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PUBLIC HEALTH, OCCUPATIONAL SAFETY, AND ENVIRONMENTAL CONCERNS IN MUNICIPAL SOLID WASTE RECYCLING OPERATIONS

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PREFACE

The United States faces the challenge of effectively managing municipal solid waste (MSW) as the amount of waste generated per capita increases. In response to this challenge, recycling is actively being promoted and integrated into solid waste management plans. The Environmental Criteria and Assessment Office has initiated an effort to evaluate and identify the potential hazards associated with MSW recycling.

The purpose of this document is not to compare recycling with other MSW methods but to provide a general overview of possible hazards associated with this practice.

This report identifies the possible public health, occupational, and environmental hazards associated with MSW recycling. The report identifies activities that might present hazards to health or the environment but does not assess actual risks to health or the environment. Such a risk assessment requires further study, particularly quantitative data on exposure. The scope of the document is thus limited, in line with an intent to survey for potential hazards and identify need for further work.

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DPE	High-density polyethylene
HGD	High-grade deinking
LDPE	Low-density polyethylene
MP	Mixed paper
MRF	Material recovery facility
MSW	Municipal solid waste
NIHL	Noise-induced hearing loss
NPDES	National Pollution Discharge Elimination System
OCC	Old corrugated containers
ONP	Old newspaper
OSHA	Occupational Safety and Health Administration
PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinyl chloride
RCRA	Resource Conservation and Recovery Act
V	Vinyl

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Note: The views expressed in this reports do not necessarily reflect those of the expert panel. Participation on the panel does not imply complete endorsement of this document.

1. INTRODUCTION

1.1. PURPOSE

The U.S. Environmental Protection Agency's (EPA) Environmental Criteria and Assessment Office (ECAO) initiated an effort to characterize safety in municipal solid waste (MSW) recycling operations. The objective of this effort includes assisting MSW managers in developing waste management programs by providing information on recycling options and the potential hazards associated with their implementation.

1.2. SCOPE

This report qualitatively identifies safety issues (public health, occupational, and environmental) associated with MSW recycling. Hazard identification is the first step in the more complex process of risk assessment. The report does not attempt to assess risks because insufficient information exists to fully quantify exposures and because of the potential for adverse effects associated with recycling operations. Future research that will advance the risk assessment process is identified.

The primary audience is the local solid waste manager who requires safety information for decisionmaking. An overview of processing methods identifies hazard types and points of exposure. Specific details of materials processing technologies are not provided. This report addresses the following questions:

- What is the nature of recycling hazards?
- Are recycling hazards potentially significant?
- What steps can be taken to prevent or mitigate these hazards?

This identification of hazards considers recyclable materials from the time they are separated from the MSW stream by the consumer or waste handler to when they are formed into new products or become indistinguishable from virgin feedstocks. The relative newness of the recycling industry, coupled with local requirements and regional trends, has created an industry with diverse solutions to meet individual MSW management needs. This overview addresses commonly used recycling practices and processes.

Many of the practices and processes addressed are applied in other industries, such as the collection and handling of MSW and the use of virgin material to produce goods. In addition, many of the potential hazards can be mitigated. Mitigation options are noted in the report where applicable.

The report is devoted to five materials selected on the basis of their relative amounts (refer to Appendix B) in the municipal solid waste stream, available recycling technologies, and established markets:

- Aluminum
- Glass
- Plastic
- Paper
- Steel/tin

These materials are most widely recycled by the 50 most populous U.S. cities (Table 1-1).

Recycling is a growing waste management practice. In 1990, there were 104 materials recovery facilities (MRFs) planned or operating in the United States; in 1992, there were 222 (Roumpf, 1992). Average-capacity MRFs (131 tons per day) employ an average of 18 workers; larger facilities may need 27 workers. The trend is therefore toward greater processing capacity and increased average employment. Employment levels may also rise because of increased reliance on labor-intensive manual sorting (65 percent of facilities in 1992 versus 50 percent in 1990) compared with automated sorting technologies. MRFs are also expected to handle additional materials such as household batteries, compostables, and different grades of paper. Full evaluation of MSW management options includes consideration of benefits as well as potential costs. Primary benefits of recycling

TABLE 1-1

Recyclable Materials Collected by the 50 Largest U.S. Cities

Material	Number of cities	Percent of cities
Aluminum cans	46	92
Glass containers	44	88
Old newspapers	42	84
Tin/bimetal containers	40	80
PET containers	36	72
HDPE containers	36	72
Old corrugated containers	11	22
Other	14	28

HDPE: High-density polyethylene
PET: Polyethylene terephthalate

Source: Smith and Hopkins, 1992.

are reducing the MSW stream and extending the lifetimes of landfills. It is not coincidental that the number of recycling programs has increased mostly in geographical areas where landfills are near capacity and space for new landfills is scarce. This trend is most visible on the east and west coasts of the United States. The cost savings associated with recycling is also a benefit because limited landfill space increases tipping and hauling fees for MSW disposal. Also, there are benefits to the environment from recycling programs. The potential for environmental pollution associated with more traditional methods of MSW disposal is reduced by diverting recyclables from the waste stream (personal communication between TRC Environmental Corporation and Rosalie Green, Senior Recycling Expert, U.S. Environmental Protection Agency on July 24, 1992).

1.3. LIMITATIONS

Lack of data to quantify exposures in the recycling industry currently limits a more complete hazard evaluation. Available data on recycling hazards are biased toward reporting of episodic occupational hazards. Physical injury is probably the best documented of all recycling hazards. Few data have been collected to characterize chemical or biologic hazards that might otherwise be measured in ambient air monitoring or emission/effluent studies. Subtle effects, long-term health effects, and ergonomic injuries also have not been characterized. Quantitative data that are available tend to come from small-scale studies with limited goals. No large-scale monitoring programs have been undertaken.

Variability in recycling industry practices somewhat limits the broad-based applicability of hazard information presented in this report. The degree of automation in MRFs, for example, greatly influences the type and magnitude of certain hazards. Program variability also makes it impossible to characterize each process and its associated hazards. This variability may decrease as the industry matures.

The degree to which recycling processes and associated hazards can be fully described further limits conclusions about the magnitude of potential hazards. A number of the parties contacted for this report cited the proprietary nature of a practice or process and were unwilling to provide information. Industry representatives also were reluctant to discuss hazards associated with their activities.

1.4. REPORT ORGANIZATION

This report is organized to facilitate its use as a tool for solid waste managers. Chapters 2 and 3 provide background information on project methodologies and recycling as a solid waste management method, respectively. Chapter 2 summarizes the information sources used to prepare the report, data collection methods, and the limitations of the data. Chapter 3 describes recycling as a municipal solid waste management method. Chapters 4 and 5 constitute the main body of the report. As a preface to the enumeration and discussion of hazards, Chapter 4 summarizes common recycling practices and processes. Subsections address collection, sorting, and transportation of recyclables and the processing of aluminum, glass, paper, plastic, and steel/tin. Chapter 5 describes recycling hazards by type, including the nature of the hazard and prevention or mitigation options. Included in Chapter 5 are tables that indicate preventive/mitigative options and rate the significance of each hazard. Chapter 6 is a summary of findings and conclusions. A list of additional research needs is provided in Chapter 7. References are provided in Chapter 8.

2. PROJECT METHODOLOGY

2.1. APPROACH

The "boundaries" for an evaluation of recycling hazards can vary depending on the goals of the effort. The present study covers hazards encountered from the point consumers or waste handlers separate recyclables from MSW to the point the recycled material is formed into a new product or is considered to be a feedstock comparable with virgin material. Practices and processes that are generally unique to recycling are emphasized, but many specific recycling technologies and equipment are encountered in other industrial settings, including other MSW management activities. For example, conveyors, which are widely used on sorting lines in materials recovery facilities, are components of many industrial operations. Although this equipment is not unique to recycling, recycling presents new industrial applications that may create different hazards.

The relative newness of recycling both as an MSW management option and as an industry required a flexible approach for obtaining information for this report. Where available, process overview information was obtained from published government or industry reports. More commonly, articles from trade journals and other publications and information obtained from industry contacts were used to document current trends in recycling.

2.2. METHODOLOGY

Much of the information for this report was obtained through telephone interviews with government and industry sources. Specific sources contacted are provided in Chapter 8. General sources included the following:

- State and local solid waste officials including local recycling coordinators
- State and Federal regulatory agency representatives

- Federal occupational health and safety representatives (Occupational Safety and Health Administration, National Institute for Occupational Safety and Health)

- Representatives of regional and local solid waste planning organizations

- Plant managers and other company representatives for all phases of recyclable processing, including MRFs and material-specific industrial facilities

- Recycling technology company representatives

- Academic resources

- Private consultants

- Recycling industry publication representatives

- Trade association representatives

Efforts were made to obtain information reflective of common practices across the country by contacting several representative sources. National organizations, such as the U.S. Conference of Mayors, were contacted to obtain profiles of municipalities with progressive recycling programs. Sources of information were obtained through reviews of these profiles. Formal tallies of the frequency with which practices were employed were not possible in the absence of a comprehensive survey. Where available, information on emerging technologies and practices was included, but this was not the focus of the research effort.

Documentation of recycling hazards was found to be very limited and nonexistent in some areas. Few data are available to characterize the frequency of occurrence or magnitude of hazards related to the recycling industry. Few comprehensive, industrywide studies of hazards were located. As a result, it was necessary to rely on anecdotal accounts from facility representatives, regulators, and occupational health and safety professionals as a primary source of hazard information. In addition, the existence of certain recycling hazards was extrapolated from analogous situations in other industrial settings.

