like liquid that contaminated the dump. Some alternatives to landfilling exist for scrap tires, including physical recycling, chemical recycling, and waste-to-energy.

Physical Recycling

Several methods are available to physically recycle the whole tire or some fraction of it. Whole tires have been used for landscape borders, highway trash barriers, artificial reefs, and erosion control (95). Retreading of used tires also occurs, but the market for retreaded tires has declined considerably in the last 10 years and is expected to decline even more in *the* future. In 1978, 31 million tires were retreaded and sold, while in 1986 this figure declined to only 15 million. By 2005, only 6 million tires are expected to be retreaded and sold (176).

Some used tires have been processed into specialized industrial products and household items such as doormats. However, these processing techniques are limited to fabric-belted tires, which have been losing their market share to steel-belted models (95).

Mechanical or cryogenic processes have been developed to break tires into fine particles, known as crumb rubber. Crumb rubber can replace virgin rubber in carpet backing, asphalt, and friction break materials (95). An innovative crumb rubber plant with a capacity to process 3 million tires a year has been built in a remote part of Minnesota. The facility, operated by Rubber Research Elastomeric and capitalized with public funds, is attempting to increase the marketability of the crumb rubber by adding various polymers. During 1988, however, the plant operated at less than one-third of its production capacity, because there was limited demand for the product. In the first 9 months of 1987, the plant processed only 100,000 tires and lost $1.5 million. It expects to process about 750,000 tires in 1990 (196). The remote location of the plant may act as a deterrent to potential markets and the company operating the plant is seeking to expand to other locations in the United States.

Chemical Recycling

Scrap tires can be converted into gas, oil, and char through a process known as pyrolysis (thermal decomposition in the absence of oxygen) (ch. 6). The tires are heated to 1,000° F to 1,800° F to volatilize the oil and gas, separating them from the carbon (char) and inorganic materials (e.g., steel). Condensation at various temperatures, along with filtration, allows the recovery of oil and gas fractions.

Chemical reclamation has also been used in the past to recover the rubber. However, since the composition of tires has changed from primarily rubber to synthetic elastomer blends, this process has become less economical.

Waste-to-Energy

Scrap tires also can be incinerated to recover energy. Different technologies can be used, including fluidized beds, rotary kilns, and cement kilns. Depending on the facility, either whole tires or tire-derived-fuel (TDF) can be used. Cement kilns and facilities that use rotary kilns can bum both whole and shredded tires. Facilities equipped with fixed or traveling grates tend to bum TDF, since this fuel bums more rapidly and evenly than whole tires. However, the steel belts in tires can cause problems in the combustion chamber when TDF is burned. Consequently, many shredding operations that prepare TDF for incinerators, paper mills, or cement kilns remove as much steel as possible.

During combustion, up to 15,000 Btu per pound of scrap tires can be generated. In the past, the costs of competing fuels, such as wood chips and coal, have caused prices of TDF to drop and processors to lose money. Between 1986 and 1987, for example, the price of TDF dropped from $35 to $33 per ton.

One company that produces TDF had to increase its tipping fee for accepting waste tires by 63 percent (tipping fees vary considerably, ranging from $8 to $100 per ton) (196).

Only one cement manufacturer, in Redding, California, is burning tires as the primary fuel. Often, however, tires are used to supplement other fuel sources in cement kilns. In German and Japanese cement operations, up to 20 percent of the coal typically used to fire the kilns has been replaced by whole tires.

Similarly, two Firestone Tire plants, one in Illinois and one in Iowa, use a pulsating floor technology to bum tires along with other solid waste (105). At these facilities, the fuel (tires and mixed combustible solid waste) is forced into the primary combustion chamber with a hydraulic ram and then forced along the hearth with pulses of air. Gases produced by this process are burned as they pass through three subsequent combustion stages.

In fluidized bed incinerators, gasses are blown through the bed containing the solid fuel; the fuel can include MSW combined with shredded tires. The velocity of the gas is such that it counteracts the forces of gravity and places the fuel in suspension. This provides a high rate of mixing of air and fuel.

A recently constructed powerplant in Modesto, California, bums scrap tires to generate electricity. This technology was developed and used for 12 years in West Germany prior to installation at the Modesto facility. The plant cost $41 million to build, bums 19,200 tires a day at 2,000° F, and generates 15 megawatts of electricity. Pollution control equipment includes a lime slurry scrubber, baghouse filters, and a thermal DeNOx process (ch. 6). Air emissions reportedly are below California's permitted limits (232). A centralized computer system has been installed to monitor emissions and to maintain temperatures at 2,000" F in case of an upset. Steel and zinc oxide are recovered from the ash residues; the steel is sold to a scrap dealer, while zinc oxide is sold to Zinc Corp. of America (148). Gypsum recovered from the lime slurry is sold to cement and fertilizer manufacturers.

The company that runs the Modesto plant is being sued, however, by the California Attorney General and a number of environmental groups, which claim that the tire pile at the plant constitutes a nuisance. Moreover, the company has encountered opposition to the siting and construction of additional facilities along the east coast. Despite local opposition, a larger, 25-megawatt facility has been given siting approval in Sterling, Connecticut. A tire incinerator in New York also has been proposed, but it has not yet been sited.

Used Oil

Approximately 700 million gallons of used vehicle oil are generated in the United States every year, and an additional 500 million gallons of used lubricants are generated by industrial operations (144). Of the vehicle oil, more than 360 million gallons is generated at households by individuals who change their own oil (13). Much of this oil from households is disposed in the trash, on the ground, or down sewers.

Two-thirds of the total of 1.2 billion gallons of used oil are recycled, mostly by burning it as fuel. To reprocess used oil for burning, it usually undergoes dewatering through distillation or evaporation, or chemical treatment to produce a suitable fuel.

An alternative to burning used oil as fuel is to re-refine it, which happens to about 100 million gallons of used oil per year. Re-refining essentially removes various additives and contaminants in used oil--detergents, dilutants, combustion byproducts, heavy metals, metal deactivators, lead scavengers, anti-oxidants, and compounds designed to maintain viscosity. Additives can comprise up to 25 percent of lubricating oil. Although re-refining technologies can cope with these additives, the contamination of used oil with hazardous waste constituents can hamper re-refining processes (34).

To re-refine used oil, it typically undergoes three stages of distillation (34): water removal, high-temperature removal of light hydrocarbons (fuel constituents), and high-temperature and vacuum separation of the lubricant from contaminants. After distillation, the oil is finished by a clay contact process and filtered to remove coloring and odor-causing constituents. However, this step also creates a clay-oil sludge that eventually must be disposed. A finishing process that creates less sludge residual, but that is more costly, is hydrofinishing. In this process, the distilled oil is catalytically hydrogenated at temperatures between 600 and 700" F; this produces a higher quality lubricant with less loss of oil than does the clay contact procedure.

EPA prohibits the burning of "off-spec" oil without prior notification to the Agency. Off-spec oil is used oil containing more than any of the following: arsenic, 5 ppm; cadmium, 2 ppm; chromium, 10 ppm; lead, 100 ppm; and total halogens, 4,000 ppm. In addition, the used oil may not have a flashpoint that is less than 100° F. EPA also regulates the burning of used oil contaminated with PCBs under TSCA, which places the burden of proving that the oil does not contain PCBs on the persons handling it.

Some contaminants separated from the lubricant in the distillation process often are used as asphalt extender. However, many of the contaminants removed during re-refining, such as detergents, combustion byproducts, and heavy metals, result in a solid or hazardous waste. Moreover, the water removed during the initial distillation phase is contaminated with hydrocarbons and must be treated and discharged.

An additional environmental hazard caused by re-refining used oil is posed by operations that have gone out of business. In the 1960s, numerous operations went bankrupt because of the increased use of additives in oil, which necessitated the use of more sophisticated and costly re-refining technologies. The re-refining industry expanded in the 1970s, in response to the oil ''crisis, ' but capacity has been declining again for the last decade. Abandoned operations can leave behind leaking surface impoundments, storage tanks, and other disposal units that can pose substantial threats to surface water and ground water (34).

Plastics

The presence of plastics in landfills, on streets, and in marine waters has raised tremendous controversy. Plastics comprise an estimated 7.3 percent by weight of MSW, or 10.3 million tons (81); this percentage is similar in other industrialized countries, where plastics constitute between 5 and 10 percent of MSW. About half of the plastics discarded in the United States, or 5.6 million tons, was equally divided between containers and packaging. These nondurable goods are the target for almost all of the current concern about plastics in MSW and provide a useful starting point for discussing prospects for increasing the relatively low level of plastics recycling. Box 5-D provides an introduction to the properties and types of plastics.

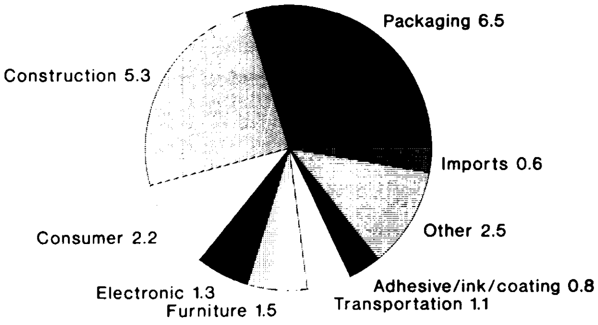
Structure of the Primary Plastics Manufacturing Industry

The plastics manufacturing industry is growing and thriving. Between 1981 and 1986, it had one of the highest compound growth rates of any industry and maintained a positive balance of trade (along with only one other commodity group, chemicals) (220). In 1986, about 22 million tons of plastics were sold in the United States in several market sectors (figure 5-8, table 5-4). Production of many commodity plastics is currently operating at or near capacity. After about 4 years of relatively stable prices, resin prices rose by 50 to 100 percent from 1987 to 1988, and small users had difficulty insuring a stable supply of some resin types. Prices reflect world supply and demand. Prices have flattened in recent months and some analysts predict that prices may soon drop (3).

The industry is categorized into two major groups (in the Standard Industrial Classification codes), one for plastics materials and resins and one for miscellaneous plastics products. In 1986, these two groups were among the 15 largest manufacturing industries in the United States (220). Fewer than 300 companies manufacture plastic resins in the United States, and fewer than 25 companies manufacture each of the commodity plastics. On the other hand, the number of processors of plastics into finished products is on the order of 10,000.

One trend in the use of plastics has significant implications for MSW management—in particular, the growing demand for single-service, convenience products in response to changing demographics and lifestyles. Plastics are expected to comprise an increasing share of the packaging and consumer/institutional markets, especially at the expense of more traditional materials (paper, glass, and metal). Thus, greater amounts and a larger proportional share of plastics will be disposed of as MSW. However, plastics are normally lighter than the products they replace and in most cases they are also less bulky (ch. 4).

Figure 5-&Plastics Markets, 1986 (millions of tons)



NOTE. Total U.S. Market Sales = 22 million tons.
SOURCES" Office of Technology Assessment, after Society of the Plastics Industry, *Facts and Figures of the U.S. Plastics Industry* (Washington, DC, 1987); Modern Plastics, "Materials 87," *Modern Plastics,* pp. 55-65, January 1987.

Status of Post-Consumer Plastics Recycling

Most experts agree that recycling in the United States is constrained by the lack of collection of plastics. In 1986, less than 100,000 tons of post-consumer plastic discards-less than 1 percent of the amount in MSW—were recycled. This increased to about 125,000 tons in 1988.

Given the variety of plastics. however, it is appropriate to consider sales and discards of specific types. Current recycling of post-consumer plastic wastes is focused almost entirely on containers made of two resins, polyethylene terephthalate (PET) and high-density polyethylene (HDPE). These containers are relatively easy to identify and are not degraded significantly by reprocessing. In 1986, 65,000 tons of PET from soft drink containers were collected for recycling, up from **4,000** tons in 1979 (21). This comprises about 20 percent of the PET used for soft-drink bottles and about 10 percent of U.S. PET sales in 1986. PET collection increased to 75,000 tons in 1987.

Total estimated HDPE collection in 1986 was about **30,000** tons, about 1 percent of U.S. HDPE sales. Roughly half of the recycled HDPE came from base cups for PET soft drink containers (22). An estimated 17,000 tons of HDPE from milk jugs were recycled in 1986 (157). This is only 5 percent of the HDPE used in milk bottles. HDPE collection in 1987 is estimated to be 36,000 tons, again divided equally between milk jugs and base cups from PET soft drink containers (22).

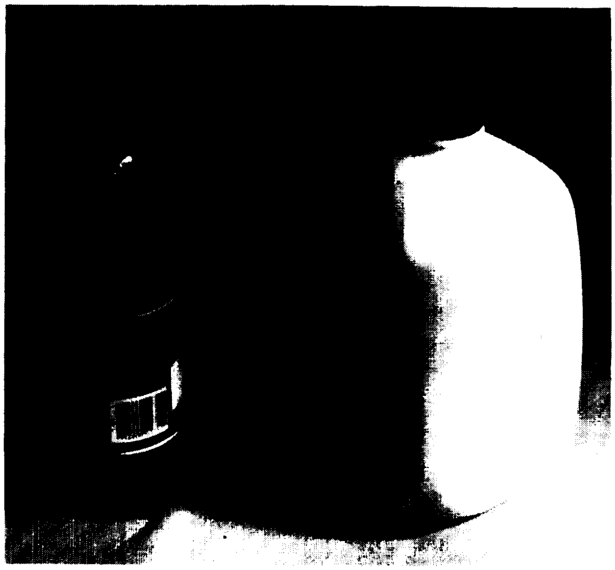


Photo credit: Office of Technology Assessment

Current recycling of plastics from MSW focuses on containers made from polyethylene terephthalate (PET) and high-density polyethylene (HDPE), which are relatively easy to identify and are not degraded significantly by reprocessing. Only about 1 percent of the plastic in MSW is now recycled.

The recycling of other post-consumer plastics in the United States is negligible. Efforts are focused on nondurable goods, especially containers and packaging: some small-scale recycling of mixed plastics is occurring; polystyrene (PS) recycling began in 1989 at two pilot-scale plants; and more limited experiments are underway on post-consumer polyvinyl chloride (PVC). Most PVC recycling efforts are focused on contaminated pre-consumer waste. Post-consumer recycling tends to focus on finding ways to reuse PVC bottles (1 15,000 tons per year in the United States). These bottles are more difficult to identify than PET and HDPE bottles, and are used mostly for products with a low turnover rate, such as shampoo and vegetable oil (135). PET is replacing PVC in some bottles. FDA is preparing an environmental impact statement (EIS) for its proposed action to establish the safe conditions for use of PVC. The EIS will evaluate, among other things, the potential effects of PVC on post-consumer recycling programs (53 *Federal Register 47264,* Nov. 22, 1988).

Recycling of post-consumer plastics from durable goods, such as old appliances and furniture, is also

Table 5-4--Major U.S. Resin Markets, 1986 (millions of pounds)

Markets	Thermoplastics								Thermoses	Total
	LDPE	PVC	HDPE	PP	PS	E T	Engineering	Other		
Packaging	5,605	497	3,560	1,128	1,360	747	15	5	97	13,014
Building/construction	213	4,711	522	34	418	0	84	154	4,541	10,677
Consumer/institutional	507	277	783	732	1,296	608	31	31	233	4,498
Electrical/electronic	421	478	147	277	360	0	236	332	307	2,558
Furniture/furnishings	71	380	16[a]	1,103	47	0	10	425	923	2,975
Transportation	0	149	232	237	0	0	123	477	1,020	2,238
Adhesives/inks/coatings	231	83	38	24	0	15	0	977	285	1,653
Imports	715	201	45	25	17	0	0		118	1,255
Other	760	467	821	1,162	814	0	132	216	714	5,086
Total[b]	8,523	7,243	6,164	4,722	4,312	1,370	631	2,751	8,238	43,954

[a] Polyethylene transportation and furniture/furnishings markets assumed to be HDPE.

[b] These estimates calculated by OTA differ from those of SPI (1987) and Modern Plastics (1987) because of nondisclosure of market Information and exclusion of polyurethene data by SPI and inclusion of import data by OTA.