Limited information on the magnitude of recycling hazards precludes quantitative evaluation of the significance of the hazards (i.e., risk). However, the relative significance of recycling hazards to each other, to those associated with other MSW management options, or to those associated with other industrial processes is of paramount importance to the solid waste manager. This study rates hazards based on a Delphi approach. Hazards are rated as low, medium, or high based on a qualitative assessment of the following criteria:

- The frequency or severity of the hazard
- The ability to control the hazard with current technologies
- The ability to control the hazard through regulations
- The prevalence of the hazard in related industries

3. RECYCLING AS A MUNICIPAL SOLID WASTE MANAGEMENT METHOD

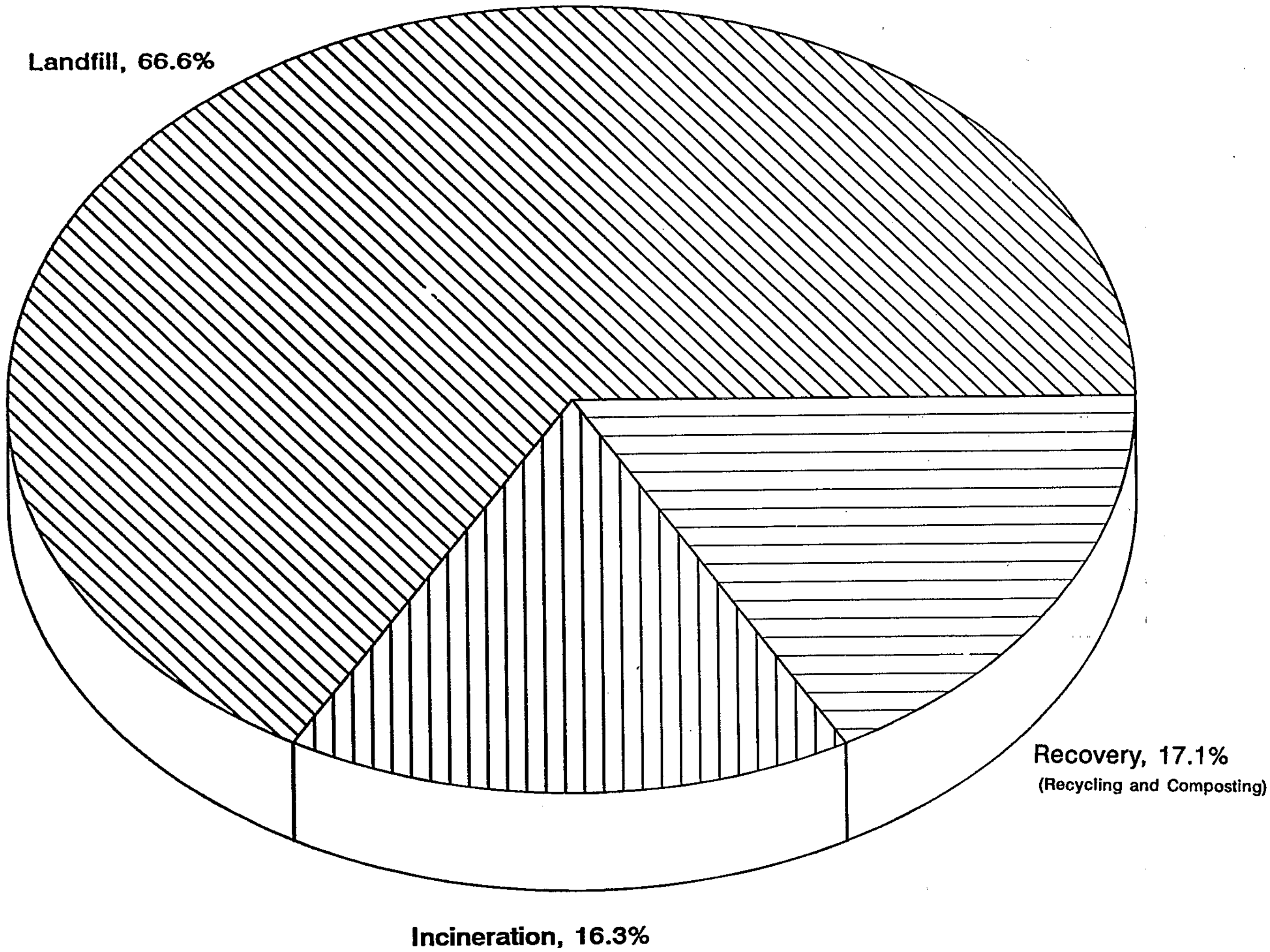
3.1. INTRODUCTION

The United States faces the challenge of effectively managing municipal solid waste as the amount of waste generated per capita increases. Recycling is one of the solid waste management options of the integrated waste management system outlined by U.S. EPA's Agenda for Action (1989). U.S. EPA (1989) recommends the use of an integrated waste management system that requires the complementary use of a variety of waste management practices to handle safely and effectively the MSW stream with the least adverse impact on human health and the environment.

To most effectively reduce waste management problems at the national level, the waste management industry, state governments, and municipalities should use the following hierarchy of integrated waste management: (1) source reduction (including reuse of products), (2) recycling (including composting), (3) waste combustion (with energy recovery), and (4) landfilling. Recycling and composting are near the top of the hierarchy because they prevent potentially useful materials from being combusted or landfilled and preserve waste disposal capacity (U.S. EPA, 1989). Section 3.2 discusses MSW management methods and the role of recycling. Information about Federal, state, and municipal efforts to regulate and encourage recycling is located in Appendix C. A description of the amount generated and a market summary for each of the five recyclable materials addressed in this report are provided in Appendix B.

3.2. MUNICIPAL SOLID WASTE MANAGEMENT METHODS

Three primary MSW management methods are currently available: landfilling, incineration, and recycling. As Figure 3-1 shows, of the 195.7 million tons of MSW generated in 1990, 67 percent was landfilled, 16 percent was incinerated, and 17 percent was recycled. The amount of MSW generated is projected to increase to 208 million tons in 1995 and 222 million tons in the year



Total Weight = 195.7 Millions Tons

Source: U.S. EPA,1992

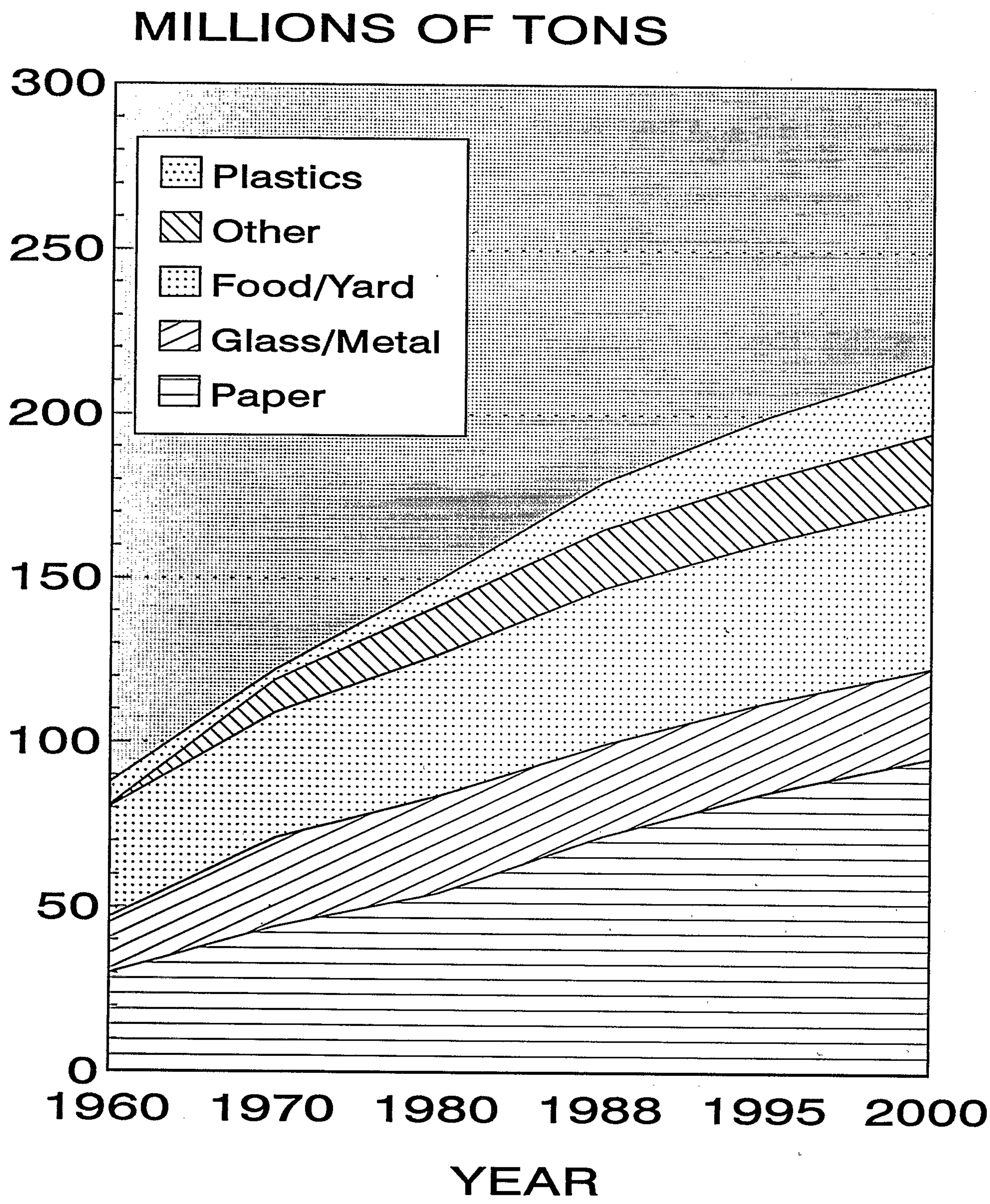
FIGURE 3-1
Municipal Solid Waste Disposal for 1990

2000 (U.S. EPA, 1992). Figure 3-2 illustrates the projected increase of specific MSW components.

Although MSW generated in the United States is disposed in landfills, the capacity of existing landfills is declining and siting new landfills has become difficult. Many older landfills were sited before environmental regulations were in place to control the potential for environmental contamination. Proposed facilities thus face problems in ensuring the protection of public health and the environment. Despite these difficulties, landfills will continue to handle nonrecoverable and noncombustible materials and the residues of incinerators and other waste treatment methods.

Municipal waste combustors reduce the volume of MSW that must eventually be landfilled. Most combustors are mass burn systems that burn commingled MSW; some systems recover energy that is sold to industries or utilities. Like landfills, incinerators are perceived as potentially hazardous to public health and the environment. Although new incinerators are being sited, the process is long and costly because of public concern about impact on local real estate values and potential toxic releases from the incinerated waste. Although issues such as operating cost, compliance with stringent air emissions standards, and incinerator ash disposal problems have impeded progress, it is predicted that incinerators increasingly will be used as a major management method for MSW.

In response to the challenge of effective and safe management of MSW, EPA established a national goal of reducing the amount of waste to be disposed by 25 percent through source reduction and recycling. In several cases, recycling conserves energy and natural resources by substituting waste materials for virgin materials. It also reduces the volume of waste that ultimately will be landfilled or incinerated. As discussed in Appendix A, markets for recyclable materials strongly influence the success or failure of municipal recycling programs. The availability of technologies to handle and process recyclables also influences these programs. Clearly, recycling has significant hurdles to surmount before it can capture a greater share of the MSW generated.



Source: U.S. EPA, 1992

FIGURE 3-2

MSW Generation, 1960-2000

Appendix D provides a brief bibliography on MSW management options, including landfilling, incineration, and composting, a form of recycling for organic material such as food and yard waste.

4. OVERVIEW OF RECYCLING PRACTICES AND PROCESSES

4.1. INTRODUCTION

The municipal solid waste recycling industry uses a variety of equipment and program strategies to meet expanding needs. In general, recyclables are collected from the consumer, sorted and prepared to meet market specifications, and used in the manufacture of new products. Recycling program strategies range from simple community drop-off centers to automated systems employing state-of-the-art collection vehicles and sorting facilities. Technologies and program organization are selected and integrated to increase the volume and quality of the salable recyclable stream. Program features vary to match numerous community-specific factors, including location, demographics, market specifications, existing equipment, and funding. Increasing program participation rates and lowering costs are often the primary considerations in selecting collection and sorting systems.

Although an array of organizational and technical recycling options is now available, some type of collecting and sorting followed by material-specific processing is fundamental to both private and public programs. Some programs rely more heavily on consumers or collection workers to sort recyclables at the point of collection, whereas other programs collect mixed recyclables and sort them at a dedicated sorting facility. A transportation mechanism must be in place to transfer recyclables from the consumer and among subsequent processing facilities. Although most municipalities are concerned about the aspects of recycling that directly affect their communities, namely collection and sorting, material-specific processing that is unique to the recycling industry also should be considered. The materials addressed in this section include aluminum, glass, paper, plastics, and steel/tin. Figure 4-1 illustrates representative recyclables flow pathways through various stages of the recycling industry. This chapter, an overview of some of the more common program alternatives, discusses the basic industry segments in four sections (4.2, Consumer Collection; 4.3, Curbside Collection; 4.4, Sorting Recyclables; and 4.5, Material-Specific Recycling

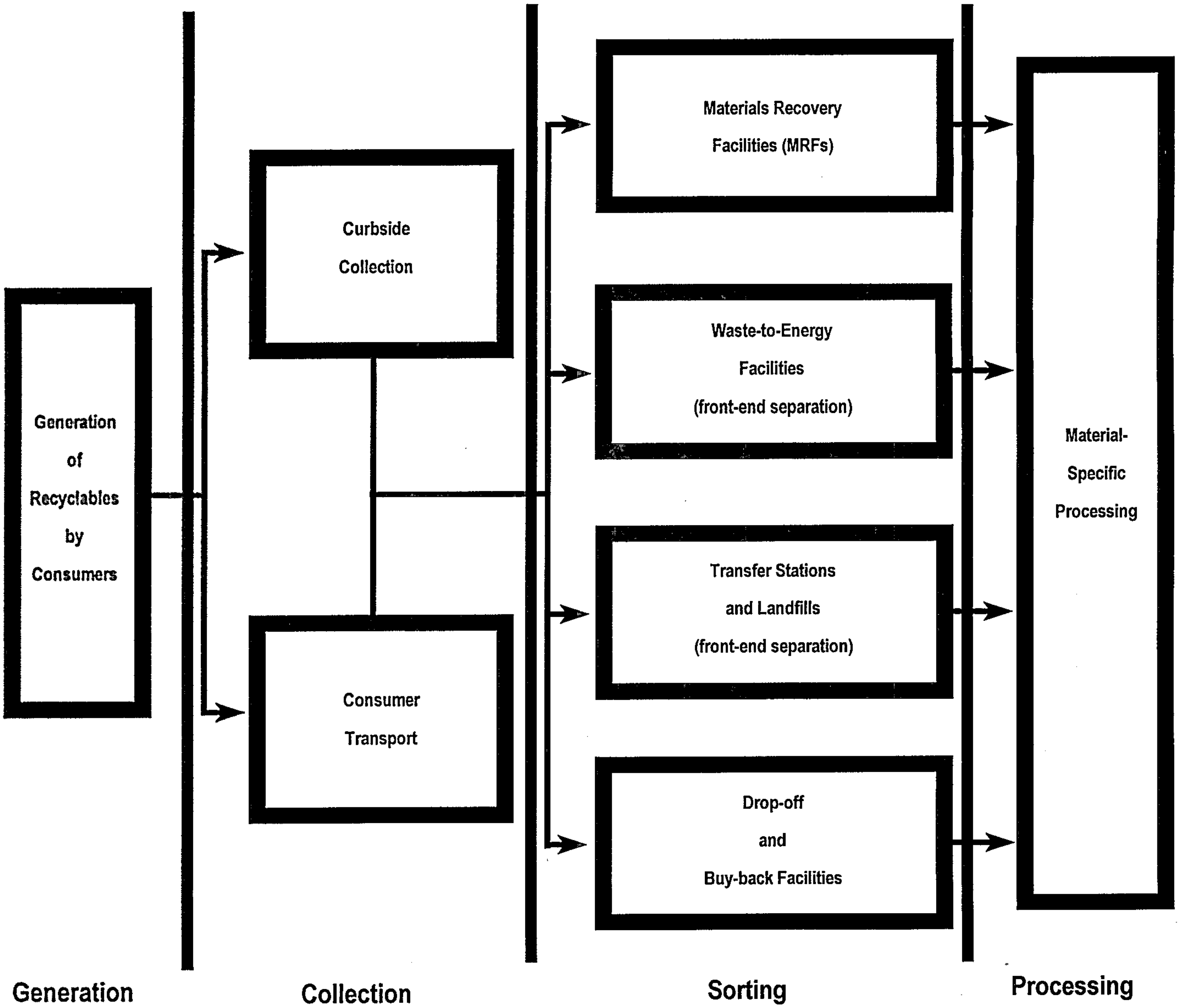


FIGURE 4-1

Recyclables Flow Through Primary Recycling Stages

Processes). The information can be used as a guide to identify appropriate technologies that relate to pertinent hazard information in Chapter 5.

4.2. CONSUMER COLLECTION

Consumers are responsible for the initial stages of recycling postconsumer recyclables generated in the home. With few exceptions, municipal recycling programs require the consumer to segregate recyclables from municipal solid waste (MSW) and prepare and store them for collection or deliver them to a drop-off or buy-back facility.

4.2.1. Consumer Separation and Storage

Both curbside and drop-off recycling programs require consumers to separate, sort, clean, and store recyclables. The degree of sorting and preparation required of the consumer varies depending on how recyclables are collected and the degree of postcollection processing they are to receive. For example, recyclables destined for a materials recovery facility outfitted to separate containers by material need not be sorted as thoroughly as recyclables bound directly for a material-specific reprocessing facility. Some programs require consumers to wash, delabel, and flatten containers, while others accept recyclables mixed with the remainder of the waste stream. Programs that require separation of recyclables usually expect consumers to store materials in the home between collections or deliveries to a drop-off facility.

It is common for programs to provide barrels, bins, or bags that residents can use to store recyclables and transport them to the curb. Apartments and multi-unit complexes sometimes provide residents with a centrally located recyclables collection area that serves a number of units or buildings.

4.2.2. Consumer Transport

Communities that operate drop-off or buy-back facilities generally require residents to transport recyclables to the facility (see Section 4.2.3 for more information on collection facilities). The use of personal vehicles to drop recyclables at collection centers results in increased traffic in the vicinity of the collection facility. However, recyclables may be dropped off during trips that include other local errands and therefore may represent only a minor increase in overall travel distance and time for the consumer. It is common in states that have enacted a bottle bill for beverage container collection facilities to be located at stores where beverages are sold.

4.2.3. Drop-Off and Buy-Back Facilities

Drop-off and buy-back facilities are technically simple collection operations. After preparation, sorting, and storage in the home, recyclables are delivered to one of these collection facilities at the consumer's discretion.

4.2.3.1. *Drop-Off Facilities*

Drop-off facilities are often established by municipalities as an initial, low-cost method for collecting recyclables. They function as either independent facilities or a front-end operation in conjunction with a landfill or transfer station. The public delivers recyclables to the facility and may be required to sort them by material into collection bins or dumpsters. Containers used at facilities to segregate recyclables by material include indoor storage bays, outdoor bins and dumpsters, and truck trailers. Facility workers may perform a "casual" inspection and sort to remove major contaminants before shipping. To conserve space during storage or shipping, recyclables may be baled or shredded. Drop-off facilities use a variety of material-handling equipment (e.g., forklifts, balers, shredders, conveyer belts) to move, consolidate, and load recyclables.

4.2.3.2. *Buy-Back Facilities*

Buy-back facilities are operations that pay the public for recyclables (usually aluminum, glass, plastic, and steel beverage containers) that are collected and delivered to the facility. Buy-back facilities are often managed as private, over-thecounter operations in conjunction with a retail beverage outlet or as large scrap yards. In states that have enacted bottle bill legislation, beverage vendors may be required to operate an in-store buy-back facility where consumers can redeem bottle deposits. Self-service machines that pay the collector for materials deposited in the machines are also available.

Consumers are responsible for sorting and collecting recyclables in the home before delivering them to the buy-back facility. The facility staff may perform additional sorting depending on the end-market specifications. Redeemable containers are frequently sorted by distributor, whereas nonredeemables are sorted by material. Sorting is usually performed manually when the recyclables are received. Mechanical systems also may be used for baling or shredding before shipping or storage. Recyclables at buy-back centers are typically stored in plastic bags or cardboard boxes.

4.3. CURBSIDE COLLECTION

Recyclables that are not delivered by the consumer directly to some type of collection facility are picked up from the public through a regular curbside collection program. These collection programs have become increasingly common as municipalities have attempted to increase participation rates by making recycling more convenient for the consumer. A wide variety of collection alternatives have evolved in attempts to maximize collection efficiency, improve material quality, and reduce costs. Many municipalities offer a system that combines both curbside collection and drop-off options.

4.3.1. Curbside Handling

Curbside handling can range from loading bags of mixed recyclables (without handling individual materials) to manually sorting individual recyclables by type. At a minimum, this process requires that the collection worker step to the curb, lift bins or bags to the side of the truck, and sort or dump materials into the collection vehicle. System variations include automated loaders that require the worker to hook or fasten barrels or buckets to dumping mechanisms and trucks with low-mounted body designs that allow the worker to hold bins of commingled recyclables at waist level while sorting the materials to compartments along the side of the truck. The type of container handled by workers varies with the community. Plastic bins, barrels, buckets, carts, and bags are used to collect recyclables. Collection carts are gaining in popularity because they can be rolled to the curb rather than carried. Some specialized carts are designed to be hoisted by automatic loading equipment.