SOURCES: Office of Technology Assessment; after Society of the Plastics Industry, *Facts and Figures of the U.S. Plastics Industry* (Washington, DC, 1987); Modern Plastics, "Materials 87," *Modern Plastics, p.* 55-85, January 1987.

negligible. Some of these materials, such as old appliances, are handled by scrap dealers but the plastics components are usually discarded.[36]

An estimated 95 percent of clean, pre-consumer industrial scrap from processing and from off-spec virgin thermoplastic resins is recycled, comprising as much as 10 percent of all production (56). The amount of contaminated industrial scrap material, or obsolete product inventories and overruns, that is recycled is unknown, but significant.[37] This off-spec material is often used as an inner layer with virgin material as the outer layers.

The number of companies involved in recycling post-consumer plastic wastes is small, but growing. Most are relatively small operations. A few large companies are involved in recycling post-consumer plastics, and several large resin producers are announcing plans for new recycling plants. Also, the number of traditional scrap dealers and brokers dealing with post-consumer plastics appears to be increasing.

Current Products and Markets—Post-consumer plastic wastes, especially plastic bottles, can be recycled into products that replace or supplement virgin materials, or that replace other materials such as lumber, concrete, or metal. HDPE, for instance, is recycled into lumber substitutes, base cups for soft drink bottles, flower pots, pipes, toys, pails and drums, traffic barrier cones, golfbag liners, kitchen drain boards, milk bottle crates, soft drink bottle carriers, trash cans, and signs (222).

PET is recycled into dozens of products (222). Some examples include strapping, scouring pads, fence posts, parking space bumpers, industrial paints, paint brushes, fiberfill for pillows, ski jackets, sleeping bags, carpet fibers, rope, sails, and tire cord. PET is also used to produce: polyol used in making urethane foam and furniture; unsaturated polyester used in making boat hulls, bath tubs, swimming pools, automobile exterior panels; engineering plastics used for appliance parts and automotive components; and thermoformable sheets used to Produce six-pack carriers for soft drink bottles, nonfood containers, and audiocassette cases. New uses are frequently introduced, such as transparent egg cartons.

One of the major products made from mixed plastics is plastic "lumber." Plastic lumber is being used for posts, poles, marine pilings, dock surfaces and piers, and also for nonstructural applications such as decking, agricultural pens, fences, park benches, and parking space bumpers.[38] Based on ongoing experiments, some of the properties of plastic lumber appear to be superior to wood, while others are not (21). Superior properties include its resistance to rot, water, chemicals, and insects, as well as its lack of splintering and its ability to hold nails better and in any direction (unlike wood, which only holds nails well across the grain). However, plastic lumber loses strength when heated and does not hold screws as well as wood; as a result, carpentry joining may be a problem in hot weather if the plastic softens slightly. This probably can be overcome by using bolts to join pieces together.

Some post-consumer plastics are being exported to Asia and Europe. There are currently no PET reclaimers on the west coast so plastics collected there are shipped to Asia, which is cheaper than shipping to east coast reclaimers. Several east coast companies also export some of their collected post-consumer plastics. Data are not available on the size of post-consumer plastic export markets.

Recycling in Japan and Europe—h Japan, recycling of post-consumer plastics has always been low and has declined recently because of: the difficulties of separating pure plastics from MSW; the poor quality of products from mixed plastics using technologies available in the early 1980s; and the high cost of collection, separation, and processing (170). As a result, the number of Japanese municipalities with plastics recycling programs declined from 25 in 1982 to 1 at the end of 1988. PET, the most common resin recycled in the United States, is used only in small quantities in Japanese products. However, interest in post-consumer rhs-

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[36] Limited research on technologies to reuse plastic components recovered from automobile and appliance shredder residues is underway (189,190,191). The problems faced are similar to recycling other post-consumer plastics but are more difficult to overcome because of the variety of plastics mixed together. Suggested markets for these materials are similar to those proposed for other mixed plastics.

[37] Industry is very secretive about how much of this scrap is recycled and in naming sources because of the price advantage gained using this material.

[38] One parking space bumper, or carstop, consumes 400 PET beverage bottles including caps, labels, and base cups left on the bottles (31).

Box 5-D-Introduction to Plastics

Definition of Plastics

Plastics are chemicals—long-chain polymers—made from fossil fuels and chemical additives. Most polymers have little practical value without a small percentage of additives that give the plastic materials useful properties.

Additives impart physical properties to meet specific applications and improve processing. Over 4,000 individual types of additives exist, including a variety of mineral and chemical derivatives. Additives can be classified into four major types: reaction controls (e.g., catalysts, initiators, auxiliary processing materials); processing additives (e.g., blowing agents and lubricants); stabilizers (e.g., antioxidants, heat stabilizers, light or ultraviolet stabilizers, preservatives); and performance additives (e.g., fillers and reinforcements, plasticizers, colorants, impact modifiers, flame retardants, antistatic agents, coupling agents) (96).

The majority of additives are inert fillers such as calcium carbonate; many (e.g., reaction controls and processing additives) are used in manufacturing processes and do not remain with the finished polymer. Most additives are used in very small quantities, usually less than 1 percent. Exceptions include ''plasticizers' (i.e., chemicals added to impart flexibility) that can account for 40 percent of some plastics products, including wire and cable insulating material and artificial leather made from PVC. Colorants can represent 1 to 10 percent of some plastics.

Concern about the disposal of plastics and their additives in MSW has focused primarily on the use of metal additives, particularly lead and cadmium used as heat stabilizers in PVC and as colorants in other plastics. Heavy metal stabilizers are used primarily in nonpackaging markets **such** as PVC wire and cable insulating material, furniture film, floor tiles, and pressure pipes. Heavy metal colorants are applicable to a wide variety of thermoplastics. Only a small percentage of PVC is used in packaging and containers (table 5-4).

In addition to questions about heavy metals, however, questions also exist about the environmental fate of other additives when plastic wastes are discarded. Of particular concern is the use of organic and halogenated chemicals [e.g., phthalate esters, which account for roughly 70 to 75 percent of plasticizers). Phthalate esters are considered priority pollutants by EPA under the Clean Water Act. Because these additives do not become a permanent part of the polymer molecule, they are more susceptible to migration than many other additive types.

Additives used in plastic food packaging are subject to premarket approval by the Food and Drug Administration (FDA). FDA conducts safety evaluations of food additives and considers the amount of additive that can migrate to food and the toxicity of the additive. Extraction tests are required for new food additives or new applications to determine migration potential and this data is used to review the environmental effects of disposal. Some additives may be automatically considered acceptable to FDA if they are included on the list of substances "generally recognized as safe. "

Properties of Plastics

The properties of plastics make them highly desirable to manufacturers and consumers, particularly for packaging. Although plastics often cost more to produce than alternative materials, their properties may make plastics more cost-effective and the preferred material for particular uses. As a result, plastics have been replacing glass, aluminum, steel, and paper for many uses.

In general, plastics are light-weight and inert; they resist breakage and are not subject to environmental deterioration (121). They also can be tailored to suit almost any specific need—rigid, flexible, stretchable, insulating, sterilizable, breathable, impermeable, transparent, translucent, opaque, colored, etc. Compared to alternatives, plastics also are relatively cheap to transport because of their light weight.

Plastic Types

Plastics can be classified into four groups: commodity thermoplastics, engineering thermoplastics, thermoses, and multicomponent plastics. This classification is based on the uses of plastics that affect their presence in MSW, their relative cost, sales volume, and properties that affect their potential for recycling.

1. ***Commodity thermoplastics are*** produced at low cost, in high volumes. They include the five resins that **account** for about two-thirds of all plastic sales (table 5-4): low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP), and polystyrene (PS). They also include polyethylene terephthalate (PET), which has only recently been used in sizable quantities for packaging. Other commodity thermoplastics include acrylonitrile butadiene styrene (ABS) and nylon. In general, commodity thermoplastics are candidates for recycling because they soften when heated and can be remolded. PET and HDPE are the predominant post-consumer resins that have been recycled in the United States.

   No **current data quantify the amounts** of resins found in MSW in the United States. However, it can be **assumed that** polyethylene (LDPE and HDPE), PP, and **PS** are major plastic components of MSW. **PVC** and PET are probably present in lower **quantities because** of their more limited use in short-lived markets such as packaging and consumer/institutional products. Limited information indicates that MSW in Europe is comprised of roughly 60 percent PP and polyethylene (i.e., polyolefins) (29).
2. Engineering ***thermoplastics are*** produced at high cost in low volumes. Examples include polycarbonate (Lexan) and polytetrafluoroethylene (PTFE or Teflon). Engineering thermoplastics are used in the construction, electric/electronic, and transportation markets (220,221). These plastics are not considered a major component of MSW. In general, the higher the price of a thermoplastic, the greater the driving force to recycle it. PTFE, a relatively high-priced resin. is one of the few plastics that has been recycled in significant quantities (12). Engineering thermoplastics are targeted for increased recycling by at least one major manufacturer. For example, in 1987 General Electric announced a campaign to recycle one of its engineering thermoplastics, polycarbonate, into structural panels, building insulation, and other long-life construction markets.
3. ***Thermoses,*** compared to thermoplastics, are low-volume materials. but they still comprise about 20 percent of the U.S. plastics market. Two resins, phenolic and polyurethane, are sold in sizable quantities (1.4 million tons and 1.3 million tons, respectively), predominantly for long-lived products such as building insulation. The major markets for thermoses are building and construction, transportation, and furniture and furnishings (table 5-4). Unlike thermoplastics, thermosets generally are not considered recyclable because they do not soften when heated and thus cannot be remolded. However, they **can be** recycled as a filler.
4. ***Multicomponent plastics and laminations are combinations*** of different plastics or of plastics and other **materials** such as paper or metal foil. These materials are primarily used for packaging. In 1988 about 1.3 million tons of plastics were used in multicomponent films and semi-rigid sheets and almost two-thirds of this amount was used for food packaging (39). This type of packaging is expected to expand significantly in the coming years because it offers increased shelf life, reduced need for refrigeration, and **the** feasibility of using food processing methods that result in improved flavor and texture. Multicomponent plastics provide an economical way of combining the needed properties of different materials. For example, recently available plastic ketchup bottles are made from several plastics—including an exterior plastic for appearance and strength, an adhesive to hold different plastics together and attach the label, a special oxygen barrier plastic, and an interior plastic to resist fats and acids. This combination of materials makes these plastics technically difficult to recycle except into mixed plastic products,

tics recycling remains high, especially given recent technological advances.

The outlook may be more encouraging in Europe, although the current rate of plastics recycling is low. In West Germany, over 20 sorting plants have been built in the last decade (106). Many of the new mixed plastics recycling technologies originated in Europe *and numerous* plants are now in operation and being planned.

Plastics Reclamation Technologies

Theoretically, any type of plastic-either as single resins, separated from other plastic types, or as mixed plastics, combining several different resins or a few resins with similar properties-can be recycled. Single resin recycling can only be done with thermoplastics (box 5-D), which can be remolded easily because they melt when heated. Mixed plastics recycling can be done with thermoplastics, multicomponent plastics and laminations, and thermoses. Technical limits on the quantities of different resins that can be used in mixed plastics depend on the specifications required for the final product. Additives can be used to improve the compatibility of different resins.

Numerous proprietary techniques are being used to recycle plastics. Some techniques are available commercially; except for initial preparation steps to remove contaminants they do not differ substantially from the equipment used to fabricate some products from virgin resins.

Initial Preparation-Initial preparation of separated plastic containers may include washing and separation to remove unwanted materials. Separation methods are based primarily on differences in physical properties such as density. Automated techniques are suitable for mixtures of relatively pure polymers, but not complex mixtures of products containing many types of plastics or plastics that are altered by fillers or coatings (42). The resin recovered after separation is usually in the form of flakes or pellets.

Separated HDPE milk jugs may require removal of labels and closures. PET bottles, however, require much more sophisticated washing and separation steps. Most PET bottles have base cups made from HDPE, caps made from aluminum or polypropylene, and a paper or plastic label with adhesive. Thus, a typical PET bottle is composed of 70 percent PET, 24 percent HDPE, 1 percent aluminum, and 5 percent label and adhesive (192). PET bottles without HDPE base cups are also available.

Some separation technologies are available commercially. For example, the HDPE/PET reclamation process developed by the Center for Plastics Recycling Research (CPRR) at Rutgers University is available for licensing at a nominal cost. Investment costs for the system are $2.0 million to produce 5,000 tons and $2.5 million to produce 10,000 tons of 99.9 percent pure PET each year (48). Some separation technology is proprietary, however. One proprietary system uses a solvent (1,1,1 - trichloroethane) to separate PET from aluminum in a closed system that is claimed to minimize environmental releases (164).

Processing Into Usable Plastic Products-The basic technologies used to make products from virgin resins are also used to recycle large amounts of clean, pre-consumer industrial scrap. They also can be used to make products from clean, post-consumer single resins. They basically involve melting and extruding it into objects or pellets (42). Prior to extrusion, the recycled plastic maybe mixed with additives to improve processing and enhance properties and/or mixed with virgin resin. Additives are discussed in box 5-D.

Two basic technologies for processing mixed post-consumer plastics are also available from Europe. A third technology has been patented by a U.S. company. One of these technologies, the Extruder Technology I (ET/I), is used in 12 European and 3 U.S. plants. ET/I has the advantages of moderate price and modular design. The basic extruder and molds costs $300,000 for a capacity of 175 to 400 pounds per hour. In general, the system including preparation equipment (grinder, shredder, densifier, blenders, and conveyors) costs $375,000 to $450,000 (29). A second technology, the Recycloplast Technology, is used in three plants in Germany; other European plants are being negotiated and the first U.S. plant began operations in Atlanta, Georgia, in spring 1989. Recycloplast is more costly than ET/1, and the German plants use about 30 percent industrial scrap to improve quality control and broaden the range of end products. Equipment costs vary depending on the size of the operation and the amount of preparation equipment needed for preliminary cleaning. A typical plant has a capacity of 5,000 tons per year on three shifts; plant and installation costs are $5 to $6 million, with 15 percent of that cost earmarked for pollution control (30). One company, Polymer Products, began commercial operations in Iowa in late 1986 after patenting an upgraded version of another European technology. Its process accommodates a wide variety of mixed plastics with varying degrees of contamination and produces lumber substitutes, metal substitutes, and concrete substitutes (31).

Another new technology can produce high-quality polyolefin resin (i.e., all types of polyethylene and polypropylene) from mixed plastics. One version of this technology was developed by the German company AKW Equipment and Process Design. The technology involves grinding, magnetic separation to remove metals, granulating into flakes, liquid separation to remove minerals, washing, air separation to remove PS, PVC and others from the lighter PE and PP, drying, mixing, and then extruding into pellets. The end product is a pelletized polyethylene raw material containing less than 5 percent polypropylene. According to tests on MSW plastic waste samples from Massachusetts and Rhode Island, the final product performs very similar to virgin PE. It cannot be used for film or plastic bags, but is suitable for making bottles (32). The first industrial-scale AKW plant in West Germany produces 4,000 to 6,000 tons per year. Polymer Resource Group, Inc., a joint venture between AKW and ITC Inc., has announced plans to open a plant in the Baltimore-Washington area. Similar technology (Transplastek) is producing bottle-grade polyolefins in Quebec, Canada.

Chemical dissolution systems to recover specialized plastic resins are also being marketed. This technology involves adding chemicals that cause the plastic to dissolve in water. After dissolution, the particles theoretically can be recovered and reused. As of 1988, this technology had been developed to be applicable to acrylics, styrenes, and other resins. Current economics are not favorable for producing polyethylene, and further technical development would be required to do so, but these technical problems do not appear insurmountable (27). Commercial products include coatings to protect new automobiles that can be hosed off when they reach the showroom and a bottle label that can be readily removed by washing. Products being studied include laundry bags that would dissolve when put through a washing machine cycle with the laundry and plastic backings for diapers that could be flushed down toilets (27).

***Technical Constraints*-Several** factors constrain the use of recycled plastics in making new products. Among the most important are the presence of contaminants and the effects of natural degradation processes.

Contaminants in collected plastics include paper, metals, other plastics, residual products, adhesives, pigments, and dirt. These substances can make a plastic technically difficult to recycle. In addition, the Food and Drug Administration (FDA) has stated that it cannot authorize the safe use of recycled plastics for use in contact with food unless additional information is provided to resolve the uncertainties about these contaminants (1 10). The FDA did not object, however, to a request to use recycled plastics as an outer layer in a multi-layer food package when it was demonstrated that there was little likelihood that contaminants in the recycled layer would migrate through the food contact layers.

In general, the performance of recycled resins is not as good as virgin resins. Reprocessing and environmental exposure degrades some of the beneficial properties of some plastics, such as durability and dimensional stability, so recycled plastics usually are used in products with less demanding applications than the original products.

Degradation of some properties can be overcome with the use of additives, by making the recycled product thicker, or by coextrusion (making a product with a recycled core and a virgin outer layer). For example, garbage bags made from recycled plastic (usually industrial scrap) are generally thicker than garbage bags made from virgin resin. A pilot plant in France is coextruding recycled PVC bottles with virgin PVC to make pipe.

Infinite recycling is technically impossible, however, because degradation eventually occurs (55). Thus, while recycling recovered plastics defers the need to use other management techniques, it does not eliminate the need for eventual disposal. Ideally though, recycled products would have long-lived utility, especially relative to the short-lived utility of plastic packaging.

***Energy Consumption*-The** production of virgin plastics accounts for a relatively small percentage of total energy consumption in the United States. According to a recent EPA report, current domestic production uses 5 percent of the oil and less than 1 percent of the gas consumed by the Nation (252). Plastics production accounts for the dominant use of three major feedstocks—in 1985, 72 percent of the ethylene produced, 59 percent of the propylene, and 76 percent of the benzene (220).

Plastics production is not limited to the use of petroleum and natural gas. Depending on the techniques used, different raw materials, such as coal, can be used to produce feedstocks (130). However, history and relative economics make oil and gas the current materials of choice.

Making products from recycled plastics can result in considerable energy savings compared to virgin plastics production. Table 5-5 shows the production energy used for the major commodity thermoplastics. It takes about 1,000 to 2,000 Btu per pound to melt these plastics (11).[39] Therefore, recycling these resins would save 92 to 98 percent of the energy needed to produce single virgin resins (excluding energy used to collect and transport recycled resins).

The manufacture and use of plastics products may require less energy than the manufacture and use of nonplastic alternatives, based on data from 1978 in a study conducted for a plastics industry association (80). Based on 1978 production data, the study estimated that using plastics instead of alternative materials would result in energy savings of about 71 percent. The study concluded that plastics products save nearly as much energy as they consume, primarily because their light weight is beneficial in terms of raw materials used and in subsequent transportation costs. The use of some plastic products also can result in significant energy savings; for example, automobiles with plastic parts are lighter and have improved fuel efficiency.

Materials Cost Comparisons-A general rule of thumb states that recycled resins must be priced 33 to 50 percent lower than virgin material before a fabricator will find it worthwhile to use them (212). However, supply-demand-price relationships are not well established and decisions about using recycled resins depend on the unique circumstances of the individual fabricator. For many low-priced, high-volume plastic products, small savings in raw material costs may make a big difference in profits.

The price of post-consumer plastic bottles varies by color, cleanliness, the way it is packaged (i.e., baled or ground), and geographic area. Once the material is reprocessed, the price is also determined by its quality and the geographic region, form (i.e., flakes or pellets), additive content, and color. According to the CPRR and the Plastics Recycling Foundation, post-consumer plastic bottles can be sold for about 6 cents per pound (prices as of 1987), and reclaimed PET can be sold profitably for 25 cents per pound in flake form or 30 cents per pound in pellet form. For comparison, virgin PET pellets sell for about 56 cents per pound (192).[4] Recycled HDPE from base cups can be sold for 17 cents per pound, compared to virgin resin at about 40 cents per pound.

Barriers to Increased Recycled Plastics Use

As stated earlier, lack of collection is the major factor limiting plastics recycling. This opinion is widely held by plastics manufacturers and recycling businesses, based on their experience and on market studies for PET, HDPE, and mixed plastics. The lack of technologies to separate different plastic types and product quality are also problems in some instances.

Available markets have not yet been a problem for recycled plastics, largely because of the limited collection that has taken place. As discussed below, market studies for HDPE, PET, and mixed plastics show enormous potential, compared to current levels of recycling, but it remains to be seen whether these markets can be developed to use a significant quantity of the plastics in MSW. Information is not available on potential markets for other single resins.

Collection-The major methods now used to collect plastic bottles for recycling are bottle deposit systems for PET containers and curbside collection. Drop-off programs are also used in some jurisdictions to collect HDPE milk jugs, but such programs are very limited and are usually located near a reprocessor to avoid transportation costs. A buy-back system for plastics has been in operation in the Bronx since 1983 (145).[41]

Bottle deposit systems have been the most successful method for collecting PET soda bottles. This method is used by 9 States, and in 1986, 98 percent of collected PET was from bottle bill States (159). However, the plastics, beverage, and food store and many other industries are generally opposed to deposit systems (ch. 8) and have been effective at

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[39] Energy requirements for the PET/HDPE reclamation process developed by CPRR are 820 Btu/pound (48). The ET-1 process requires 1,910 Btu/pound, including auxiliary equipment, according to manufacturer's information.

[40] This translates into $600 per ton, making recycled plastics far more valuable than many other recycled materials, such as newsprint at $40 per ton and glass at $30 per ton,

[41] The responsible company, R2B2, will buy any separated, identifiable plastic brought to its door. Materials purchased for up to $0.10 per pound have subsequently been sold at $0.015 to $0.31 per pound to domestic and export markets. For a six month period in 1988, plastics sales totaled $50,000 and revenues averaged $200/ton. More plastics were recovered than used beverage cans.

Table 5-5-Energy Requirements To Produce Selected Plastics

Plastic	Production energy (Btu/lb)	Feedstock (%)	Electricity (%)	Oil and natural gas (%)
LDPE	38,500	73	17	10
HDPE	36,500	75	10	15
PS	34,300	69	4.5	26.5
PET	48,700	51	10	39
PVC	25,600	49	26	25

SOURCE: Argonne National Laboratory, Energy and Materials Use in the Production and *Recycling of Consumer Goods Packaging,* ANL/CNSV-TM-58, prepared for U.S. Department of Energy (Argonne, IL: February 1981).

preventing bottle bills from being adopted in other areas.

One technology, the reverse vending machine, is being used to collect PET bottles in some bottle deposit States. These machines shred the bottles for later shipment to reprocessors. The next generation of machines, scheduled for distribution at the end of 1989, is expected to be able to separate clear from colored PET, which can enhance the value of the product. The new machines will also accept HDPE milk jugs and all other plastic containers. Plans are to sell clear PET and HDPE separately for reprocessing and make the other plastics that are collected into a plastic lumber product (60).

Experts consider curbside collection of PET and HDPE the simplest way to start a community plastics recycling program (227). Limited curbside collection of plastics now occurs, but it is the likely future direction of plastics recycling, primarily because of opposition to deposit legislation. Also, curbside recycling is increasing for other materials and the costs of including plastics are perceived not to be excessive (ch. 2). More than 60 curbside programs are known to include plastics (33).

Major Collection Problems--Concerns about plastics collection programs include the space used by uncompacted plastic bottles, the variety of plastics found in post-consumer waste, and the costs of collection and processing.

The difficulty of collecting rigid containers that have high-volume and low-weight has limited curbside collection of post-consumer plastics. For example, adding plastics to an existing collection program can be a problem if the collection equipment is not designed to handle resilient materials that are not easily crushed. The space required to collect plastic bottles also can reduce the number of households that a collection truck can stop at before the truck is full; one estimate of the potential reduction is 30 percent for uncompacted plastic bottles and 17 percent for bottles compacted 50 percent before collection (227). Several companies are working to develop on-truck densification equipment and at least six projects are underway or pending to use on-truck densification of plastics in curbside collection (33).[42] One alternative being studied by plastics processors and waste management companies is to attach densifiers or compactors to existing collection trucks to allow subsequent sorting of flattened whole plastic bottles. Although transporting shredded or ground plastics would take up less space, on-truck granulators pose several problems including safety hazards to operating personnel and poor marketability of reground mixed resin (33).

The variety of plastics in MSW is a concern because only PET and HDPE resins have much of a market at present, and single resins have a much higher value than mixtures of resins. Collection of single resins is problematic because of the difficulty in identifying and separating different resins. Limited information from curbside collection programs that include separation of plastics shows a measurable amount of contamination with other wastes. For example, a pilot study in Rhode Island found 6.5 percent contamination with other materials, with 18 percent of the contamination being other plastic containers (125). Another pilot study in Westchester, New York, found 14 percent contamination (107).

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[42] Sites include Nepean, Ontario; Seattle, Washington; Rhode Island; Winona, Minnesota; and several Chicago, Illinois suburbs.

To help resolve the identification problem, the Society of the Plastics Industry (SPI) is sponsoring a voluntary coding system to get manufacturers to label the resins on bottles and jars. One concern about this labeling system is the difficulty of reading codes after bottles have been flattened to facilitate collection.

Separation Technologies-Most separation of plastics is now done manually. New technologies could be developed to improve the separation of different plastic types. Research on new automated approaches to separating plastic containers made from different resins is now underway at CPRR. The center is studying ways to identify resin types based on bar codes using photoelectric beams, machine vision, and near infrared technology (79). Other innovative approaches may be applicable to a wider variety of resins and plastic products. For example, additive "tags" could be put into all types of virgin resins to facilitate automatic identification and sorting (163). Chemical separation techniques are also under investigation, including a project at Rensselaer Polytechnic Institute to use selective solvent dissolution and flash devolatilization to recover individual polymers. An automated approach to separating PET and PVC plastic bottles is used in Europe, where many more PVC bottles are used than in the United States. The technology uses an electromagnetic scanning technique to detect the chlorine in PVC (135).

The breakeven cost of collection and processing is a major concern. Unless avoided costs of tipping fees for other disposal options are included in an analysis, recycling plastics does not appear to be financially viable from a collector's viewpoint (ch. 2). For example, according to one study handling costs for deposit systems (including collecting, crushing, baling, and shipping to reprocessors) can range from $0.20 to $0.40 per pound of PET (42). These costs are greater than the recent scrap value of PET bottles, which ranges from $0.05 to $0.10 per pound.

One market analysis for post-consumer HDPE milk bottles estimated that processing and transportation costs ranged from $0.03 to $0.49 per pound for transporting material 100 miles to market, depending on the type of processing equipment used (granulators or balers) and the amounts processed each year (157). Granulators produce a higher priced product than balers, but this may change as purchasers discover that they can more easily determine contamination levels with baled materials. In some cases, the costs can be less than revenues for selling collected HDPE; some sellers have noted a rise in some areas from around $0.06 per pound in 1987 to $0.15 per pound in 1988 (145).

Another study of plastics collection programs concluded that even without specific cost estimates, most operators believed that it was worthwhile to collect plastics (145). This opinion was based on the improving resale value of plastics and the willingness of the public to participate in collection programs. Higher participation rates were found for "user-friendly systems, " especially those that included some combination of containers, minimal preparation requirements, public education, frequent pick-ups, and a broad range of targeted plastics.

Quality of Recycled Plastics-Quality control is a major concern that affects the willingness of manufacturers to use recycled materials. According to studies sponsored by CPRR, many potential users of recycled plastic resins are unaware of the progress being made in recycling technologies for post-consumer plastics (20). CPRR has also found that many recycling success stories are kept secret because of the competitive nature of the business. This leads to duplication of research efforts.

Standardized tests, such as those developed by the American Society Testing and Materials (ASTM), are used within the plastics industry to provide basic information on the properties of plastic materials. Test results on different generic virgin plastic types are published. The tests, however, do not necessarily y provide precise information on how a fabricated product will perform under various conditions (59). Given potential variations in the life-history of plastics that are recycled, such as exposure to sunlight, heat, and other environmental factors that may degrade plastics properties, it may be difficult to generalize about the performance of recycled products without quality control testing. Standardized methods are needed to test performance, quality assurance, and contaminants in recycled resins to ensure the reliability of these materials. ASTM is preparing a guidance document to address these concerns (79).

The quality control programs used by recyclers, for both finished products and source materials, often are considered proprietary. For example, Wellman, Inc. maintains its own laboratory and testing facilities to determine the suitability of recycled source materials, including their potential for new products. The Coca-Cola Co. and Pepsico consult with Wellman, Inc. and other PET recyclers when they are planning potential changes in PET bottles, such as labels, adhesives, or barriers, to note any impacts on recyclability.

Another key issue is the impact of degradable plastics on recycling efforts. Recyclers of plastic bottles are concerned that the presence of degradable plastics in post-consumer plastic wastes could cause deterioration of recycled products and complicated liability problems, hurting and potentially killing current plastic recycling efforts. Producers of degradable plastics disagree, contending that degradable would not be a problem and that potential adverse effects could be minimized by carefully considering the properties of the recycled product and/or by modifying reprocessing technologies to accommodate the presence of degradable. OTA has not found any data to demonstrate whether the presence of degradable plastics would cause a problem for recycling plastics. The issue of degradable plastics is explored further in box 5-E.

Potential for Increased Recycling

Several factors work in favor of an increase in the recycling of post-consumer plastics. At present, commodity plastics production is operating close to capacity and prices of virgin resins have almost doubled in the past year. As a result, demand for plastic resins is very high and is expected to increase over the next decade (221).

Political and institutional factors--especially the threat of bans on particular plastics products, and State and local initiatives to increase recycling—are stimulating the plastics industry to expand recycling opportunities. Various industry representatives have formed lobbying coalitions to promote recycling (and/or incineration) of plastics. New industry programs are being announced frequently, making it difficult to present an up-to-date picture in a document like this. Some companies are working to increase the availability of plastics for recycling by helping communities study collection options. Some companies are setting up programs with waste haulers to collect plastics for reprocessing (e.g., Wellman/Browning-Ferris Industries and DuPont/ Waste Management, Inc.).

Industry has established two pilot programs for recycling foam polystyrene. Amoco Foam Products Co., McDonald's, and wTe Corp. are collecting unseparated post-consumer wastes from 20 McDonald's restaurants in the New York City area for recycling. The waste is separated and washed, and PS is cut into fluff and then sent to be repelletized at another location. Then it will be mixed with virgin PS to produce building foundation protection board for construction uses. In another pilot-scale program, Mobil Chemical Co. and Genpak Corp. will recycle PS collected by New England Container Recovery, Inc. (NECRInc) from schools and institutions and fast-food restaurants. The recycled PS can be reused in products such as coat hangers, flower pots, wall and building insulation, and protective packaging.

Research and Development-Many industry and government groups are sponsoring research on recycling technologies and collection systems. Worldwide patent activity indicates that innovation is occurring in reclamation technologies. For example, 450 patents covering equipment, processing, and products (for polymers that include plastics, rubber, and textiles) were issued from 7 industrialized countries in 1986, 1987, and the first 2 months of 1988 (169). Almost half of this activity (212 patents) focused on recycling products into alternative uses.

Twelve major resin suppliers of the Council for Solid Waste Solutions, a division of SPI, have each pledged $1 million a year for the next 3 years for research, development, and lobbying on plastics reuse. Research areas will include technology to minimize the costs of collecting, sorting, and reprocessing post-consumer plastics packaging (165). Producers and users of specific resins are also joining together to sponsor research. For example, the Vinyl Institute supports research on PVC recycling, and the Polystyrene Packaging Coalition is coordinating research activities on PS. NECRInc, Wellman, Inc., Eaglebrook Plastics, Inc., and Waste Management, Inc., are sponsoring joint projects to develop on-truck densification units to overcome

Box 5-E—Degradable Plastics and MSW

Most plastics are inert and designed to resist attack by microorganisms. The relative impermeability of plastics and high molecular weights tend to make plastics nondegradable (98). However, plastics can be designed to be degradable, either by physical, chemical, and/or biological means.

Two factors are driving the sales and development of degradable plastics: legislative mandates and economics. Legislative mandates can require degradable products to be used (e.g., connecting devices for containers-such as 6-pack rings-are required to be degradable in 17 States and EPA must establish similar regulations under Public Law 100-556 by 1990). Many of these laws were passed as a result of concerns about plastic litter on land and later over the entanglement of marine and land-based animals.