Although sorting recyclables at the point of generation (i.e., in the home or at the curbside) greatly increases the purity of the materials collected, it requires more work by consumers or collectors. Many communities have moved to simplify their collection systems, eliminating consumer sorting by collecting commingled batches of recyclables. Consumers place all recyclable materials in bins or bags for pickup. Workers do not sort at curbside; they simply empty the bins or throw the bags into the collection vehicle. To increase the volume of material that can be collected per route, compactor trucks are often used to collect bagged recyclables. Some programs collect bagged recyclables in the same vehicle with other MSW.

4.3.2. Loading

There has been a proliferation of specialized trucks and trailers designed specifically for collecting recyclables at the curbside. Vehicles intended for both manual or automated loading include features to make collection faster and safer. Design parameters depend primarily on the nature of the program being served. For instance, programs that collect commingled recyclables at the curb may require a truck with only one or two compartments. Programs that rely on curbside sorting must have trucks with enough compartments to accommodate all types of materials collected.

A number of design innovations have facilitated curbside recycling for collection workers. One variety of truck has sorting compartments positioned much lower to the ground, decreasing the height that workers must lift materials during loading and sorting. Some recycling collection trucks are also fitted with a second steering wheel and a full driver compartment on the curb side of the truck to limit worker exposure to traffic on the street side of the vehicle. Others allow recyclables to be loaded on both sides of the truck cab. Cab floors lowered to curb height and taller doors reduce the strain of continually adjusting to or from seat height when entering or exiting the vehicle. Although modern truck designs allow one worker to efficiently drive and collect recyclables, some communities still use two-person crews.

4.3.2.1. *Manual-Loading Trucks*

Vehicles designed for manual collection are less expensive and more flexible than automated equipment. These trucks or trailers vary in complexity from traditional dump or pickup trucks to specialized vehicles featuring an assortment of compartments for holding different types of recyclables. One type of specialized truck requires workers to lift materials into side-loaded compartments with metal panels that are raised as the vehicle is filled. These trucks may have built-in steps or perches along the side and back of the truck on which workers can stand as they lift and dump materials. Another type of collection vehicle is the low-profile truck that places collection compartments as much as 10 inches lower than on standard trucks (Keller, 1989). Both types of trucks can be designed to allow sorting on either side of the vehicle.

4.3.2.2. *Automated-Loading Trucks*

Semiautomated and automated collection systems have been developed in an effort to make curbside collection faster and more efficient for a single worker. Side- and top-loading vehicles are the predominant automated collectors. Overhead loading trucks include a sorting container along the side of the vehicle. When the container is full, a worker initiates an automatic hydraulic load sequence that lifts the container to the top of the truck and dumps the materials into separated compartments. Side- and rear-loading vehicles often feature automatic hydraulic hoists or arms that hook or grab barrels or other containers, lift them, and dump their contents into compartments.

4.3.2.3. *Compactors and Crushers*

Conventional compactor trucks are also used to collect recyclables. This equipment works well for programs that collect loose or bagged commingled recyclables. Both traditional MSW collection vehicles and recycling vehicles fitted with compactors effectively reduce the volume of recyclables during collection, increasing route efficiency. The primary drawback to compacting recyclables is the high levels of broken glass that may result with excessive compaction ratios. Because some recyclables such as plastics pose a particular collection problem due to their high volume, compactors and crushers are included on some manual collection trucks solely to reduce the volume of containers and other recyclables.

4.3.3. Unloading

Most collection trucks are designed to unload from the rear. On vehicles with multiple compartments, the operator releases partitions between compartments to separately discharge the different materials at the receiving facility. Some sophisticated compartment trucks hydraulically lower each compartment's contents to the side of the truck. This method allows materials to be unloaded to material-specific bins and at the same time reduces the distance the recyclables are dropped (Combs, 1991). Drop distance and potential breakage are concerns with glass containers, which are much easier to handle when collected intact.

4.3.4. Transportation Associated With Curbside Collection

Transportation equipment and program alternatives adopted by a community to collect recyclables at the curbside vary depending on a wide range of factors, including the availability of equipment and funding, the size and layout of the community, and the proximity and capacity of the processing facility. In general, the selection of transportation alternatives reflects the importance of increased program efficiency at the least cost. Municipalities face the challenge of integrating the additional transportation demands of recyclable collection with the management of an existing MSW fleet. Some of the more common vehicle and schedule options are described below.

The proportion of recyclable collection vehicles to other MSW collection vehicles varies in both the private and public sectors. In Hampton, New Hampshire, BFI uses only two manual-loading compartmentalized trucks to collect recyclables whereas 13 compactors collect MSW (personal communication between TRC Environmental Corporation and Mike Hastings, Portsmouth District Manager for BFI, in August 1991). Recycle America, a division of Waste Management, Inc., operates a curbside collection program in Seattle, Washington, using a one-to-one ratio of recycling trucks to MSW trucks (personal communication between TRC Environmental Corporation and Jim Yaniglas, operations manager for Recycle America, Waste Management, Inc., Seattle, WA, in August 1991). The City of Austin, Texas, uses 11 straight-bed trucks with compartmentalized trailers and two compartmentalized-bed trucks to collect recyclables. Approximately 60 compactor trucks collect MSW (personal communication between TRC Environmental Corporation and Alan Watts, recycling coordinator for Solid Waste Services, a division of the Environmental Conservation Services Department, Austin, TX, in August 1991).

4.3.4.1. *Dedicated Recyclable and MSW Collection Vehicles*

The addition of a curbside recycling program necessitates an increase in a municipality's hauling capacity through rerouting the existing fleet or by adding vehicles to the fleet. In many cases, programs choose to add vehicles to their MSW collection fleet. These vehicles may be intended exclusively for the collection of recyclables. Truck manufacturers build vehicles on request with customized cab, chassis, and body combinations. In general, specialized recycling bodies tend to be mounted on smaller, light-duty cab-chassis combinations with smaller, more efficient engines than those of heavy-duty mixed MSW collection vehicles.

4.3.4.2. *Combined Trailer and Truck Collection*

Collection trailers provide a flexible alternative that can be added easily to existing collection equipment. Trailers can be designed to hold any number of recyclables in separate compartments and can be towed by recycling or MSW collection vehicles. Depending on how it is implemented, this alternative may not represent a significant increase in collection truck trips.

4.3.4.3. *Collection of Recyclables and MSW Using Same Truck*

Some programs use the same trucks to carry out separate recyclable and MSW collections. The collections may take place on the same day, different days, or even staggered weeks. A program in Pittsburgh, Pennsylvania, uses the same vehicles to serve up to 80,000 households (Magnuson, 1991). Twenty trucks were added to an existing fleet of 66 when recycling services were implemented (personal communication between TRC Environmental Corporation and Sean McHugh, environmental planner, Recycling Division, Environmental Services, Pittsburgh, PA, in August 1991). Although this represents an increase of about 30 percent in the total number of trucks, the total distance traveled by all vehicles was approximately doubled because each truck used for recycling was able to cover three of the standard MSW routes.

In some cases, the same general truck type, with modifications, will be used to collect MSW and recyclables. In Boulder, Colorado, a truck bed specifically designed to collect recyclables was mounted on the same cab-chassis as the traditional collection truck, representing little or no change in transportation-related emissions (personal communication between TRC Environmental Corporation and Leanne Connelly, recycling coordinator, Western Disposal Services, Boulder, CO, in July 1991).

4.3.4.4. *Cocollection*

Cocollection refers to the collection of recyclables and MSW in the same collection truck at the same time. Recyclables and MSW are collected in separate bags, dumped into the same collection truck, and separated when the truck unloads its contents at the sorting facility. In Houston, Texas, BFI used this method with traditional compaction trucks in a pilot study serving 19,000 households (Magnuson, 1991). Western Disposal uses this same method to serve 1,500 to 2,000 households in Boulder, Colorado (personal communication between TRC Environmental Corporation and Leanne Connelly, recycling coordinator, Western Disposal Services, Boulder, CO, in July 1991).

4.4. SORTING RECYCLABLES

Once collected, recyclables must be sorted into homogeneous material streams (i.e., aluminum, glass, paper, plastic, and steel) and prepared to meet market specifications. A large number of technologies are available from which to select the most appropriate sorting system for a given community.

Historically, recyclables have been separated from the waste stream at landfills, transfer stations, and waste-to-energy facilities. Sorting has also occurred at drop-off and buy-back centers as discussed previously. As programs have moved to collect mixed or partially sorted recyclables at the curbside, it has become necessary to sort recyclables after collection. The MRF, or intermediate processing center, has emerged as a popular sorting alternative. Most MRFs include a combination of manual and automated sorting and preparation for shipping. An exception to MRF-based systems is the limited number of programs that collect recyclables mixed with general MSW, which are handled at a waste processing facility. These facilities separate recyclables from MSW in addition to isolating them by material.

4.4.1. Transportation Associated With Sorting

In addition to the transportation associated with consumer drop-off (Section 4.2) or curbside collection (Section 4.3), recyclables must be transported between a variety of intermediate processing facilities. The method of transportation used to haul materials to these facilities varies greatly according to the type of material recycled and the specifics of the recycling program.

The most common destination for recyclables following collection is a sorting facility or an intermediate transfer station. In some programs, the sorting facilities are located within close proximity to the travel routes (0 to 12 miles in Austin, Texas [personal communication between TRC Environmental Corporation and Dave Anderson, Acco Waste Paper Co., Austin, TX, in August 1991]). In other locations, curbside collection vehicles deliver recyclables to a local landfill, but "roll-off" trucks must then transport the material to a sorting center farther away (approximately 50 miles in Hampton, New Hampshire [personal communication between TRC Environmental Corporation and Mike Hastings, Portsmouth District Manager for BFI, in August 1991]).

4.4.2. Materials Recovery Facilities

As with many recycling technologies, there is no precise definition of an MRF. One common definition is a facility that sorts a stream of commingled recyclables that has already been separated from MSW. MRFs accept materials from myriad sources, including curbside collection programs, drop-off centers, commercial collectors, and institutions. They sort recyclables, remove gross contaminants, and bale or otherwise consolidate recyclables for shipment to marketers, reprocessors, or manufacturers, depending on the material.

Since MRF design is so variable, the material-handling systems used at recycling facilities are supplied by a range of manufacturers, including distributors of equipment traditionally used in farm and construction applications that now market products for recyclable processing applications. A few vendors market complete recycling systems. Many recycling programs assemble the necessary equipment one piece at a time as it is needed (or as it can be afforded) and add it to an existing system.

MRFs are generally designed with two major recyclable processing lines: one for paper and paperboard products and another for mixed containers (aluminum, glass, plastics). Small-scale MRFs, which may process less than 100 tons of recyclables per day, rely on manual sorting (Figure 4-2). Automated sorting systems (Figure 4-3) are most often found in larger facilities designed to handle several hundred tons per day (Glenn, 1990).