Alternatively, legislation can ban or threaten to ban the use of nondegradable (e.g., nondegradable fast-food packaging) because of concerns about MSW management capacity (254). For example, legislation has passed to require the use of biodegradable materials in at least two States and two localities to help with MSW management or to increase the nonfood use of surplus agricultural commodities.[1] As of May 1989, at least 31 States had legislation introduced concerning mandates for degradable products, recycling, packaging, taxes on packaging, and waste reduction (ch. 8).

Economic factors have stimulated the development of degradable products that may be more cost-effective to use than their nondegradable alternatives. For example, the use of degradable plastic agricultural mulches can save farmers the cost of removing a nondegradable mulch. However, degradable plastic products cost about 8 to 14 percent more than comparable nondegradable products (238). Degradable plastics may also provide a market for surplus agricultural commodities.

It is not clear whether degradable plastics can actually help solve MSW disposal problems, or whether degradable might actually aggravate existing problems and constrain emerging solutions like recycling. It is also unclear whether they degrade into environmentally safe byproducts. Little information is available to shed light on these issues, and this hinders the development of degradable materials. In addition, legislative bans or restrictions may have little impact on actual MSW management, because the products usually subject to bans make up a very small portion of MSW and substitutes for banned or restricted products may require more disposal capacity.

The expanded use of degradable plastics for solving MSW problems is questionable until the uncertainties about what happens to them when they are landfilled, incinerated, or mixed with nondegradable materials for recycling are answered. One role which appears promising is the use of degradable plastic bags for collecting yard wastes as part of a comporting program. Other applications that may be appropriate include the use of degradable for specialty products such as agricultural mulch (where some operational economies are associated with its use) and possibly products that cause severe litter problems or become marine debris.[2]

Another concern is that some people may see degradable plastics as a "license to litter. ' Other observers see waste in allowing plastics to degrade into ''nothing' when they have such a high energy value for incineration.

Types of Degradable Plastics

Biodegradable Plastics-There is no formal definition of biodegradable plastic, but it generally indicates a plastic that can be broken down by biological means (i.e., the metabolic activities of microorganisms such as bacteria and fungi). As the term is used, it does not necessarily mean complete biodegradation, which would be breakdown into carbon dioxide and water. Two related terms also are used. Biodisintegration is the biological breakdown of plastic into smaller sized (but not molecular) particles. Biodisfiguration occurs when the surface of the material becomes blemished or contaminated by the growth of microorganisms, but no structural changes in the material occur.

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[1] Minnesota; Iowa; Berkeley, California; Suffolk County, New York.

[2] Another specialty use of degradable plastics, using different technologies than those discussed here, is for medical applications (e.g., sutures and time-release capsules).

A number of technologies to make plastics biodegrade are being marketed or developed. One approach is to add biodegradable materials such as starch to the resin. At least three starch-based/polyethylene technologies are available for licensing or sale.[3] These technologies vary in the amount of starch used, the types of additives used to ensure degradation and shelf-life, and the need for special processing. They also vary in their claimed effectiveness, whether the starch is metabolized and thus the remaining plastic loses strength and disintegrates, or whether other chemical reactions occur that break down the plastic component into smaller particles (of lower molecular weight) that can eventually be metabolized. One firm has combined photodegradable and biodegradable technologies.

Another approach is to develop plastics entirely with biodegradable materials, referred to as “second generation” biodegradable plastics. Materials of this type are claimed to degrade into products that are naturally present in the environment. At least one technology of this type, bioengineered bacteria-synthesized resins, is being produced on a pilot scale.[4] Other products still under development include plastics made from lactic acid.

The rate of biodegradation depends on the presence of microorganisms, temperature and moisture conditions, starch content, and additives used (27 1). For example, one firm predicts that one of its starch-based products, with a shelf-life of 2 years, will biodegrade within another year into small particles (centimeter-sized or less) when the product is placed in a bacteria-rich, moist environment, and that it will continue to biodegrade depending on its composition (146). Biodegradable plastic bags are now being tested for applicability to yard waste comporting operations and suitability for food contact use. Special attention is being given to degradation byproducts and toxicity.

Photodegradable Plastics—Photodegradable refers to plastics that break down in the presence of ultraviolet (UV) light. These plastics are made by including chemicals that make the polymer sensitive to UV light (e.g., carbon monoxide, vinyl ketone, nickel, cobalt, iron) in the structure of the photodegradable plastic (98).[5] Upon exposure to sunlight, the plastic absorbs radiation and the sensitizing chemicals cause reactions that break the long plastic chains into smaller segments of the polymer. However, other cross-linking reactions may occur and make some portions of the material less susceptible to degradation (53). The subsequent biodegradation rate depends on the chemical make-up of the original polymer, particle size, and molecular weight (98). Some plastics also use ‘‘photo-initiated oxidation,‘‘ in which sensitizing chemicals continue the degradation process after initial exposure to UV light, including after burial.

Sensitizing chemicals can be selected to cause a reaction only when exposed to particular wavelengths of light. For example, plastics can be made to degrade when exposed to a sufficient amount of sunlight-i but not behind window glass since glass blocks UV penetration.

The rate of photodegradation depends primarily on UV intensity (which varies seasonally, with latitude, and time of day), length of exposure, and, to a minor extent, on thickness of the plastic (98). The time lag between exposure to UV and degradation can be controlled in the manufacturing process or the fabrication process, depending on the technology; different formulations show degredation to dust-sized particles in periods ranging from 48 hours to 1 year.[6]

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[3] These include: 1) Archer Daniels Midland additive that is used to make PE that contains 6 percent cornstarch, an unsaturated polymer, and a very small quantity (ppm) of transition metal catalyst; 2) St. Lawrence Starch masterbatch additive with 6 to 15 percent starch and a fatty acid (an earlier patent from the developer of the ADM material); and 3) Agri-Tech Industries compounds with 20 to 80 percent starch, plus polyethylene, polyethylene co-acrylic acid, urea, ammonia, and various additives depending on the application.

[4] Poly(hydroxybutyrate-valerate), or PHBV, is produced by Imperial Chemical Industries (ICI). Current production is about 100 tons per year Of a resin with properties similar to polypropylene, at a cost of $15 per pound. ICI’s goal is full-scale production of 10,000 tons per year, at a cost of $1.50 to $2.00 per pound.

[5] Carbon monoxide is incorporated during the manufacture of the resin, while vinyl ketone or metallic salts are incorporated as additives during fabrication.

[6] The 48-hour degradation resulted when 6-pack rings containing 13 percent ethylene carbon monoxide were tested. Commercial degradable 6-pack rings, however, use only 1 percent carbon monoxide to maintain product integrity and function in differing climatological conditions (121,142). As another example, “Plasugone” agricultural mulch can be designed, using metal additives, to last between 30 days and 1 year (104).

(continued on next page)

After photodegradation occurs, it is unclear whether subsequent biodegradation will be complete. Some investigators have predicted complete biodegradation in 1 year for PP and 10 years for PS (made with vinyl ketone comonomers), based on laboratory tests of biological oxygen demand (98), but other reviewers of the same tests and data question whether the biodegradation would be complete (271).

Chemical Dissolution-Plastics also have been developed that will dissolve when a chemical is added with water. After dissolution, plastic particles theoretically can be recovered and recycled back into plastics products. The developers claim the particles are similar to detergent additives, flocculants used at wastewater treatment plants, and soil conditioners, and that they are not harmful to the environment (18).

Problems With Degradable Plastics

Lack of Standard Definitions and Testing Methods-One fundamental question about degradable plastics is what the term really means. ASTM is developing standard definitions for different degradable plastics and standard tests to evaluate degradability. This work will likely result in de facto industry standard definitions within 2 years (171). More research will likely be required to develop standard testing protocols.

Without standard definitions, it can be difficult to determine what is really meant when a product is called photodegradable or biodegradable, and under what environmental conditions and timeframe the claim is valid. In general, it can be assumed that a product marketed as photodegradable or biodegradable will become brittle and break into fragments in the presence of ultraviolet light or microorganisms, respectively. It is not clear what size the fragments will be and what will happen next—whether the material will ultimately degrade into inert dust-sized particles, into organic intermediates, or eventually into biomass, carbon dioxide, and water. It is also not clear what will happen to any additives such as colorants. The General Accounting Office (254) pointed out the need to develop standard definitions and testing methods to assure consumers of satisfactory products and to facilitate manufacturers' compliance with legislation.

Uncertain Performance and Safety—Many important questions about the rate and timing of degradation in different environments and about the environmental safety of degradation products have either not been addressed or the research is only now underway. For example, FDA is concerned about the possibility of a shortened shelf-life of degradable food-packaging material. In evaluating the safety of new additives in food-contact materials, FDA must consider potential problems **such as enhanced migration of food-packaging components as a consequence of accelerated degradation of the polymer (1 11).** As **another example, little is known about what happens to plastics** when they biodegrade. It is not known how specific fungi and bacteria degrade particular plastics, if nonbiodegradable materials affect the microbes in any way, how sunlight affects biodegradable plastics, and how physical and chemical aging affect the properties of biodegradable plastics (270). Whether biodegradable plastics, including their nondegradable components, cause any hazards to animals (e.g., invertebrates, fish, birds, mammals) is unknown. Although much of the interest in degradable plastics has been stimulated by concerns about marine litter, few tests have been conducted on the degradability of available plastic products in seawater (175). Limited seawater testing of the deterioration of photodegradable material now used in 6-pack rings, as well as polyethylene and polystyrene products common] y found as marine debris, has been completed by the Research Triangle Institute for the Northwest and Alaska Fisheries Center. Scientists are now concerned that degradable plastics in marine waters may serve only to substitute one hazard for another. That is, with the use of degradable plastics, the hazard of ingesting plastic fragments may replace the hazard of entanglement in nondegradable plastics. Tests of degradability of some products in landfills are also planned (147).

A few communities (e.g., Urbana, Illinois, and Lincoln, Nebraska) are testing biodegradable mulch/trash bags for disposal of leaves and grass clippings. Results of the first year pilot study in Nebraska raised questions about the rate of degradation of the bags and fate of color additives (102). A second year of testing is planned with more rapidly degrading bags and alternative collection of yard waste in large trash containers. Preliminary tests of garbage bags made of a photo-initiated oxidation material showed that only bags of leaves on top of a pile began to degrade (46). It maybe difficult to ensure the adequate exposure to UV prior to burial so the bags will continue to degrade once buried or landfilled.

Uncertain Impact on Recycling---One concern about degradable plastics is that expanding their use might adversely affect plastics recycling. The plastics industry (i.e., those who produce nondegradable plastics) contends that if degradable plastics get mixed into the post-consumer plastic waste stream destined for recycling, they might threaten the physical integrity of products made from recycled plastics. In turn, this could cause complicated liability problems for product manufacturers and potentially reverse current increases in the recycling of plastics.

Technical experts who work with degradable plastics disagree. They contend that potential adverse effects will vary depending on the particular degradable plastic, but that the problems will be minimized by: 1) dilution of the degradable material in the overall volume of MSW; 2) addition of appropriate steps to the recycling process (e.g., separation of degradable, chemical treatment, use of additives) to negate any effects of degradable materials; or 3) careful consideration of the intended uses and properties of the recycled products. They consider quality control of the incoming resin, processing, and the final product as the key to avoiding adverse impacts of degradable plastics on recycling.

Markets for Degradable Plastics--Commercial products made with degradable plastics include 6-pack ring carriers, agricultural mulches, and trash bags. Sales of these products are approximately $100 million per year, less than 0.1 percent of the overall $150 billion plastics market in the United States (104).

Over half of all degradable plastic sales are of polyethylene beverage packaging rings. About 30 percent of these 6-pack rings are photodegradable, as required now by various State laws (104). This market share is expected to rise as Public Law 100-556 is implemented; this law requires EPA to regulate the use of certain degradable ring-type devices by 1990, and it asks for a report on the feasibility of expanding the requirements to other packaging systems.

The market shares for other degradable plastic products are very limited to date, but some may be growing. For example, degradable garbage bags have captured 10 percent of the market in New York City, Boston, and Hartford (104). Several communities are distributing degradable bags for yard waste collection. Many additional potential products are being investigated for degradable plastics, including films, bottles, and other containers.

some of the problems associated with collecting high-volume plastic containers.

The Plastic Recycling Foundation, another industry group, had a budget for 1988 of $1.2 million. Much of this funding (along with funds from the New Jersey Commission on Science and Technology, Rutgers University, other States and universities, and the National Science Foundation) has been awarded to the CPRR. The Center's total 1988-89 research budget was $2.3 million. Over half of the funds will support research on reclamation, end use markets, sorting, and collection. The remaining funds were used for pilot plant experiments and information services (193).

ProjectedMarkets for Single and Mixed Resins—An estimated 6.2 million tons of plastic containers and packaging are projected to be discarded in 1990 and this is expected to increase to 8.2 million tons by 20(K) (81). If market projections are realized for recycled PET and HDPE, by the mid-1990s the Nation could achieve a 10 percent recycling rate for plastic containers and packaging. If recycled plastic products could capture a significant share of the treated lumber market, plastics could achieve a 25 to 40 percent recycling rate for packaging over the next decade. However, if recycling rates are calculated by comparing the amount recycled with all plastics discarded, rather than with containers and packaging discards, then plastic recycling rates will more likely be around 5 percent by the mid-1990s, if only the projected HDPE and PET recycling is realized, or between 15 and 20 percent if the treated lumber market is captured.

Additional market development will be necessary to accommodate expanded collection of post-consumer plastics. Expanding the use of recycled plastics to replace some virgin resin markets, tap nonplastics markets, and attract the interest of particular industries (e.g., automotive and construction) will require some effort.

PET—Projections of the amount of PET that might be recycled by 1993 range from about 300,000 to 350,000 tons, or at least 50 percent of all PET beverage bottles (22,172). This would replace up to 4 percent of virgin PET sales. These increased amounts could be sold easily in established and newly developing markets. For example, Wellman, Inc., the company that now recycles about 75 percent of all recycled PET beverage bottles, claims it could use two to three times the number of available bottles, and it plans to more than double the size of its operation by 1990 (21 1). Wellman, Inc. has also recently announced plans to work with Browning-Ferris Industries, a major waste hauler, to collect PET bottles. Dow Chemical Co. has announced plans for a joint venture to reprocess 25,000 tons of PET and HDPE per year into high-value building materials like roofing shingles by 1990. Dow is one of the first producers of commodity thermoplastics to move into the recycling business (165).

HDPE—in 1987, approximately 36,000 tons of HDPE were collected for recycling, up from about 30,000 tons in 1986 (22). The current potential market for recycled HDPE is estimated to be about 200,000 tons (54) and is projected to be as much as 330,000 tons by 1993; if the latter level were achieved, almost 6 percent of virgin HDPE sales would be displaced. The use of recycled HDPE is expected to increase and expand into new markets including nonfood bottles (193). The Proctor & Gamble Co. plans to include 20 to 30 percent recycled HDPE in non-food bottles (166).

Mixed Resins—Products from mixed plastics are technically capable of replacing a portion of the treated lumber market, especially decorative landscape ties and erosion control applications (21). This market was estimated at 1.8 million tons per year. However, it is questionable how much and how rapidly mixed plastics markets can be developed. Investment in technologies for mixed plastics recycling is very limited in the United States. OTA could only identify four U.S. businesses using post-consumer waste to produce mixed plastics products (Polymer Products in Iowa; Processed Plastics, formerly Summit Steel Processing Corp., in Michigan; NECRInc in Massachusetts; and CPRR in New Jersey). Both NECRInc and CPRR began operations in early 1988 and the CPRR facility is a research/pilot-scale operation.

Plastic lumber from mixed resins may also have to compete with plastic lumber products made from single resins, both recycled and virgin. The appearance and properties of these single resin products can be controlled more easily than similar products made from mixed plastic wastes, and thus may be able to tap more specialized markets.

Comporting

Comporting refers to the process of biological decomposition of solid organic materials by microorganisms (mainly bacteria and fungi). "Compost" is the stabilized, humus- or soil-like product.[43] Comporting has been popular for years because compost products help improve soil structure. Now it is gaining favor as an MSW management method because, in addition to stabilizing organic materials, it can divert them from landfills and reduce some of the risks associated with landfilling and incineration (chs. 6 and 7). (Another way of handling organic materials involves anaerobic bacteria, but this process does not produce compost; see box 5-F).

Comporting involves manufacturing a product, just like other industrial practices, and its effectiveness depends on how well the decomposition process is designed and controlled. To maximize the rate of microbial activity within a mass of organic materials, factors such as temperature and moisture must be controlled. With proper controls, comporting can occur rapidly, yield a product that meets end-use quality specifications, and reduce the original volume of the materials by more than 50 percent.

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[43] "Stabilized" refers to the point at which microbial activity reaches a low and relatively constant level.

The biodegradable organic materials in MSW include yard wastes (i.e., leaves, grass clippings, weeds, prunings), food wastes, and paper from residential, commercial, and institutional uses. Yard wastes make up 10 to 30 percent of MSW, although this portion varies greatly geographically and seasonally; food waste constitutes another 5 to 10 percent (ch. 3).

A critical decision has to be made prior to comporting-whether to keep the organic materials, particularly yard wastes, separate from other components of MSW, or to begin with mixed MSW and extract the organic materials later for subsequent comporting.[44] Yard wastes that are kept separate from the rest of MSW can be handled and composted easily-they require fewer controls on the comporting process itself and yield products that tend to have low levels of contaminants. This is especially true for leaves, and many facilities have been dedicated solely to leaf comporting. However, the disadvantage is that separate collection of yard wastes is necessary. In contrast, mixed MSW must be mechanically sorted into different portions prior to comporting (43).[45] The disadvantages of mixed MSW systems are that mechanical separation involves more equipment and higher capital and operating costs, subsequent comporting requires greater control, and the resulting product tends to have higher levels of metals. Mixed MSW systems can be desirable, however, because they handle the entire waste stream and do not require special collection efforts.

Biological Decomposition

Microorganisms, or microbes, are the essential agents of decomposition. To maximize the rate of microbial activity, the comporting process must be designed to properly control factors such as temperature, oxygen and nutrient availability, physical substrate, moisture, and pH (43,71-76,90,178,229).

Box 5-F—Anaerobic Systems

Anaerobic systems use bacteria that do not need oxygen (i.e., anaerobic bacteria) to convert organic materials into saleable methane gas and carbon dioxide. Anaerobic systems do not produce compost. They can be attractive, however, because methane gas can be an alternative to natural gas (38). Several methane recovery systems are operating in Europe and Japan, and laboratory-scale research has been conducted in the United States (62).

One demonstration plant in Florida was built specifically to test methane production from MSW (38,188,263). The plant processed up to 100 tons of MSW per day and was operated for research purposes between 1978 and 1988. The plant had ‘‘digestor’ reactors that used fermentation and other anaerobic reactions to yield methane and carbon dioxide; these reactions required careful control of parameters such as temperature and pH (188). The methane gas was purified to remove acid gases, water vapor, and other impurities.

In France, the Valorga Company opened its first plant in 1981, with a 60-ton-per-day capacity (1 15). This plant mechanically separates glass and metals, then the organic wastes (i.e., food and paper) undergo anaerobic fermentation in the digesters. The resulting methane gas is captured. About 30 percent of the MSW remains after processing and is incinerated. A new plant designed to handle about 300 tons per day (including sewage and industrial sludge) cost about $19 million (1 15). The plant was not fully operational as of October 1988, and only the sale of gas (to Gas France, which is a 20 percent owner) and scrap ferrous metals had been arranged; no buyers had been found for cullet or the compost-like product (“digestate”). The plant appears to have some problems with materials becoming contaminated during the mechanical separation

Temperature is a key factor controlling the comporting process because the microbes that decompose organic material can survive and function efficiently only at certain temperatures. **As** microbes decompose organic material, they generate heat as a metabolic byproduct. The organic material loses its original identity and eventually becomes stabilized, at which point microbial activity ceases and heat generation subsides. However, the material can retain excessive heat, and if temperatures rise above 60° C before the material is stabilized the

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[44] Yard and food wastes also can be composted or mulched in backyards. OTA considers this to be a form of waste prevention (ch. 4).

[45] Most mixed MSW composting operations use mechanical processes (e.g., screens, magnets, air classifiers, trommels, hammermills, and shredders) and/or handsorting to remove materials such as tires and bricks, recover recyclable materials such as glass and ferrous metals, reduce particle size, and mix the waste,

Photo credit: Office [illegible] Technology [illegible]ssessme[illegible]

Composting [illegible] decompos[illegible] d [illegible] organic material by micro[illegible]organisms [illegible] gaining [illegible] as a management method because [illegible] diverts material [illegible] and [illegible] reduce some [illegible]ks associated with [illegible] and [illegible]. [illegible] its effectiveness depends [illegible] how well the decomp[illegible] process [illegible] designed and [illegible]ed.

microbes begin to die and further microbial activity is severely limited. In practical terms, then, temperatures sufficient for microbial activity must be maintained, but excessive temperatures must be prevented. Deliberate removal of heat from the material often is essential, although low-level leaf comporting appears to be an exception. According to some researchers, current EPA guidance on comporting leads to inhibitively high temperatures and improper functioning (73,74,75,76).

Because comporting relies on aerobic bacteria (i.e., bacteria that require oxygen), sufficient oxygen must be available, either from air in the spaces between particles or from air immediately outside the waste mass. Sufficient aeration results in greater microbial activity, faster and more complete decomposition, and more control over odors and pathogens (43,71 ,72). Excessive aeration can reduce temperatures below those best for maximum microbial activity; insufficient aeration leads to overheating, minimal activity, and foul odors.

In general, if temperatures are maintained properly and the mass of materials is ventilated, then oxygen availability is assured. Ventilation can be accomplished effectively by blowing air through the mass (i.e., forced aeration) and to some extent by mechanically agitating the mass (i.e., turning, stirring, or tumbling). In some cases, ventilation is conducted in conjunction with temperature controls (71-76). Agitation also helps control temperature and moisture, reduce particle size, and increase bacterial access to nutrients by replacing "used" substrate with "fresh" material.

Curing and Finishing-once initial comporting is complete, composted materials must still be ''cured' to ensure that the product is stabilized (i.e., biological activity is low enough so few odors are present). Depending on the system, this can take several months or more. After curing, compost can be 'finished' or upgraded to meet market specifications by using methods such as screening, pulverization, destoning, pelletization, and crumbling (207). Compost also can be enhanced by adding nitrogen, mixing with peat or other products for use by nurseries, or blending with other soils for landscaping (43).

System Configuration

The configuration of a comporting system refers to the layout of equipment and machinery used for handling materials and for ventilation, along with any enclosing structures or special features (71,72). These features can be combined in numerous ways.

General Terminology—The language of comporting configurations typically uses terms such as windrow, static pile, and in-vessel or reactor systems. However, this terminology has been criticized for overemphasizing the physical design of a comporting facility and underemphasizing the biological decomposition process (71 ,72). According to critics, any of these configurations might be compatible with effective, ventilation-based control of the process, so the terms do not indicate the key factors affecting the biological process. OTA agrees that the process is more important than design; the design of a particular facility will depend more on the needs of a particular community (e.g., location, costs). The terminology is still widely used, however, so the terms are described briefly.

Windrow and Static Pile Systems-Windrow and static pile systems typically process material in an unconfined area, and the product is stored in piles to undergo further stabilization. The size and depth of windrows and piles are limited by several factors, particularly compaction, ability to ventilate and agitate, moisture, and temperature (43,71 -76). In windrow systems, compostable material is placed in elongated piles or “windrows” and then is agitated to increase aeration. In static pile systems, large piles are formed over a network of perforated pipes that pull (i.e., vacuum) or force (i.e., inject) air through the material (207).

In-Vessel Systems—’’In-vessel” or “reactor” systems process material in confined structures. A few of these systems have operated for over 30 years (43,68,178,224). Most systems co-compost sewage sludge with the organic portion of MSW (24,90,21 5). Sewage sludge increases the moisture content and adds nitrogen, which helps the growth of microbes, but it also can increase odor problems and potential contamination with metals. Additional research is needed on the quality of compost products obtained from co-comporting operations.

***Configurations for Leaf* Composting-Leaf *com*-**posting can be accomplished with relatively simple system configurations. For example, most leaf comporting systems do not require deliberate ventilation (71,72), although they can be designed with this feature. This simplicity is attractive because leaves are a significant waste management problem in some communities. In some areas, for example, leaves and grass clippings can comprise over 60 percent of the MSW generated at residences during summer and fall (88,207,229).

Although leaf comporting systems are generally simple, a range of configurations still can be used depending on the needs of a particular community (228,229). In **minimal** technology systems, the only activity is turning large piles of leaves once a year; compost is produced in 2 to 3 years. A large buffer area is needed, however, because the piles become anaerobic and odorous. In low-level systems, front-end loaders turn smaller piles several times a year so the piles do not become anaerobic as readily; compost is produced in 1 to 2 years. In **intermediate** systems, piles are watered periodically and turned by specially designed machines; compost is produced in 6 to 12 months. **High-level** systems produce compost in less than 6 months by grinding leaves before comporting, providing more aeration and turning, and controlling temperature and moisture. Minimal and low-level systems thus require less management and expense, but more time and space. Intermediate and high-level systems require more control over the biological processes, but more capital investment.

Operational **Problems**

Odors-Odors usually indicate that the process of biological decomposition is not proceeding properly. Odor generation can be controlled, however, through proper temperature controls and agitation. Grass clippings often cause odor problems because their high moisture, nitrogen. and organic content makes them decompose rapidly, which can lead to anaerobic conditions (229). As an alternative, homeowners can leave clippings on lawns after mowing, as long as they are not too thick (208).

Leachate-Leachate formation can occur when the moisture content of the comporting material is too high. Source-separated organic materials, for example, tend to have a higher moisture content than does mixed MSW (77,1 15). Leachate can be collected several ways, including conducting operations on a paved surfaced designed to collect leachate or by collecting runoff in sedimentation ponds (43,233). Important questions are whether heavy metals are leached from compost and whether organic chemicals (e.g., pesticides) are present and leachable (see “Pollution From Primary and Secondary Manufacturing Processes” below).

Pathogens, Plants, and Fungi—Various pathogens (e.g., bacteria such as *Salmonella,* parasites such as *Ascaris) can* be present if comporting is not well controlled. The existence of pathogens varies with the type of waste, but potential contamination is higher when co-comporting with sewage sludge occurs. Some microbes also can be released into the air on dust particles and aerosols generated during composting (43); health effects related to inhalation of *Aspergillus fumigatus,* for example, have been of concern, although none have been documented (228). Weed seeds and fungi also can be present in yard waste and sewage sludge and thus can reduce final product quality. In general, temperatures over 50” C, maintained throughout the entire comporting pile for a sufficient time, are needed to destroy pathogens and weed seeds (71,72,91,178); comporting cannot continue above 60° C, however, or the microbes needed for decomposition begin to die.

Operational Facilities

Mixed MSW Facilities-At least six mixed MSW comporting facilities currently operate in the United States (table 5-6), and one additional facility is being built in Minnesota. Most of the composting facilities that operated in the 1950s and 1960s closed because of economic or technical problems (90,207,252). About three dozen additional projects are in the planning, design, and bid stages (207). Portland, Oregon, for example, began negotiations in July 1988 to build a $23 million comporting facility (120,265); the facility would process 180,000 tons of waste and produce about 100,000 tons of compost annually.

Five of the existing facilities are publicly owned, and at least three co-compost with sewage sludge. The Delaware facility is designed to process 1,000 tons of MSW and 350 tons of sewage sludge per day; the planned Minnesota facility also will be large, with a capacity of over 1,000 tons per day. The other facilities are relatively small and began operating only recently (43). The Delaware facility and the facility under construction in Minnesota are designed with front-end mechanical separation. Besides separating various materials for recycling (e.g., metals, glass) and producing RDF (from plastics and paper), the Delaware facility can produce about 180 tons of finished compost per day (24); the operators expect to market about half of the output to the fertilizer industry.

Limited information is available about the costs of mixed MSW comporting. Total capital costs for existing facilities range from $700,000 (1987 dollars) for the Minnesota facility to $73 million (1983 dollars) for the Delaware facility (161,252); this corresponds to about $13,000 to $54,000 per ton of design capacity. Aside from size, differences in capital costs are related to equipment specifications, construction and insurance costs (43), and storage space requirements (237). Operation and maintenance costs have been estimated to range from about $17 to $33 per ton (43).

Mixed MSW comporting has been more common in Europe than in the United States, and a few facilities have proven successful over long periods of time (23,68,106,141).[46] However, many facilities (e.g., in Belgium, Switzerland, West Germany, the Netherlands, and Sweden) have had difficulties marketing their products (23,106,1 15). Mixed MSW comporting has declined in Sweden, which had a high rate, because of problems with heavy metals and marketing (23). Even before this, many Swedish facilities simply transported much (between 61 and 80 percent) of their compost to landfills (23,115).

Yard Waste Programs—Many communities in the United States compost yard wastes, especially leaves. Yard wastes are collected several ways, including using front-end loaders to pick up bags, vacuuming from curbsides, and using packer trucks to empty waste bins. No estimate of the total number of yard waste facilities exists, but hundreds are known, for example, in New Jersey, Michigan, Wisconsin, and Minnesota (88,151,161). As of December 1988, New Jersey alone had 180 permitted facilities, most for leaf comporting; the State uses a manual on leaf comporting as its guidance document for such facilities (229). In Massachusetts, about 25 percent of all municipalities participate in yard waste comporting programs (209). However, these States have not estimated the amount of yard waste handled, and most do not have specifications regarding the quality of final products from such programs. Numerous reports describe local programs (e.g., 25,217,233).

Few data are available on the costs of yard waste comporting. In one study of eight municipal operations, collection and transportation costs to the municipality ranged from $0 (where residents or landscapers dropped wastes off at a facility) to over $80 per ton, and processing costs ranged from $4 to $23 per ton (233). In general, collection and transportation costs were 1 to 11 times greater than processing costs. For leaf comporting, operating costs for low-level systems are estimated to range from $2 to $4 per cubic yard (228).

Comporting of yard and food wastes that have been separated from other MSW is increasing in Europe (77,1 15,103,156). In West Germany, for example, in 1988 at least 71 source separation projects existed for organic wastes (93,218). These projects served an estimated 430,000 households,

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*study indicated that France had over 100 comporting facilities in operation (194). However, most of these plants probably arc sludge comporting or co-comporting plants (136).

Table 5-6-Operational Mixed MSW Composting Facilities in the United States

Location	Year opened	Processing capacity (tpdof MSW)	Type of composting system	Co-compost with sludge
Wilmington, DE	1984	1350	In-vessel	Yes
Sumpter County, FL	1988	65-100	Windrow	NA[b]
Dodge City, KS	1987[a]	30	Windrow	NA
St. Cloud, MN	1988	50	In-vessel	Yes
Fillmore County, MN	1987	25	Windrow	No
Portage, WI	1986	30	In-vessel	Yes

[a] Not commercially operating; run for research and demonstration by vendor.
[b] Information not available.

SOURCES: Cal Recovery Systems, Inc., "Composting Technologies, Costs, Programs, and Markets," contract report prepared for U.S. Congress, Office of Technology Assessment (Richmond, CA: January 1989); Ron Albrecht Associates, Inc., Composting Technologies, Costs, Programs and Markets," contract report prepared for U.S. Congress, Office of Technology Assessment (Annapolis, MD: December 1988).

and they composted an estimated 200 pounds per person of organic wastes each year. Heidelberg's program is one of the largest, serving over 100,000 people (78,1 15).

Food Wastes—No MSW facilities in the United States are used solely for comporting food waste (252). Some U.S. companies, however, collect and process certain food wastes. For example, one operation in Virginia collects waste grease, bones, fat, and offal from slaughterhouses, restaurants, and supermarkets and processes it into an animal feed additive (126). In New Jersey, some farmers are licensed to collect food wastes and feed them to swine (58).

Products, Markets, and Standards

The main value of finished compost is its humus-like characteristic, which can help improve soil by adding organic matter and increasing water-holding capacity. The positive effects of compost on plant growth and yield are well documented (178,194). The nutrient content of compost is low relative to chemical fertilizers, however, so compost usually is not used as a fertilizer unless it has been chemically enhanced (43,178,267). Compost products are used by many businesses (e.g., private landscapers and contractors, vineyard operators, farmers, golf course operators, topsoil and nursery industries), public institutions (e.g., public works and parks departments), and some individual homeowners (207).