Recyclables usually enter the MRF when they are discharged from collection vehicles to the tipping floor and pushed or loaded to process conveyors. If recyclable paper products and containers enter an MRF commingled, an initial sort separates the two streams. Paper, cardboard, and paperboard materials are sorted by hand and baled or compacted before shipping. Ferrous metals are magnetically extracted from the mixed containers. Aluminum, glass, and plastic are then sorted manually or automatically. Few satisfactory automated technologies exist to sort certain materials such as colored glass or mixed plastic resins, so these materials must be sorted manually for shipping. Aluminum, plastic, and steel are frequently baled, shredded, or flattened before shipping. Glass is either shipped in its sorted form (usually broken) or it is crushed or ground.

The remainder of this section summarizes the following features and equipment that are often implemented in MRFs:

- Tipping floors
- Bag breakers
- Conveyor systems
- Material sorters
- Trommel screens
- Air classifiers
- Magnetic separators
- Aluminum separators
- Glass crushers/grinders
- Slicers
- Shredders
- Plastic perforators
- Balers and compactors

Tipping Floors. Collection vehicles dump recyclables onto the tipping floor, generally an indoor concrete pad, when they arrive at the MRF. Forklifts, overhead

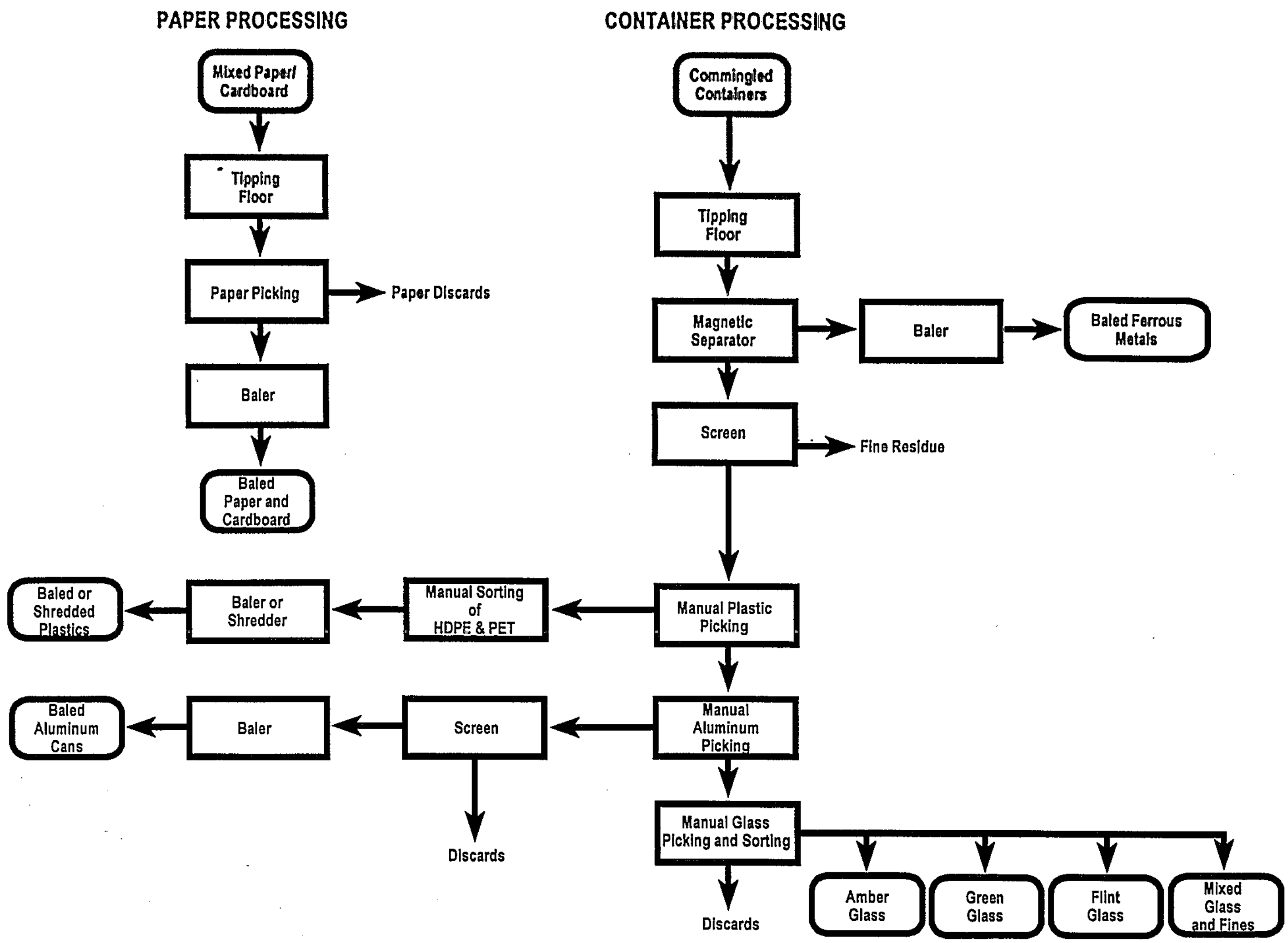


FIGURE 4-2

General Materials Sorting Process at an MRF

Source: U.S. EPA, 1991.

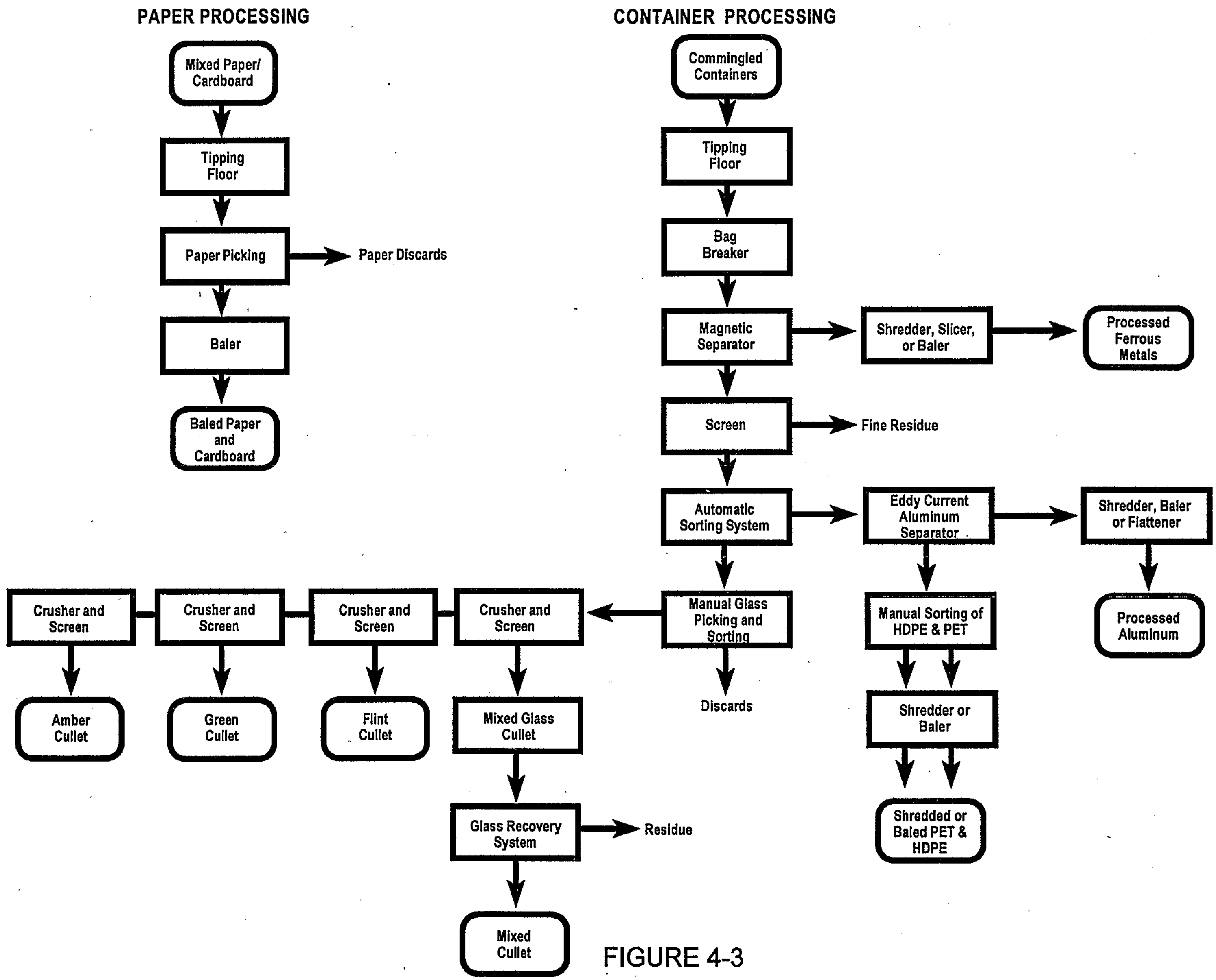


FIGURE 4-3

High-Technology Materials Sorting Process at an MRF

Source: U.S. EPA, 1991.

cranes, and front-end loaders are used to move recyclables from the floor to conveyors.

Bag Breakers. Single bag curbside collection (see Section 4.3) delivers commingled recyclables to the MRF in plastic bags that must be broken and removed before processing. Front-end bag-breaking equipment is designed to tear open bags with as little glass breakage as possible. Technology is still under development, but one system currently available uses a slowly spinning (15 rpm) tine wheel to tear open collection bags (Katz, 1991).

Conveyor Systems. Conveyor belts are common to nearly all MRFs. At facilities that rely on either manual sorting or gravity-based automated systems to sort materials, conveyors are used to move recyclables past sorting stations or to the top of processing equipment. Specialized conveyor systems are engineered to turn paper over or spread recyclables to a uniform depth to assist manual sorting (Egosi and Romeo, 1991). Conveyors are often mounted at or below floor level on the tipping floor so that material may be pushed directly onto the belt.

Material Sorting. Although recyclables processing has become increasingly automated, manual sorting remains the dominant means of sorting commingled materials. Paper or glass, plastic, and metal container streams are usually sorted on a conveyor belt that passes the workers. Both positive and negative sorting techniques are used. Positive sorting removes the desired recyclable material from a mixed waste stream, resulting in low contaminant levels. Negative sorting is the removal of contaminants from the stream of desired recyclables. This method is marginally effective because sorters inevitably overlook some contaminants that remain mixed with the recyclables.