In general, municipalities should not expect composting to be profitable; revenues from the sale of compost products can only partially offset operating costs (71 ,72,267) (see ch. 2). Gross wholesale revenues for yard waste compost products exhibit a wide range, from $0 (when given away for free) to $25 per ton (233). Products that cannot be sold or distributed usually have to be used as cover material at landfills.

General Market Demand-Each end use of compost requires that the product meet certain specifications. As a result, consistent quality, as well as consistent availability, are critical in determining marketability (43). Mixed MSW, or organic waste from previously mixed MSW, usually contains small pieces of glass and plastics, stones, and other objects. Mechanical screening processes can remove much, but not all, of these materials. Whether these contaminants are a problem depends on the end use of the product.

In general, products with consistently high quality are required for food production and horticultural uses, while products with lower quality can be used for revegetation and landfill cover (71 ,72). A top-grade product generally has dark color and earthy smell, minimal pathogens and toxic substances, uniformly small particle size, and proper nutrient and moisture content (43).

The potential market for compost products is impossible to quantify, but proponents contend that existing markets are small relative to their potential (24,43,61). However, compost must compete with sewage sludge compost and other products (e.g., sawdust, fish processing wastes, peat products, manure, bark, natural topsoils). Almost 200 sludge comporting facilities are operating or are being planned, and competition is likely to increase in the

Northeast and mid-Atlantic regions (2). Many compost products are only marketed locally because their weight and bulkiness (e.g., 700 to 1,000 pounds per cubic yard) makes transport expensive and energy-intensive.

The market for compost in large-scale agriculture is small, because compost is not intended to be used primarily as a fertilizer and because of its bulkiness. Given increasing concerns about depletion of organic matter in soil, however, some analysts consider farmers to be a strong potential market for using compost as a soil conditioner (43,237). Overall energy use in agriculture also might decrease if compost could help reduce dependence on energy-intensive chemical fertilizers and lower the energy needed for soil preparation (61).

The potential market for compost in landscaping (horticulture) and smaller scale agriculture (e.g., row crops and orchards) may be large (43). Market evaluations indicate that landscape contractors and suppliers, sod services, nurseries, and retailers of soil conditioners are likely to show increased interest in bulk compost (237). Homeowners represent another potentially large market for bagged products. Marketing surveys, however, indicate that many individuals are reluctant to use composts made from MSW and sewage sludge (43).

***Standards*-Many** States require comporting **facilities** to obtain permits from the relevant environmental or health agencies (161,207). For mixed MSW facilities, permits can require hydrogeological site investigations, studies of odor dispersal, and monitoring plans. Some States (e.g., Florida, Massachusetts, New Jersey, and New York) require water pollution controls. Local regulatory agencies also may issue permits to address storm water and sediment control.

Yard **waste** facilities tend to be regulated less stringently than mixed MSW facilities. For example, Michigan, Pennsylvania, Texas, Virginia, and Wisconsin do not require community operations to obtain a permit, and New Jersey recently made it easier for small operations to obtain permits. Some proponents suggest that these facilities continue to be less stringently regulated (88). Although this approach would provide incentives for yard waste comporting, it would not necessarily ensure protection of human health and the environment or the production of compost products that meet specifications.

State policies regarding the use of compost **products vary** widely (43). Regulations for products from mixed MSW are based on EPA guidelines (40 CFR 257) and Department of Agriculture standards (e.g., for chemical quality) originally developed to address the application of sewage sludge to land (177,207). The guidelines set the maximum rates at which metals can be added to soil, based on the fate of metals and their impact on the food chain, soil properties, and crop types. More research is needed on the extent to which leaching of metals and uptake by plants **occurs.**

Few States have developed standards for different classes or uses of compost. Similarly, few standards exist to regulate organic chemicals (e.g., pesticides) in compost products. Some States, however, are beginning to regulate these products (table 5-7). For example, Minnesota has proposed standards to control the levels of contaminants in compost products. Under these rules, Class I compost, made without sewage sludge and containing metal and PCB levels below specified limits, would be safe for unrestricted use. Class II compost, either made with sewage sludge or containing levels of metals and PCBs above the limits, would be restricted according to soil properties and land use.

Future comporting regulations could be designed in several ways. For example, they could require testing of compost products (e.g., for toxicity) or they could specify performance standards to be met by comporting processes and facilities.

Another problem is the lack of guidelines or standards to help municipal buyers of comporting technologies evaluate claims about decomposition rates and product quality (43,72). Some vendors of mixed MSW systems claim, for example, that they can produce a stable compost product in a relatively short time (less than 2 weeks in some cases).

Pollution From Primary and Secondary Manufacturing Process

Proponents of recycling have made many claims about the relative levels of pollution generated by primary and secondary manufacturing processes, often arguing that recycling reduces pollution. In

Table 5-7-Selected State Standards for Compost Products
(parts per million dry weight)

	Minnesota[a]	New York[b]		Massachusetts[c]	
Substance	Class I	Class I[d]	Class II[d]	Class I[d]	Class II[d]
Boron				300	300
Cadmium	10	10	25	2	25
Chromium	1000	1000	1000	1000	1000
Copper	500	1000	1000	1000	1000
Lead	500	250	1000	300	1000
Mercury	5	10	10	10	10
Molybdenum				10	10
Nickel	100	200	200	200	200
Zinc	1000	2500	2500	2500	2500
PCBs	1	1	10		

[a] For any compost made without sewage sludge; if levels are met, unrestricted use is permitted.
[b] For sewage sludge and mixed MSW compost,
[c] For sewage sludge, mixed MSW, and yard compost.
[d] Class I refers to food crops; Class II refers to non-food crops.

SOURCES: Cal Recovery Systems, Inc., "Comporting Technologies, Costs, Programs, and Markets," contract report prepared for U.S. Congress, Office of Technology Assessment (Richmond, CA: January 1989); M. Mayer, H. Hofer, and U. Maire, "Trends in Yard Waste Comporting," BioCycle 29(6): 60-63, July 1988; Minnesota Pollution Control Agency, "State Solid Waste Policy Reportl, A Focus on Greater Minnesota, Background Paper XII: Composting," Office of Waste Management Grants and Assistance, draft report (St. Paul, MN: December 1988); C.J. Rosen, N. Schumacher, R. Mugaas, and S. Proudfoot, Comporting and *Mulching: A Guide to Managing Oganic Wastes,* Minnesota Extension Service Report AG-FO-3296 (St. Paul, MN: 1988).

general, recycling may result in fewer pollutants when the entire MSW system is considered, In particular, if recycled products replace products made from virgin materials, potential pollution savings may result from the dual avoidance of pollution from manufacturing and from subsequent disposal of replacement products made from virgin materials.

However, it is usually not clear whether secondary manufacturing produces less pollution per ton of material processed than primary manufacturing. Such an analysis, which is beyond the scope of this report, would have to examine all the pollutants produced during each step in production, as well as pollution generated while providing energy to the process itself and for transporting materials. It would also be necessary to account for the effects of water and raw materials use on ecological systems. Definitive research has not been conducted, however, on all the relevant primary and secondary materials processes. To provide a starting point, this section reviews some comparisons of manufacturing using recycled versus virgin materials. Box 5-G briefly illustrates some of the pollutants generated in secondary manufacturing processes,

Numerous publications have documented pollutants emitted from manufacturing processes that use virgin materials (e.g., 131). In the mid-1970s, EPA concluded that recycling of waste materials generally resulted in less pollution than did manufacturing from virgin materials (251).

This generalization does not necessarily hold true in all cases. Using EPA data on paper production processes, for example, one researcher found no clear difference in measurements of chemical and biological oxygen demand and of total suspended solids in water effluents from recycling and virgin materials processes (262). The EPA data also indicated that 5 toxic substances ''of concern" were found only in virgin processes and 8 were found only in recycling processes; of 12 pollutants found in both processes, 11 were present in higher levels in the recycling processes.

This researcher also noted that EPA's analyses of pollutants from virgin materials processing did not account for pollution from mining, timbering, and transportation (262). He concluded that "there are clear materials and energy conservation benefits to recycling, [but] the picture regarding environmental benefits and risks is complex, especially when

Box 5-G-Pollutants Generated in Secondary Manufacturing Processes

Heavy Metals

Iron and Steel Recycling—Solid wastes produced by iron and steel foundries that primarily use ferrous scrap can contain lead, cadmium, and chromium; these wastes may be classified as hazardous (181). Sludges from core-making processes and baghouse dusts also are hazardous in some cases, depending on emission controls and the quality of incoming metal. Oman (181) cited one study indicating that"9 out of 21 foundries generated emission control residuals which would be considered as a hazardous waste on the basis of EP toxicity for lead. Air emissions also are common. Electric arc furnaces, which normally operate on 100 percent scrap, avoid some air emission problems because they do not use coke oven gases as a heat source; however, they can emit high levels of particulate if they use scrap with high concentrations of dirt, organic matter, and alloys (131).

Aluminum Recycling—When aluminum scrap is melted, associated substances (e.g., painted labels, plastic, and oil and grease) are burned off. The resulting air emissions can contain particulate matter in the form of metallic chlorides and oxides, as well as acid gases and chlorine gas (261). Similar types of emissions are likely from plants that smelt other scrap metals.

Paper Recycling—Printing inks often contain pigments that contain heavy metals such as lead and cadmium (261). These and other metals can be present in wastewater and de-inking sludge from paper recycling; for example, de-inking sludges have been reported with lead concentrations ranging from 3 to 294 ppm (dry weight) (64).

Materials Recycling Facilities (MRFs)—Very little testing has been conducted at MRFs to determine levels of pollutants. Even the results of testing that has been done at one facility that handles sorted paper, glass, and metals are ambiguous. At that facility, air withdrawn from within the building (i.e., prior to emissions controls) exhibited relatively low emission rates (in terms of pounds per hour) for cadmium, chromium, lead, mercury, and nickel (117,262). However, actual concentrations of the metals in the emissions were high. No data were available about emissions after air pollution controls or on heavy metal concentrations in dust that settled in or around the plant.

Comporting—Concentrations of heavy metals tend to be higher in compost from mixed MSW comporting **facilities than from compost made from separately collected organic wastes, primarily because mechanical separation** cannot remove all metals. Compost from MSW that is co-composted with sewage sludge also tends to have high metal concentrations. Sewage treatment processes remove metals from effluent and concentrate them in sludge, and this emphasizes the role industrial pretreatment programs can play in reducing the metals entering treatment plants (240). The concentrations of metals in mixed MSW compost and co-compost samples vary from site to site (161). In some cases, zinc and lead exceeded State limits (26), while in other cases lead levels were lower than the limits. Problems also have been noted with heavy metals in mixed MSW compost in Europe (23,92,101,1 15,132,149,156). In one West German study, average concentrations of seven heavy metals were almost always lower in compost made from source-separated organic waste; in some cases they were essentially the same as soil concentrations (77,78). More research is needed on the composition of leachate from compost products under different conditions.

Dioxins

Dioxins can be produced at paper mills, as a byproduct of pulp bleaching, and can be present in the effluent or sludge (241). Limited testing by EPA has shown that concentrations of 2,3,7,8-TCDD in sludges from two mills that use waste paper are relatively low, ranging from 2 to 37 parts per trillion (17).

Dioxins also have been detected in post-pollution control emissions from certain secondary metals smelting facilities. For example, dioxins have been reported in post-control emissions from (127):

c steel drum reclamation;

. scrap wire reclamation (combustion to remove wire insulation, with afterburner); l and

. metals recovery from electronic scrap such as telephones and circuit boards (combustion, with afterburner and baghouse).

Other Organic Chemicals

Paper—Inks that need to be removed during recycling also contain acrylics, plastics, resins, varnishes, defoamers, and alcohols, some of which are discharged in wastewater. Paper recycling processes, particularly those with a bleaching step involving chlorine, also are known to discharge effluents that contain various chlorine-based compounds, including carbon tetrachloride, dichloroethane, methylene chloride, and trichloroethylene (261). In addition, the dispersing agents used in the de-inking processes (e.g., detergents and emulsifiers) end up in the sludge.

Plastics-Residues from the recycling of plastics are difficult to assess without knowing the specific details of proprietary systems used to wash materials and remove contaminants. Wash water and air emissions may be contaminated by residues from other products associated with recycled plastic, such as food or pesticides. At least one PET reclamation system planned to operate at a scale of 25,000 tons per year by 1990 will use 1,1,1-trichloroethane to remove residues. This toxic solvent is a well-known groundwater contaminant (239). However, according to Dow, the developer of the technology, the solvent is used in a closed system that will not result in release to the environment (165).

Compost—Few data are available on organic chemicals in compost. Compost from the Delaware facility has been found to contain PCBs in concentrations up to 5 parts per million (42), which is below the allowable limit of 10 parts per million set in Delaware's regulations. Questions have been raised about chemicals in grass clippings, particularly nitrogen from fertilizers and organic chemicals from pesticides (228). Many of these chemicals are insoluble and may bind to particles instead of being leached into groundwater, but there is little data to evaluate this. It also is unclear whether they could be taken up in food crops grown on compost containing the chemicals (228).

Chlorine and Sulfur

Chlorine and sulfur are common components in many products and chlorine is used in some recycling processes, so it is not surprising that both elements are found in residues at recycling facilities. For example, Visalli (262) calculated that uncontrolled emissions from one secondary aluminum smelter contained 1.7 pounds of hydrogen chloride and 1.8 pounds of $S0_2$ per hour.

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[1] It is likely that dioxins and furans are produced from burning plastic wire coating. Wire scrap makes up a small percentage Of total metal scrap processed.

specific hazardous pollutants are taken into account. '

Paper

Virgin pulp processes generate various liquid and gas residues, depending on the type of paper, type of pulping process, and extent of bleaching (131). In general, large amounts of mill effluent are generated and this contains suspended solids, dissolved organic solids, various chemicals, and high BOD. Wastewater generated in the bleaching stage can contain dioxins, chlorine dioxide, hypochlorite, and other bleaching chemicals and byproducts. Spent liquor generated in the pulping process can contain a wide variety of chemicals; the liquors often are burned in a recovery furnace or fluidized bed. Other byproducts from the virgin paper process also can be *used to* generate energy. Gas emissions include chlorine, chlorine dioxide, sulfur dioxide, particulate, and hydrogen sulfide. Metals from de-inking are present in sludge residues; the concentration of lead in these sludges appears to be in the same range as in sludges fro-m mills that use secondary fibers (64).

Aluminum

At primary aluminum smelters, one major concern is with the ‘potliners’ ‘—pots lined with carbon that serves as the cathode and that contain compounds of aluminum, fluorine, and sodium. The potliners are replaced every 4 or 5 years, and disagreement has arisen over whether used potliners should be listed as a hazardous waste under RCRA. As of August 1988, EPA has been required to list potliners as hazardous waste. The aluminum industry claims, however, that potliners can be used to fire cement kilns, among other things, and therefore should not be considered a “waste. The designation of potliners as hazardous waste discourages this recycling. Most aluminum smelters in 1989 are disposing of spent potliners in hazardous waste landfills.

Steel

Various residues are generated during the steps necessary to produce steel (e.g., coking, sintering, ironmaking, steelmaking, rolling, and finishing steps) (131). Air emissions from coke ovens, for example, contain particulate and sulfur dioxide. Wastewater from steelmaking contains suspended and dissolved solids, oxygen-demanding substances, oil, phenols, and ammonia. Solid waste residues also are common, particularly from open hearth and oxygen furnaces. One study (131) modeled production processes and estimated that using less scrap and more ore would result in increased generation of phenols, ammonia, oxygen-demanding substances, sulfur dioxide, and particulate, and decreased generation of suspended solids.

Plastics

Once a resin is produced, the environmental risks associated with fabricating products from the resins are the same whether the resin is produced from virgin or secondary materials. However, primary production processes generate air emissions, wastewater, and solid waste. The types and amounts of these wastes vary with different processes and types of plastics, and some are managed as hazardous waste. According to one analysis, five of the six chemicals whose production generates the most hazardous waste in the United States are chemicals commonly used by the plastics industry (268).

In general, air emissions are highest during the initial processing and recovery steps for monomers, solvents, catalysts, and additives. Wastewater associated with the primary production process can contain suspended monomers, co-monomers, polymers, additives, filler particulate, soluble constituents, and solvents that are washed or leached from the plastic. Solid waste is produced at various points, mostly from spillage, routine cleaning, particulate collection (from feeding, handling, grinding, and trimming processes), but also from production errors and a few production process byproducts. It can contain mostly polymers and small quantities of plasticizers, fillers, and other additives.

Some emissions are associated with the reprocessing of secondary plastic materials. For example, volatile air emissions can be generated during the heating of plastics, and residues can be contained in the rinse water used to cool the remelted resins.

Barriers to Increased Recycling

Nature of Commodities Markets

One important factor in any commodity-based industry is the volatility of markets. This volatility creates heightened uncertainty in evaluating the financial viability of a business venture, discouraging growth to some extent. Markets for both primary (or virgin) and secondary (or recovered) materials are subject to this volatility to varying degrees. Therefore, the nature of commodity markets, and the causes of their volatility, should be considered when barriers to increased recycling are evaluated.

Both primary and secondary materials are used as inputs in one or more "downstream" production processes. As such, the demand for most raw materials is based on factors far removed from the immediate use of the materials as an input for another product. For instance, demand for packaging materials depends on the demand for the multitude of products for which packaging is used. This means that demand for a raw material is not very sensitive to its own price, especially in the short run. Rather, the demand for raw materials is more strongly dependent on current technology and the availability of substitute and other inputs in an intermediate product, as well as final consumer preference factors (45).

When considering market manipulation in an attempt to stimulate recycling, it is essential to consider these demand factors for basic raw materials. **Because demand factors can be in a constant state of flux, with a market having many actors and an increasingly global nature, it is very difficult to externally control or balance the markets for these raw materials, whether primary or secondary.**

The demand for raw materials often is volatile because of the "distance" between the production of the raw material and final consumption. This volatility is sometimes more marked for secondary than for primary materials, resulting in even greater price fluctuations. This is particularly true when the secondary material is a marginal supply (i.e., the least desirable and first to be cut during business downturns). In those markets, secondary materials prices are always more volatile than those for primary inputs, although they generally exhibit similar longer term trends. This situation applies most to iron and steel scrap, lead scrap, and lower grades of waste paper, and is dependent on the industrial infrastructure and the regulatory regime.

In any waste management program, the ultimate fate of waste, including materials that can be recovered, largely depends on the costs of different management options. Recycling, of course, competes with landfilling and incineration. Moreover, markets for materials recovered from MSW depend on demand for recycled products. Where primary manufacturing produces less costly goods, demand for recycled goods will tend to be lower, creating an economic environment that favors disposal. Consequently, recycling must compete simultaneously with primary manufacturing and traditional waste disposal methods.

Types of Constraints to Increased Use of Secondary Materials

Materials recovered from MSW can be used to produce a variety of new products. In some of these products, secondary or recovered materials compete as inputs only with their primary or virgin counterparts, while in others they compete with different virgin or secondary materials. The relationship between similar primary and secondary materials must be understood to assess the potential for increased consumption of materials recovered from MSW.

Markets for secondary materials are, for the most part, competitive, and they operate under a complex set of dynamics. **Any attempt to provide specific incentives to increase the use of secondary materials should recognize that the dynamics of these markets, and the barriers impeding them, are different for each material. The** nature of the barriers determines the types of policy options likely to be most effective.

Both economic and noneconomic barriers exist to increased recycling (83). **Economic** barriers are factors that limit markets through economic forces, such as:

- the costs of raw materials, capital, and labor;
- the costs of transportation;
- new business or capacity expansion decisions; and
- end-product prices.

These economic factors can be broadly classified as supply-side or demand-side factors. Supply-side factors affect the procurement and processing of raw materials prior to manufacturing. Demand-side factors affect the end users of goods in the commercial, institutional, and household sectors. Mills and other recycled materials manufacturing establishments are at the pivot point of the system, being direct participants in both supply-side and demand-side factors.

The degree to which each secondary material is used is determined by a unique set of market factors. For example, old newspapers are relatively easy to collect, and little doubt exists that current rates of collection could be increased. However, the two primary end products for ONP—recycled paperboard and newsprint-are sold to limited markets. Competitive products made of virgin materials serve most of those markets, and the market share for recycled products has declined in the last decade. Thus, ONP is demand-side limited, and this limit must be removed if more ONP is to be recycled.

An evaluation of demand-side or supply-side limiting factors for secondary materials is presented in table 5-8. The most opportune incentive points in the system that might help increase recycling also are presented. In the example of ONP, incentives to end users would be most effective. In contrast, old corrugated containers present a different situation. Products made from recycled OCC compete well against products made of virgin materials in many markets. In this instance, incentives to collectors and processors of OCC and to primary manufacturers to use OCC would likely result in increased recycling. One group of materials-plastics-is listed as being both supply-side and demand-side limited. Postconsumer plastics recycling is in its infancy, and many problems need to be worked out at all points in the system.

Economic barriers can be related to technical issues, on both supply and demand sides. Technical barriers are often related to material quality, which can limit the substitutability of secondary materials for virgin materials. One example can be found in recycled printing and writing paper. These papers

Table 54-Overview of the Recycling System for Various Materials: Limiting Factors and Incentive Points

	Limiting factors		Appropriate incentive points		
Materials	supply	Demand	Collection/ processing	Mills	Industrial/ commercial consumers
Old newspapers		x		x	x
Old corrugated containers	x		x	x	
Office papers	x		x		
Mixed papers		x		x	x
Plastics	x	x	x	x	x
Glass	x		x		
Tin cans	x		x		
Aluminum	x		x		
Used oil		x		x	x
Tires		x		x	x

SOURCE: Franklin Associates, Ltd., ”Economic Incentives and Disincentives for Recycling of Municipal Solid Waste;’ contract prepared for U.S. Congress, Office of Technology Assessment (Prairie Village, KS:1988)

are generally about 50 percent secondary fiber, consisting mostly of pulp substitutes (pre-consumer waste). Greater quantities of post-consumer waste cannot be used, however, because of the inability of the current process to sufficiently remove contaminants in the waste paper.

Similar technical constraints exist for the use of scrap in steelmaking. Currently unremovable contaminants in some iron and steel scrap (particularly post-consumer) compromise the strength of the final steel product, thereby limiting the amount of scrap that can be used and the types of products in which it can be used. Post-consumer plastics, too, face similar constraints concerning contaminant removal.

Relative cost also can act as an economic barrier. Whether a cost differential results from higher transport costs, subsidies to the virgin material, or higher processing and handling costs, the outcome is that the manufacturer will minimize costs in the production process by choosing the lowest cost material. In some cases, this turns out to be the virgin material.

Finally, the manufacturer may be unable to obtain secondary materials because they have not been removed from the waste stream in large enough quantities. The glass industry claims that this factor alone inhibits greater recycling of glass cullet. Collection is a serious problem for plastics.

Noneconomic barriers to increased recycling can be caused by value judgments in the decisionmaking process. These factors include the attitudes of manufacturing personnel or consumers, attitudes about quality control, and long-standing corporate policies and procedures.

Some noneconomic factors are demand-related. Some consumers are unwilling, either for real or perceived quality deficiencies, to buy products made from secondary materials. The preference for a virgin content product is based not on an inability of the secondary material to perform, but on the desire of the consumer to have a ‘‘more attractive’ product. In other cases, the consumer is not even aware of the existence of secondary materials in the product, and is therefore unable to make a decision on that basis. For example, it is impossible to distinguish between primary and secondary aluminum.

Another example of the importance of noneconomic factors is illustrated with writing paper. Consumers prefer bright white paper, which is more difficult to produce if the paper has a high post-consumer waste content (above about 10 to 15 percent). It is likely that lower brightness paper would be sufficient for many uses, but people view this as a sign of inferior quality.

Supply-related noneconomic barriers exist where the manufacturer is unwilling to obtain secondary materials to use as inputs in the production process. Such unwillingness is more common in vertically structured industries, where the source of the virgin raw material is owned by the manufacturer. This barrier is difficult to overcome because the industrial infrastructure is built around this long-held economic relationship. Unwillingness may also be a result of the manufacturer being unaware of technical advances in reprocessing technologies. This problem has been noted for plastics.

Concerns about liability under Superfund legislation also act as an additional barrier to increased recycling. Scrap handlers and processors increasingly are unwilling to handle scrap materials contaminated with known hazardous substances. This has long been a concern for lead-acid battery recyclers, and it is becoming one for auto scrap processors as air bags containing sodium azide and other nonmetallic materials are used more widely.

Tilts in the Playing Field

Recycling must compete simultaneously with primary manufacturing and traditional disposal options, yet various government actions have given economic advantages to these alternatives that in the end make recycling less appealing. These actions have resulted in market choices that, when **all** the costs are accounted, are inefficient in the economic sense.

In the competition between primary and secondary materials manufacturing, the costs of raw materials are not always accurately reflected in the price paid by the manufacturer. For example, the government sometimes uses subsidies to supplement the cost of producing some raw materials, such as timber. In these cases, the total costs of producing finished goods are not all internalized to the manufacturer. In addition, the cost of managing waste residuals produced during the manufacturing process is not always internalized, contributing to inefficient market decisionmaking. For example, if an industry emits chemicals to the environment, there may be human health and environmental costs, but these costs are unlikely to be reflected in the price of the manufactured good.

External Costs of Manufacturing-When industrial facilities fail to control the release of pollutants to the environment, an external cost is incurred because the detrimental effects of that pollution on human health and the environment are not accounted for in the cost of production. The failure to internalize these costs can affect the relationship between primary and secondary materials. Because the relative level of pollution from primary and secondary production processes is not always clear, it is not possible to determine how these external costs affect the choice between primary and secondary materials. Those facilities generating more pollution will have an advantage because they are avoiding more external costs. Where primary facilities produce higher levels of pollution than secondary facilities, the primary facilities thus will have an unfair advantage.

In addition, the reduced energy consumption associated with recycling certain materials, such as aluminum and some types of paper, could have indirect pollutant savings by reducing overall fossil fuel consumption. The burning of fossil fuels has been linked to problems such as acid rain and global warming. Although these externalities have not been quantified, they can be important considerations in the choice between virgin and secondary materials.

Federal Subsidies for Virgin Materials-The history in the United States of preference programs or subsidies for natural resources dates back to early in this century, when the development of natural resources was encouraged to fuel economic growth. Preferences granted within the Federal tax system are among the most visible—programs such as depletion allowances for mineral mining and petroleum production, and special tax treatment of capital gains from the sale of timber. These programs have been used for decades to stimulate, and sometimes help maintain, these sectors of the economy. As a result, the programs have become embedded in the economic system and are now an integral part of the industrial infrastructure and economics of natural resource development and production.

Federal expenditures for natural resources tax programs are summarized in table 5-9. The tax preferences most relevant to recycling are the percentage depletion allowances for minerals, oil, and gas and the special treatment of income for the timber industry. Studies conducted in the 1970s on the effects of these preferences indicated that they have not significantly discouraged the use of secondary materials; recent studies on the issue have not been conducted (83).

Table 5-9—Estimated Costs for Special Tax Treatment for Virgin Materials Production, Fiscal Years 1980 to 1989[a] (millions of dollars)

	FY80	FY81	FY82	FY83	FY84	FY85	FY86	FY87	FY88[b]	FY89[b]
Natural resources and environment:										
Expensing of exploration and development costs, nonfuel minerals	27	31	30	62	65	85	88	35	34	37
Excess of percentage over cost depletion, nonfuel minerals	493	506	466	531	589	493	500	410	318	293
Capital gains treatment of iron ore	27	25	24	45	44	32	31	10	—	—
Subtotal—minerals	548	563	519	638	698	610	618	455	352	330
Capital gains treatment of timber income	740	756	808	831	997	610	690	290	0	—
Expensing of multi-period timber growing costs	—	—	—	—	—	—	—	130	256	279
Investment credit and seven-year amortization for reforestation expenditures	—	—	2	34	49	53	57	210	203	195
Subtotal—timber	740	756	820	864	1,046	663	747	630	468	474
Total—minerals and timber	1,288	1,319	1,339	1,503	1,744	1,272	1,365	1,085	820	804
Energy:										
Expensing of exploration and development costs for oil and gas	2,980	3,419	3,428	2,639	1,978	519	639	(675)	(400)	(172)
Excess of percentage over cost depletion for oil and gas	2,041	2,656	2,667	1,944	1,771	1,659	1,936	1,030	743	618
Total—energy	5,021	6,075	6,095	4,582	3,750	2,178	2,575	355	343	446

NOTE: The corporate and individual tax categories have been combined for all years to give a total. In the energy category, the individual benefits dominate substantially; in FY85, 86, 87, 88, and 89 the corporate benefit is negative for expensing of exploration and development costs.

[a] Presented in constant dollars using an implicit price deflator with 1987 as the basis.

[b] To bring these values to constant 1987 dollars, implicit price deflators were projected for each based on the historical trend.

SOURCE: Franklin Associates, Ltd., "*Economic Incentives and Disincentives for Recycling of Municipal Solid Waste*" contract prepared for U.S. Congress, Office of Technology Assessment (Prairie Village, KS: December 1988); U.S. Office of Management and Budget, *Budget of the United States Government* (Washington, DC: U.S. Government Printing Office, individual budgets for fiscal years 1982 through 1989).

Depletion Allowance-Historically, percentage depletion allowances date back to the Internal Revenue Act of 1913 and to World War I, which placed heavy demands on the minerals industry. In 1932, depletion allowances were extended to all primary metals industries to help them recover from the depression. During World War II, depletion allowances were extended to nonmetallic minerals. In each case, it was understood that the tax preferences would likely be repealed after the difficult period ended, But when it came time to give up the subsidies, the industries fought to keep them and they have succeeded to this day.

The percentage depletion allowance enables minerals producers to deduct a percentage, between 5 and 22 percent depending on the mineral, of the value of mineral production in computing taxable income from a mineral property (subject to a limit of 50 percent of taxable income). The significance of percentage depletion allowance is that the deduction is based on production, not on the amount of capital invested in developing the property.

The basic premise for depletion allowances is that the natural resource base depletes over time, just as a production facility depreciates. In effect, a depletable resource is capital. The Federal Government provides the depletion allowance to encourage industry to undertake the risky endeavor of exploring for resources that are ever more difficult to find. Higher allowances allegedly reflect the higher costs and difficulty of replacement. These allowances help ensure an adequate supply of mineral resources to domestic industry, a factor some people consider important to national security .47

It should be noted that the minerals industries pay special taxes, in effect reducing the benefits of Federal incentive programs. State severance taxes are the most widely known special taxes on minerals. A severance tax is an excise tax levied on the quantity 01 value of production. The amount of the tax varies by State, but it can amount to a significant financial burden for a mining enterprise.[48]

Special Treatment of Income for the Timber Industry-Income from timber can be broken down into two components: 1) real income from the production of timber, and 2) income from increases in the price of standing timber. Both types of income qualify under capital gains. It has been argued that annual increases in the value of timber are no different than other agricultural production except for the longer growth period and thus should be taxed as ordinary income. The timber industry argues, however, that this longer growing period entails unusual risks and thus the increase in the value of standing timber should receive preferential tax treatment.

The Tax Reform Act of 1986 lowered the Nation's overall tax rates. It also eliminated the preferential rate structure from capital gains treatment for corporations and individuals. Even though the differential tax rate between ordinary income and net capital gains was eliminated beginning in 1988, capital gains remains as a concept in the tax law. Thus, for other tax reasons timber owners often continue to distinguish between ordinary income and capital gains.

The tax costs listed in table 5-9 seem to show that as costs for capital gains treatment of certain timber income decrease, costs for other programs, such as expensing of multi-period timber growing costs, increase. Why these increases appear is unclear. (It should be noted that the budget estimates published from year to year vary for a given year of a program, so the latest year was used. Although these data may be inaccurate, they are the only data available on the costs of these tax programs.)

The first example of a program that appeared to increase tax costs for the government was the expensing of multi-period timber growing costs. For all industries except timber, the Tax Reform Act requires that if production extends for 2 or more years, the producer must capitalize interest. This exemption allows the timber industry to distribute interest for capital costs over the entire production period. This multi-period expensing for the timber industry is not a new program. Therefore, it is surprising **that the** budget reports such tax cost increases in 1987.