Sorters traditionally stand beside a conveyor belt, reaching over it to remove and divert materials. Head-on sorting stations have also become popular. At these stations, material moves toward the sorter on a belt that discharges to a hole directly in front of the sorter. This arrangement allows the sorter to use both hands to remove material to both sides of the belt. To eliminate the number of times recyclables must be handled, many MRFs elevate sorting stations, placing them directly over conveyor belts or processing equipment. This configuration allows workers to drop sorted recyclables or waste into chutes that carry it below for further processing by balers or shredders.

An example of an automated sorting system is the Bezner System distributed by New England CRInc of Billerica, Massachusetts, currently in use at the Rhode Island Solid Waste Management Corporation's MRF in Johnston, Rhode Island. The German-engineered technology uses gravity and a series of three hanging chain "curtains" to sort a falling stream of mixed containers, including glass, aluminum, and plastics. As the containers fall down an inclined ramp, the chains divert the lighter fractions (aluminum and plastics) from the ramp to one processing line, while the heavier glass falls through the chains to a separate processing line. Although this system still requires manual sorting of glass and plastics, it eliminates the primary manual sorting step.

Trommel Screens. Trommels are inclined screen cylinders that are used to sort fine materials (e.g., glass fragments) from the remainder of the material stream. Material is fed in one end of a rotating trommel screen by a conveyor and discharged to a conveyor or storage container at the other end. Fine material that falls through the trommel screen is collected by a trough that lines the outside of the screen. The trough diverts the fine material to a separate conveyor or storage container.

Air Classifiers. Air blowers are frequently used to separate and classify (sort) lightweight recyclables. A mixed stream of materials is usually dropped from a conveyor or thrust from a shredder chamber into a vertically oriented chamber or cylinder that contains a constant, upward-blowing column of air. The heavier fractions fall from the air stream, and the lighter materials are blown to a separate bin or chute. Lightweight materials such as paper and plastics are commonly separated from heavier recyclables such as glass and metals by air classification. Air classification can also be used to separate light contaminants (e.g., scrap paper, foam plastics) from recyclables.

Magnetic Separators. Magnetic separators separate ferrous metals from the waste stream. A variety of cross-conveyor magnets are used to remove ferrous metals from material on conveyor belts (Morgan, 1987). The magnet is suspended over the conveyor belt at a height inversely proportional to its force. A belt and magnet system suspended across the material supply belt moves the attracted ferrous material to the side. Separated material is dropped to a bin or another conveyor when it passes out of the magnetic field.

Aluminum Separators. Automated aluminum removal can be achieved using electrostatic and eddy-current separators. The material stream is charged with a high-voltage ion source and then passed over the edge of a conveyor onto a rotating, electrically grounded drum. Highly conductive material such as aluminum rapidly dissipates its charge to the drum and falls into a waste bin. Nonconductive material such as plastic and glass clings to the drum's surface longer and is scraped from the drum onto another conveyor (U.S. EPA, 1977b). Another system uses a combination of rare earth magnets and steel poles to create a magnetic field that can actually pull aluminum from the waste stream (Koch and Ross, 1990).

Glass Crushers/Grinders. Crusher and grinder systems are used in some MRFs to densify glass. A variety of impact and jaw crushers use steel plates, rotors, or both to grind and crush glass into small fragments (commonly called cullet) (personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991). Glass is usually fed to the crusher by conveyor belt. Impact crushers break glass against steel rods or chains mounted along an inclined chute. Jaw crushers grind glass between two plates (personal communication between TRC Environmental Corporation and Bill Boxell, corporate process manager, Foster-Forbes, Inc., on August 28, 1991).

Slicers. Slicers employ a series of spinning blades to flatten containers and remove labels from containers. A stream of air blown over the sliced containers removes the labels for disposal.

Shredders. Shredders are sometimes used at MRFs to reduce aluminum, paper, plastic, or steel to a uniform size and minimum volume. Shredder designs vary depending on the material they are intended to reduce. Most include blades or sharp rotors that chop or tear the waste within a shredder compartment. Material is generally fed to the shredder compartment by a conveyor system that provides an even introduction of material and allows inspection before processing (personal communication between TRC Environmental Corporation and Susan Dumas of Herbold Equipment, Sutton, MA, on July 26, 1991). When the material scraps have been reduced to the target dimension, they either fall through a screen or are blown from the shredder.

Plastic Perforators. Perforators puncture multiple holes in plastic containers to release air from the containers during baling, resulting in a denser bale. The high pressures that can result within bales of nonperforated, capped containers can break bale ties or otherwise compromise the integrity of the bales.

Balers and Compactors. Recyclables (except for glass) are frequently baled or compacted to conserve space during storing and shipping. Recyclables are loaded to the baler chamber by conveyor belt, front-end loader, or by hand. Baler technology used in MRFs employs some type of hydraulic ram to compress recyclables, which are then secured with steel or plastic strapping. Bales of malleable materials (i.e., aluminum, steel) do not necessarily require strapping to maintain their integrity. Some balers use a second press to eject bales from the baler chamber.

4.4.3. Waste-to-Energy Facilities/Transfer Stations/Landfills

In addition to MRFs, a number of waste-to-energy facilities, transfer stations, and landfills have started to include front-end sorting operations as part of their processing. Some communities have tried to save money by adding a complete separation operation to existing transfer stations, and others have opted to separate only those materials that are easiest to remove, such as ferrous metals. Waste-to-energy plant manufacturers have recently started encouraging communities to include MRFs in their plans to build incinerators (J.A.S., 1988). Not only does the removal of glass and steel from MSW provide a potential source of revenue for these facilities, but it also reduces wear on incinerator equipment and reduces the amount of ash and residue that must be landfilled.

Sorting at these facilities may exist as a few front-end process steps or as an operation independent of the main facility. Regardless of their configuration, they include much of the same equipment found in MRFs. Collection vehicles deliver mixed MSW to the tipping floor where it is visually inspected and initially sorted before proceeding to a process line designed to remove target materials (Peluso, 1989).

4.5. MATERIAL-SPECIFIC RECYCLING PROCESSES

4.5.1. Introduction

Material reclamation, including the manufacture of new products, follows the collection, sorting, and associated transport of MSW recyclables. This phase of processing generally begins when the segregated materials (i.e., aluminum, glass, paper, plastic, and steel/tin) are received at a reclamation facility. For the purposes of identifying processes unique to recycling, the reclamation phase ends when the processing becomes equivalent for virgin and recycled materials. This end point is different for each material but is generally the point at which a homogeneous solid or liquid, free of "contaminants," is available for mixture with virgin material for product manufacture.

Transportation between and within facilities occurs throughout subsequent processing of recyclables. For example, separated paper must be hauled to deinking facilities; scrap metal is loaded and unloaded and transferred to different locations at steel mills. The type of transport required is both material and program specific. Trucks as well as rail cars and cargo ships can be used to transfer materials between facilities. Forklifts, front-end loaders, cranes, and other heavy equipment are used within facilities.

Market factors may affect the distances traveled and the types of vehicles used to transport recyclables to processing facilities. For example, if glass manufacturing plants are located too far away, transportation of cullet over the large distances by rail cars or cargo ships may become prohibitively expensive (Meade, 1991). However, other recyclables destined for markets abroad are containerized and exported (personal communication between TRC Environmental Corporation and Pat Schatz, office manager, Hooksett Recycling and Processing Center, Inc., Hooksett, NH, in August 1991).

The sections that follow summarize material-specific processing for the five target MSW recyclables, as follows:

- Section 4.5.2 - Aluminum
- Section 4.5.3 - Glass
- Section 4.5.4 - Paper
- Section 4.5.5 - Plastic
- Section 4.5.6 - Steel/Tin

Each section begins with an overview of the composition of each recyclable material. Knowledge of the material itself and any contaminants in the postconsumer material is essential to fully characterize processing byproducts and any associated hazards.

The second part of each material-specific section provides an overview of process technologies from which hazards can be identified in Chapter 5. The process descriptions are general and not intended to detail all possible steps or technologies. For materials for which it is impractical to address all possible feedstocks (e.g., scrap ferrous metal), one or more specific postconsumer products (e.g., food and beverage containers) are selected for discussion on the basis of their contribution to MSW and percent recovery. Figures on the percentage of each material recovered from MSW are discussed in Appendix B.

4.5.2. Aluminum

4.5.2.1. *Composition of Aluminum Recyclables*

Aluminum finds applications in numerous consumer products that may ultimately contribute to MSW. The elemental composition of aluminum products varies by product type. Table 4-1 lists elements, in addition to aluminum, that are present in different types of aluminum scrap. Aluminum used beverage containers (UBCs) constitute between 95 and 98 percent of all aluminum recycled from MSW (Franklin Associates, Ltd., 1990). Aluminum UBCs are typically treated with water-based, solvent-based, or a combination of surface coatings that are applied to both interior and exterior surfaces to isolate the can's contents from the metal body, improve appearance, protect lithography, and increase can mobility during filling (U.S. EPA, 1980a). Coatings and inks used in exterior labeling contribute a variety of organic and inorganic chemicals to the overall content of aluminum recyclables. Organic components typically used in surface coatings are summarized in Table 4-2. Pigments found in inks can be both organic and inorganic compounds. Although the trend is to use more organic pigments, the following inorganic pigments are used: cadmium, chromium, copper, iron, lead, mercury, molybdate, and zinc (U.S. EPA, 1992).

TABLE 4-1

Typical Elemental Composition of Aluminum Scrap

Source	Element %					
	Silicon	Iron	Copper	Manganese	Magnesium	Zinc
UBCs (directly reclaimed)	0.2	0.6	0.15	0.9	1.1/1.3	--
Municipal (mostly UBCs)	0.8	0.5	2.4	0.6	0.1	2.0
Automotive (automobile shredder residue)	5.0	0.8	1.3	0.3	0.1	0.6

Source: Henstock, 1988.

-- = Negligible

TABLE 4-2

Typical Organic Components of Coatings Applied to Beverage Cans

Interior Base Coat	
Butadienes	Epoxies
Rosin esters	Vinyls
Phenolics	Organosols
Overvarnish Coat	
Polyesters	
Alkyds	
Acrylics	
Primer (size) Coat	
Epoxy	Acrylic vinyl
Epoxy ester	Polyester resin
Solvents (used for interior and exterior base coats, overvarnish, and size coats)	
Mineral spirits	Ethylene glycol monoethyl ether acetate
Xylene	n-Butanol
Toluene	Isopropanol
Dicatone alcohol	Butyl carbinol
Methyl iso-butyl ketone	Paraffins
Methyl ethyl ketone	Propylene oxide

TABLE 4-2 (continued)	
Isophorone	Resityl oxide
Solvesso 100 and 150 (TM)	Aliphatic petroleum hydrocarbons
Di-isobutyl ketone	Nitropropane
Ethanol	Cyclohexanone
End sealing compound	
Synthetic rubber	
Heptane	
Hexane	

Source: U.S. EPA, 1977a.

4.5.2.2. *Process Technologies*

Secondary aluminum production from scrap aluminum began shortly before World War I and has grown at a constant rate since World War II. The technology of aluminum recycling has remained generally the same throughout the years, with changes primarily found in the method of casting ingots and the introduction of emission-control devices.

Recyclable aluminum is obtained by several means, including UBCs collected from consumers by retailers in states with deposit legislation; UBCs, other aluminum cans, foil, and closures collected from municipal recycling programs; and aluminum in many forms purchased directly from the public by scrap dealers. A relatively small quantity of aluminum is recovered and recycled from front-end separation at incinerators. Depending on the aluminum source and end-market specifications, aluminum may or may not have to be sorted by type. Large companies like ALCOA and Reynolds that manufacture beverage cans require separated aluminum. The aluminum recycling process consists of several steps, including the following:

- Baling and compacting
- Bale breaking
- Shredding
- Drying/delacquering
- Smelting
- Casting and cooling

Figure 4-4 presents a general overview of aluminum recycling. If scrap aluminum is to be transported over a long distance to a reclamation facility, it may first be densified to reduce its volume and cut transportation costs. At the reclamation facility, usually a secondary smelter, bales are broken, and the scrap is shredded, dried or delacquered, smelted, and cast. The recycling process and technologies described below emphasize UBCs because they constitute the majority of aluminum recycled from MSW.

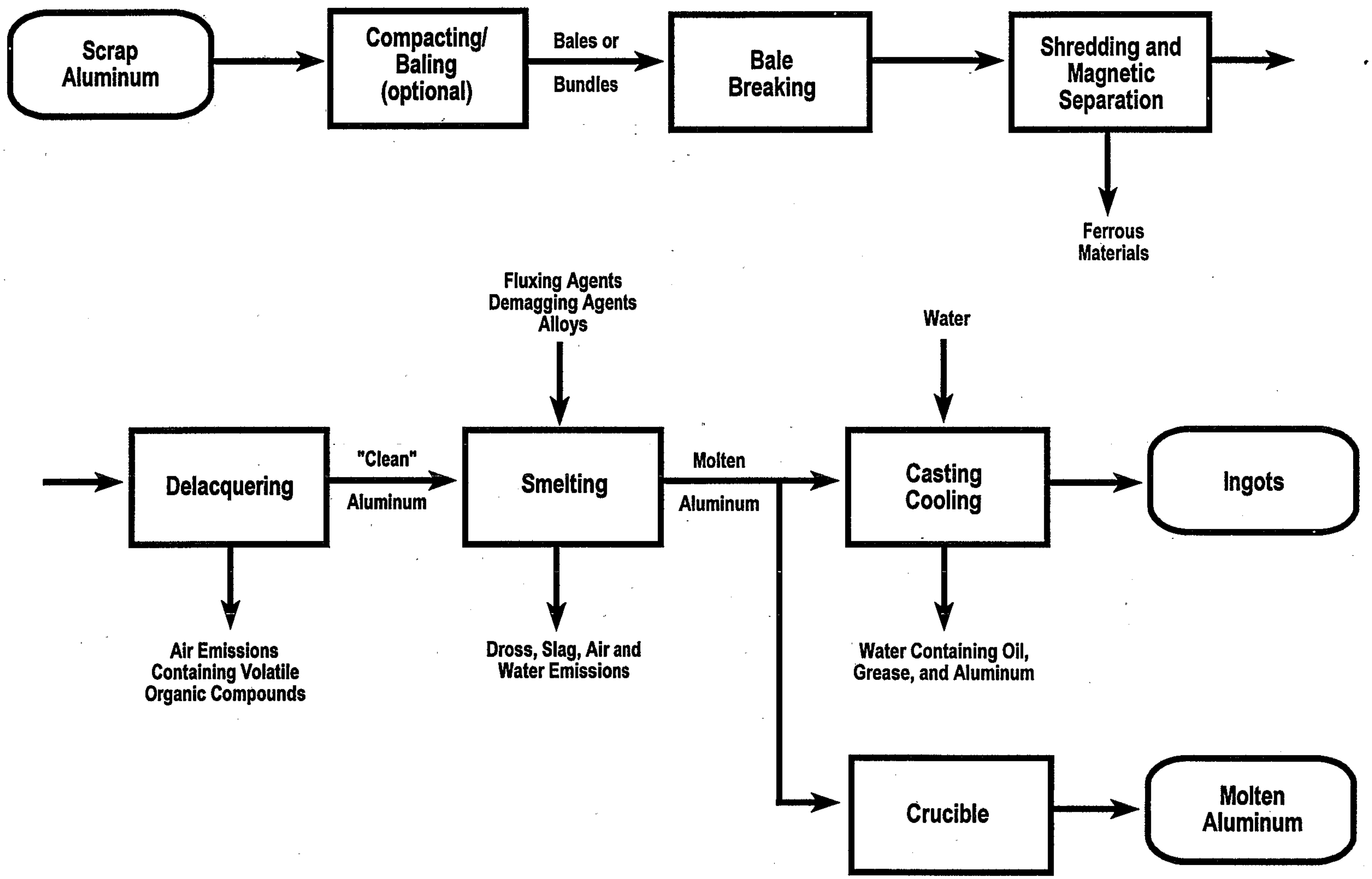


FIGURE 4-4

Generalized Aluminum Recycling Process

Balers and Compactors. Sorted aluminum scrap may be compacted to reduce its volume before transport to the secondary smelter. Aluminum UBCs typically arrive at the compactor in the form of loose, flattened cans. The "loose flats" are unloaded from the truck to high-density balers by forklift or front-end loader. Balers are of two types, either vertical (loaded on the top) or horizontal (loaded on one side). These machines compact the aluminum into bales generally weighing 700 to 1,200 pounds each (personal communication between TRC Environmental Corporation and John Vandevender of the Aluminum Company of America (ALCOA) of Knoxville, TN, on August 2, 1991; personal communication between TRC Environmental Corporation and Gene Brown of Maine Beverage Container Service, Inc., of Portland, ME, on August 13, 1991). Alternatively, the aluminum can be compacted into 35-pound biscuits that are packaged into 2,500-pound bundles (personal communication between TRC Environmental Corporation and John Vandevender of the Aluminum Company of America (ALCOA) of Knoxville, TN, on August 2, 1991). The exact size of the bales and the choice between baling or biscuiting depend on the cost of production and transport as well as operational limits such as the size of machinery of both the facility producing the compacted aluminum and the customer buying it.

Bale Breakers. Aluminum bales can be broken apart with a hammer mill or other type of bale breaker. The hammer mill uses a conveyor belt to feed the aluminum under a hydraulic or weight-driven mechanism, which crushes and breaks the bale into fist-size pieces (TRC, 1978).

Aluminum Shredders. Scrap aluminum is often shredded into small pieces before smelting to allow magnetic removal of iron contaminants and more efficient cleaning and melting. Within the shredder, the aluminum is sheared and cut into small pieces, the exact size of which varies depending on the specifications of the machinery and the size desired by the customer purchasing the shredded aluminum. The equipment uses high-speed blades that produce aluminum with sharp edges. The shredded aluminum is usually blown into the back of a trailer for transport to the secondary smelter. See Section 4.4.2 for further discussion of shredders.

Scrap Dryers/Delacquerers. Before aluminum scrap can be melted for remanufacture, impurities such as paints, coatings, container residues, and other contaminants must be removed. Impurities are removed through a process that involves drying the aluminum scrap (referred to as delacquering when recycling UBCs) or heating it in a rotary furnace or kiln until the contaminants have burned off. Aluminum fragments are exposed to heat as they tumble through an inclined, rotating kiln chamber. Paint and coatings that burn off the aluminum may produce additional heat that can be captured and used to increase kiln fuel efficiency and the combustion of contaminants. The aluminum leaving the delacquering kiln is considered clean, free of paints, coatings, and residues.

Smelting. Reverberatory and rotary furnaces are the two primary types of charge furnaces used in secondary aluminum smelting. Gas- or oil-fired reverberatory furnaces at medium to large secondary aluminum smelting operations typically range in capacity from approximately 10 to 90 tons (TRC, 1978). Shredded aluminum scrap is usually introduced to the furnace through a charge well positioned beneath the surface of the already molten aluminum. This facilitates the capture of fume emissions through the use of a collection hood and also minimizes aluminum oxidation.

Rotary furnaces have relatively small capacity and usually operate on a per-batch basis. Crucible or pot-type furnaces are used to melt even smaller quantities (up to 1,000 pounds) of aluminum (TRC, 1978).

When aluminum is in its molten form, several processes can be used to change its composition and melt characteristics. These processes include the addition of fluxing or alloying agents, the removal of excess magnesium, and the removal of dross or slag that forms on the surface of the molten aluminum.

Additives. Fluxing agents are usually added to the furnace with scrap to remove extraneous contaminants and reduce losses of aluminum. As aluminum reaches the molten stage, the fluxing agents react with leftover contaminants such as inks and coatings to form insoluble materials, which float to the top of the melt. The accumulated flux and associated contaminants are known as slag. This layer reduces loss that is due to oxidation of aluminum exposed at the surface. Flux may contain sodium chloride, potassium chloride, calcium chloride, calcium fluoride, aluminum fluoride, and cryolite. A typical flux composition is 47.5 percent sodium chloride, 47.5 percent potassium chloride, and 5 percent cryolite (TRC, 1978).

Alloying agents may be added to molten aluminum to produce a desired melt composition. Typical alloying agents include copper, silicon, manganese, magnesium, and zinc. However, little or no additional alloying is necessary when UBCs are recycled for use as new beverage cans.

Demagging. The tops of used beverage containers possess a higher concentration of magnesium than the rest of the can, and it is necessary to remove some of the magnesium to produce a homogeneous aluminum end product (Copperthite, 1989). Demagging, the process of removing excess magnesium from aluminum, uses chlorine or chlorinating agents (anhydrous aluminum chloride or aluminum fluoride) to react with the magnesium in the melt (U.S. EPA, 1989). For example, chlorine demagging introduces pressurized chlorine gas to the bottom of the aluminum melt. The chlorine bubbles upward, combining with magnesium to form magnesium chloride. As the magnesium becomes scarce in the melt, aluminum chloride, a volatile compound, is formed. Fluoride may be used to form magnesium fluoride in a process similar to chlorine demagging.