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[47] The National Materials and Minerals Policy, Research and Development Act of 1980 declares it U.S. policy to promote an adequate supply of materials to maintain a strong economy.

[48] A study conducted in 1980 indicated that the State tax burden can reach 40 percent of the total taxes paid by the mines examined (253).

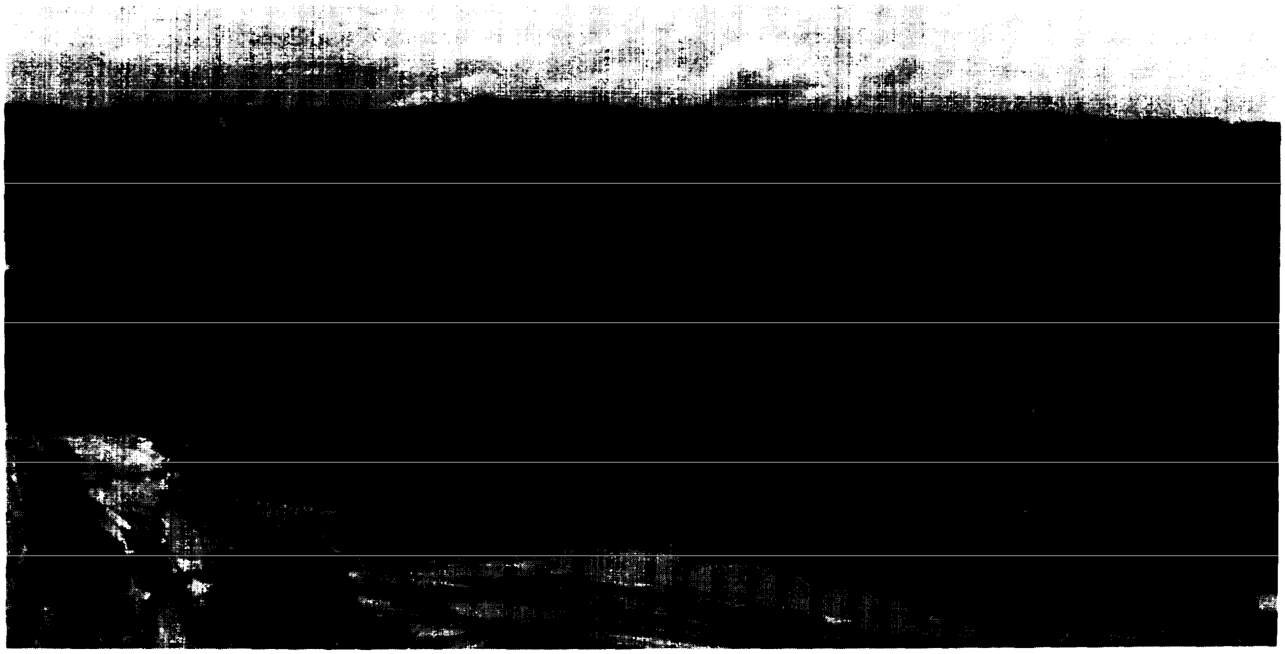

Photo credit: J.E. Robison

The Federal Government historically has given preferences or subsidies for the extraction and use of virgin materials. Tax preferences are among the most visible--depletion allowances for mineral mining and petroleum production and special treatment of capital gains from timber sales.

The second program that appears to increase tax costs is investment credit and reforestation expenditures. Under this program, the direct costs incurred by a company to reforest a site for commercial production can be amortized over a 7-year period rather than capitalized and recovered when the timber is cut in 20 or 30 years. These direct costs are also eligible for a special 10 percent tax credit as long as the investments in timber stands are not depreciable. The overall cost of this program jumped from $57 million in 1986 to $210 million in 1987. The Tax Reform Act did not change the provisions governing reforestation amortization and credit. These incentives have been available to taxpayers since January 1, 1980, up to a limit of $10,000 per year, and primarily benefit small- and medium-sized landowners.

Two additional programs, not included in table 5-9, also benefit the timber industry: below-cost government timber sales and technical support from the Department of Agriculture. The sale of timber by the Federal Government has been under fire for several years. These sales can be seen as a form of subsidy because the Federal Government sells timber on Federal land at less than market value. The timber industry argues that the reason for the reduced pricing is the additional expense incurred by the purchaser to build roads to access the timber, roads which can then be used by everyone.

The Forest Service, a part of the Department of Agriculture, carries out a number of technical assistance programs designed to improve timber management. These programs include fire protection, insect and disease control, and forest management. The costs of these programs have not been quantified.

Effects of Virgin Materials Subsidies on Recycling-- Several studies carried out in the mid- to late- 1970s analyzed the effects of subsidies for virgin materials on recycling of secondary materials (83). These studies are dated, however, so current conditions and differences in the tax codes must be taken into account when examining their conclusions. In addition, these studies did not address glass and plastics.

In general, the studies concluded that while tax benefits for mining and timber growing did exist, they did not significantly discourage or reduce the use of secondary materials. Some studies evaluated the potential effects of tax benefits on virgin materials supply (table 5-10). The tax benefits were estimated to have affected the price of virgin materials by varying degrees. Under the most likely scenario, subsidies were estimated to affect the price of virgin paper by 1 percent, copper by 5 percent, and steel by 2 percent.

The effect of subsidies on secondary materials is more difficult to describe. Two studies on the effects of eliminating virgin materials subsidies estimated that increases in the recycling of secondary materials would be relatively small (table 5-10). In recent years, in fact, the real increase in recycling has been significantly higher than these estimated increases, independent of the tax differences.

From these analyses, conducted prior to tax reform, it appears that tax preferences for virgin materials did not significantly inhibit increases in recycling. Furthermore, the tax preferences address national needs well beyond the issues of recycling and MSW management. Any consideration of removing the tax preferences must carefully examine the costs as well as the benefits associated with such an action. Nevertheless, it is apparent that virgin materials producers enjoy tax benefits not available to secondary materials, thus creating some inefficiency in the market.

Recycling v. Other Management Methods—Several factors distort the economic environment and thus affect decisionmaking among MSW management alternatives. For instance, through the Public Utility Regulatory Policies Act (PURPA) and Federal tax laws the Federal Government has promoted the use of waste-to-energy facilities as a method to manage MSW; no comparable incentives are available for recycling. Another factor that distorts economic decisionmaking is the failure to internalize external costs of recycling, incineration, and landfilling.

Public Utility Regulator-y Policies Act and the Promotion of Incineration Facilities-PURPA was enacted to encourage the generation of electricity by non-utility producers (ch. 8). Under PURPA, the Federal Energy Regulatory Commission (FERC) established rules requiring utility companies to purchase electrical energy generated by qualifying independent generators at guaranteed rates. The rates are determined by the States and are based on ‘‘avoided costs,’ the price the utility would have to pay if it were to generate the power itself or buy it from another supplier. In some states, these rates are calculated based on the cost of building new generating facilities.

The intended effect is to provide a guaranteed market at a “fair” price for power generated by MSW incinerators. Although these provisions provided strong incentive to build waste-to-energy facilities in the past, they are currently under review. If FERC restricts electricity purchases at rates above current costs, MSW incineration and recycling will compete on a more equal basis.

Federal Tax Laws Favoring Incineration—h addition to PURPA, certain Federal tax laws provide incentives for private ownership of MSW incinerators that recover energy, including an investment tax credit, an energy tax credit, and a rapid depreciation schedule. Along with these incentives, the availability of tax-exempt industrial development bonds also encouraged the building of such facilities by private parties. Most MSW incinerators built during the last decade or so enjoyed the advantages of these incentives.

The Tax Reform Act of 1986 substantially reduced the financial incentives (other than those accruing through PURPA) favoring private ownership of MSW incinerators. As a result, it now maybe more cost-effective for such facilities to be municipally owned, since tax-exempt financing is still available for municipalities. (Despite this change, waste-to-energy companies appear willing to finance new facilities.) By comparison, it is not clear that municipal tax-exempt financing is available for materials recycling operations. If a facility recovers materials from mixed waste, it is a waste treatment facility and therefore eligible for tax-exempt financing. However, if the facility processes source-separated waste materials having value, the equipment and facilities used to handle these materials generally may ***not*** be financed with tax-exempt

Table 5-10-Estimated Effects of Tax Subsidies on Virgin Materials Prices and of Eliminating Virgin Materiail Subsidies on Recycling of Secondary Materials

Material	Increase in virgin material price as a result of tax subsidies: Maximum possible impact	Increase in virgin material price as a result of tax subsidies: Most likely impact	Increase in use of secondary materials with subsidy elimination
Paper	+4.2%	+1 .0%	0.04-0.6%
Steel	+3.0%	+2.O%	0.4-2.0%
Copper	+6.0%	+5.0?/0	0.4%
Aluminum	+2.2%	—	1.0%
Lead	+3.0%	—	0.80/0

SOURCE: Environmental Law Institute, Impact of the Federal Tax Code on *Resource Recovery* (Washington, DC: 1976): Environmental Law Institute, *Evaluation of Economic Benefits of Resowce Conservation* (Washington, DC: 197S); JACA Corp., Barriers *to the Use of Secondary Materials*, report prepared for U.S. Bureau of Mines (Fort Washington, PA: 1977); Franklin Associates, Ltd., "Economic Incentives and Disincentives for Recycling *of* Municipal Solid Waste," contract prepared for U.S. Congress, Office of Technology Assessment (Prairie Village, KS: 1968).

bonds (83). This disallowance of tax-exempt financing for recycling facilities is discriminatory and favors incineration with energy recovery over recycling. Of course, recent efforts to reduce the incentives for incinerators will also reduce the importance of this point.

External Costs of Waste Management—Failure to internalize health and environmental costs can distort the market with respect to choosing between recycling and other management methods. If recycling, landfilling, and incineration are not adequately regulated, then their health and environmental risks and costs may not be fully accounted for. As a result, management decisions could be made on the basis of information that does not explicitly encompass all of these costs. In such cases, the costs of managing and cleaning up pollutants could be spread indiscriminately to those individuals and ecosystems exposed to pollutants, irrespective of how the benefits are distributed.

Because quantifying extemal costs is difficult, however, it is unclear whether any one management method is currently favored over other methods because of a failure to internalize these costs. In a practical sense, then, the most that can be done is to ensure that each management method is protective of human health and the environment and that environmental regulations are designed to explicitly address all management methods.

APPENDIX 5-A: CALCULATING THE RATE OF RECYCLING IN JAPAN

As noted in the text, some experts estimate that the recycling rate in Japan is around 50 percent, while OTA estimates that the rate could be as low as 26 to 39 percent, at least for materials for which data are available. These estimates all are based on data published by the Clean Japan Center, a quasi-governmental agency that runs recycling education and demonstration projects, about the generation of MSW and the recycling of individual materials. This appendix explains OTA's calculations and why its estimates differ from the estimate of 50 percent. If nothing else, the calculations indicate the great difficulties involved in estimating recycling rates.

Recycling rates cannot be calculated unless the total amounts of recycled, incinerated, and landfilled materials are known. No aggregate data on total recycling in Japan are gathered, and calculations of the amount of material that is recycled require making assumptions about some materials, particularly steel, These calculations then must be linked with estimates about MSW sent to landfills and incinerators. As shown below, the calculations can become somewhat tortuous.

Estimates of the amount of MSW sent to landfills and incinerators in Japan range between 40 and 60 million metric tons each year. The lower figure is based on an estimate that about 110,000 metric tons of MSW are generated per day (49). The higher figure is based on a recent estimate that the per-capita generation rate may have risen to as high as 3.0 pounds per day (51).

Information on recycling indicates that in 1984 about 9.7 million metric tons of waste paper (a recovery rate of about 50 percent), 8.7 million metric tons of bottles, and 24,000 tons of aluminum cans (41 percent recovery) were recovered (49). In addition, about 75,000 metric tons of compost were produced and 220,000 metric tons of plastics were collected in 1984. The Plastic Waste Management Institute indicates that there is little recovery of plastics from post-consumer materials (170), so this plastic may have been industrial scrap. Although data are not available for textiles for 1984, we do know that 724,000 metric tons of textiles were collected in 1981 (49). Data are not available for other commodities such as non-can aluminum, household batteries, rubber, and leather. Based on the above figures, one estimate of the amount of materials collected for recycling, excluding steel and materials for which data are unavailable, is 19.4 million metric tons.

The primary reason for the discrepancy in the estimates of Japanese recycling rates is the way in which steel recycling is treated, The 50 percent figure includes steel from the residential and commercial sectors **and** from industry. OTA's estimate of 26 to 39 percent includes steel only from the residential and commercial sectors (even this has problems, however, such as what to do about junked autos). In particular, Hershkowitz and Salemi (108) indicated that 27.7 million metric tons of steel were recovered in 1983, but their analysis did not indicate how much was industrial scrap v. post-consumer material. The analysis considered 12.2 million metric tons as industrial scrap, leaving 15.5 million metric tons recovered from post-consumer material (214).

However, if the 15.5-million-ton figure is added to the amounts of other recovered materials (paper, glass, aluminum, etc.) and to the estimates for MS W generation, then the total amount of post-consumer material would be between 75 and 95 million metric tons. The steel portion alone then would comprise 16 to 21 percent of this total. Most industrialized counties, however, have a total metal content in post-consumer material of 10 percent or less, and generally about half of the metal is not steel. On this

Table A-1—Estimated Rates of Recycling In Japan

Scenarios: estimates of total MSW generation and assumptions of steel recovery	Calculations under different scenarios			
	Estimated steel recovery[b] (mmt)	Total materials recovery[c] (mmt)	Total post-consumer material[d] (mmt)	Estimated recycling rate
40 mmt MSW[a]				
5°/0 steel, 50°/0 recovery	1.5	20.9	60.9	34.30/0
10%$_0$ steel, 100% recovery	6.3	25.7	65.7	39.1%
60 mmt MSW				
5% steel, 50% recovery	2.1	21.5	81.5	26.4%
10%$_0$ steel, 100% recovery	8.4	27.8	87.8	**31.7%**

ammt = million metric tons
bBased on solving equation discussed in text
cBased on adding the estimated amount of steel (column 2) and the amount of other recovered materials (19.4 mmt),
dtotal materials recovery, plus MSW generation
eBased on (column 3/column 4) X 100

SOURCE: Office of Technology Assessment, 1989.

basis, the 15.5 million-ton-figure poses problems. In addition, it is unclear whether the figure includes construction scrap or obsolete scrap (e.g., railroad cars) that is not considered as MSW. This indicates the great effect that different definitions can have on estimates of MSW recycling rates.

OTA re-estimated the amount of steel on the basis of the following assumptions: 1) post-consumer materials contain 5 percent metal; 2) all of that metal is steel; and 3) about half of the steel is recycled (based on an estimate that less than 50 percent of steel cans in post-consumer materials are recycled) (49). Estimates of the amount of steel in post-consumer materials can then be calculated by solving the equation:

$X = 0.05\ [0.5\ X + 19.4 + Y]$ million metric tons, where:
X is the steel (in million metric tons) in all post-consumer material;
0.05 represents the 5 percent assumption;
the figures in [] represent total post-consumer material;
0.5 X represents the 50 percent recovery of steel;
19.4 represents recovery of other materials; and
Y represents MSW generation.

Using this equation, estimates of the amount of steel in post-consumer material are between *3.0* million metric tons (using Y=40 million metric tons) and 4.1 million metric tons (using Y=60 million metric tons), and the amount of recovered steel would be 1.5 to 2.1 million metric tons, respectively (table A-1). No data are available to confirm or refute the underlying assumptions, however. One measure of how sensitive the analysis is to error is to assume that the amount of steel in post-consumer materials is actually 10 percent and, furthermore, that all steel is recovered for recycling. Using the same procedures, the relevant figures for total and recycled steel would range between 6.3 million and 8.4 million metric tons of steel. A potentially important source of error in the estimates is that the higher generation data are from 1988, while most of the material recovery data are from 1984. If the amounts of materials recovered rose between 1984 and 1988, then OTA’s estimated recycling rates would underestimate the actual recycling rate.

Using these data, estimates of the percentage of post-consumer materials (i.e., MSW generation plus total materials recovery) that is recycled range from 26 to 39 percent (table A-l). The figures could be somewhat higher if other materials were included or if material recovery rates were higher in 1988 than in 1984.

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