Skimming. Skimming is a procedure that removes dross (layer of oxidized aluminum) and slag (layer of flux and contaminant) from the surface of molten aluminum. Cooled slag and dross are removed and transported to either a residue processor, recycler, or disposal facility. Based on industry reports, water consumption for recycling slag/dross may vary from 30,000 to 80,000 liters per metric ton of slag/dross recycled (U.S. EPA, 1989). The wastewater may contain suspended solids (aluminum oxide and hydrated alumina), ammonia (approximately 200 mg/L), and metals such as aluminum, copper, and lead.

Casting and Cooling. After the furnace has been completely charged and the aluminum adjusted to meet the end-product specifications, molten aluminum is poured into casts. Ingot conveyor casting is the predominant casting method used in secondary aluminum processing (U.S. EPA, 1989). This method consists of pouring molten aluminum into molds that travel on a conveyor system. Water is commonly used to cool ingot casts. Direct chill is another method of ingot casting and involves the continuous solidification of the metal while it is being poured (U.S. EPA, 1989). Molten aluminum is allowed to flow through a distribution channel into a shallow mold. Circulating within the mold is noncontact cooling water that solidifies the aluminum. The base of the mold is attached to a hydraulic cylinder that is gradually lowered into a tank of water as pouring continues. When the cylinder reaches its lowest point, pouring is stopped. The ingot is then removed and sprayed with cooling water. Stationary casting is a method that involves pouring the molten aluminum into cast iron molds and allowing it to cool. Spray quenching may be used to cool the exposed surface of the aluminum. At some facilities, the end product is molten aluminum, which is transferred to a preheated crucible or mold for transport.

4.5.3. Glass

4.5.3.1. *Composition of Glass Recyclables*

The four common types of glass are soda-lime, borosilicate, lead silicate, and opal. The primary constituent of each of these is silica, but depending on end-product specifications, various minerals and chemicals can be added to the virgin material ("the batch"). Additives such as boron oxide, which causes the glass to withstand higher degrees of thermal shock, and lead oxide, which elevates electrical resistivity, ultimately define the properties of the glass (U.S. EPA, 1979). Table 4-3 lists the constituents of the major glass types.

Postconsumer glass can be divided into three primary functional groups: container glass, flat glass, and pressed and blown glass. Nearly 100 percent of all MSW glass recycled are containers manufactured exclusively of soda-lime glass. Glass containers received for reclamation include a significant fraction of nonglass materials. These include paper and plastic labels affixed with adhesives; paints, inks, and dyes; and plastic and metal caps. Container residues, both nonhazardous (e.g., beverage residues) and hazardous (e.g., pesticides), may also be present. The focus of subsequent discussions is soda-lime glass containers, given their predominance in recycled MSW.

4.5.3.2. *Process Technologies*

Glass processing facilities usually prefer to receive glass that has been color sorted by the consumer or at a materials recovery facility. In some cases, glass processing facilities do not accept unsorted containers. Facilities that do accept commingled glass need to assess the specifications of the cullet (crushed scrap glass) markets. If the market requires one color, then the facility must separate the glass. The cullet color and size, as well as the amount of foreign objects present in a cullet load, are highly regulated for certain markets. Some glass cullet market specifications are presented in Table 4-4. In general, only a small amount of green or amber glass can be added to a batch of flint glass (clear). Manufacturers also control the percentage of off-specification glass in green and amber batches. Table 4-5 summarizes the specifications that are generally met by cullet dealers for each cullet type.

Before cullet can be added to a virgin glass batch, it is necessary to remove as much of the associated nonglass and off-specification glass material as markets require. Since metal, plastic, or other contamination in a batch causes

TABLE 4-3

Typical Glass Compositions

Major components	Percent by weight	Major components	Percent by weight
Soda-lime glass		**Opal glass**	
Silica	72	Silica	71.2
Soda	15	Alumina	7.3
Lime and magnesia	10	Calcium oxide	4.8
Alumina	2	Potassium oxide	2.0
Other oxides	1	Fluorine	4.2
Borosilicate		**Lead glass**	
Silica	60-81	Silica	35-70
Alumina	1-17	Lead oxide	12-60
Boron oxide	5-24	Sodium oxide	4-8
Sodium oxide	1-15	Potassium oxide	5-10
Magnesia plus calcia	4-17	Alumina	0.5-2.0
Potassium oxide	1-8		

Source: U.S. EPA, 1979.

TABLE 4-4 Cullet Requirements for Primary Markets	
Market	Specifications required
Container glass	Cullet must be noncaking, free flowing, show no drainage of liquid and 140 U.S. mesh; contain <0.02% organics, <0.14% magnetic metal contaminants, and <1 nonmagnetic particle per 18 kg
Brick and concrete aggregate	Can use up to 50% cullet; should be free of metal or organics
Foamed glass	Can use up to 95% cullet; no specifications
Ceramic tile	Can use up to 60% cullet; unsorted; sized to 200 mesh
Terrazo tile	Can use up to 60% cullet; must not contain any metal
Building panels	Can use up to 94% cullet with no metal or rehydratable materials; must be sized to 200 mesh
Glass wool	Can use 10-50% cullet; accept up to 2% foreign material
Slurry seal	Can use 100% cullet; must have neutral pH and contain very little metal
Glasphalt	Can use 77% cullet; smaller than 1/2 inch; up to 15% nonglass material is acceptable

Source: U.S. EPA, 1981.

TABLE 4-5

Amount of Colored Cullet Accepted
by Container Manufacturers

Container color	Cullet color (percent of total cullet)		
	Amber	Flint	Green
Amber	90-100	0-10	0-10
Flint	0-5	95-100	0-1
Green	0-35	0-15	50-100

Source: U.S. EPA, 1981.

imperfections in the product, a major portion of the glass recycling process consists of separating and sorting stages.

In general, when glass arrives at a processing facility, a combination of the following steps and equipment is employed:

- Manual sorting
- Magnetic separators
- Air classifiers
- Glass crushers and grinders
- Screens
- Aluminum separators

Depending on the cullet grade and its expected market, glass may also be rinsed with water following the above steps.

Numerous variations of this process are in place, but an estimated 90 to 95 percent of the glass processing facilities in the United States use these basic techniques (personal communication between TRC Environmental Corporation and Roger Hecht, vice president, Bassichi's Company, on July 31, 1991). Few technologically advanced separation methods are employed, primarily because the prices of cullet are sufficiently low that most companies cannot afford expensive machinery.

The following discussion describes the most conventional process used to produce glass cullet. Figure 4-5 presents a schematic diagram of a typical glass recycling process. Although the steps outlined below are used consistently in glass recycling facilities, the order of processing steps varies from facility to facility. For example, one facility may magnetically separate the waste before crushing, another may do so after crushing, and still another may use magnets before and after crushing. Facility operators rely on trial and error to determine the most effective means of producing cullet in their setting. No single method has been proven to work most effectively under all circumstances.

Manual Sorting. Glass arriving at a processing facility has usually been presorted by color. It is first emptied into a surge hopper that feeds the glass onto

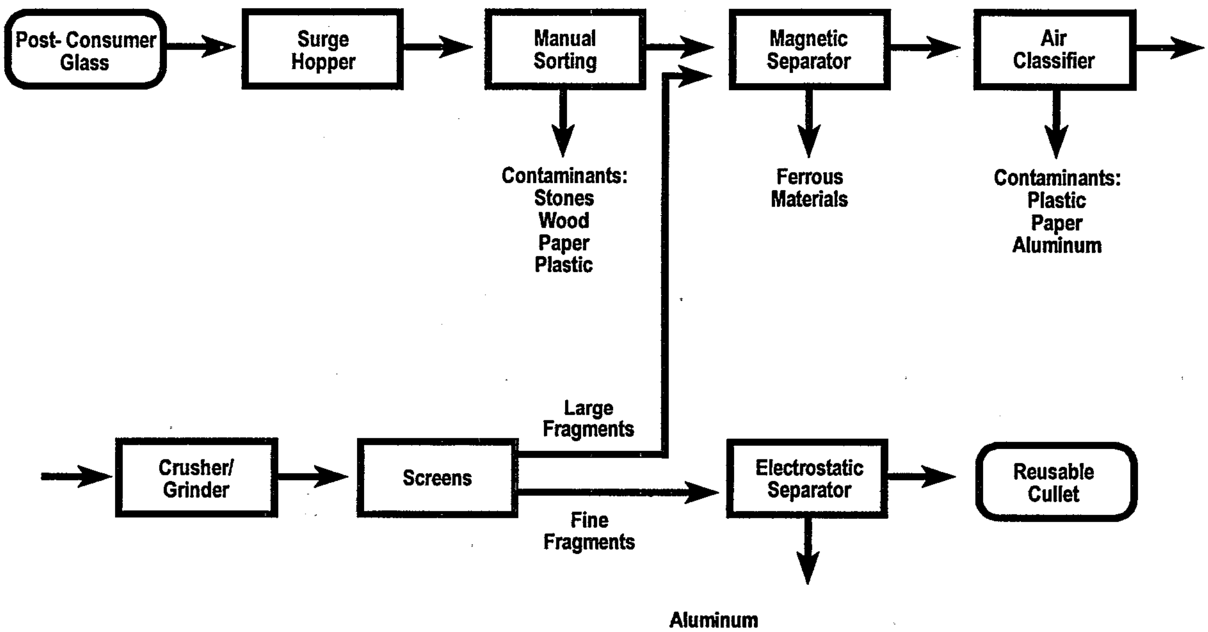


FIGURE 4-5

Generalized Glass Recycling Process

a conveyor belt. A facility often processes different colored glass on dedicated lines or at different times to avoid mixing them (personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991). The glass passes along the conveyor where workers remove any large debris such as stones, branches, or other nonglass material (personal communication between TRC Environmental Corporation and Roger Hecht, vice president, Bassichi's Company, on July 31, 1991). Most facilities process glass at a rate that requires two or three sorters per conveyor.

Magnetic Separators. Magnetic separation of ferrous material from glass or glass cullet typically follows hand sorting. The most common type of magnet used to remove ferrous material is the cross-conveyor magnet (personal communication between TRC Environmental Corporation and Bill Boxell, corporate process manager, Foster-Forbes, Inc., on August 28, 1991).

Air Classifiers. Glass passed through magnetic separators is often processed using an air classifier or vacuum to remove lighter contaminants. Some facilities use one or a series (up to 150) of powerful vacuums placed over the material supply conveyor to remove glass fines and light contaminants from heavier glass fragments (personal communication between TRC Environmental Corporation and Roger Hecht, vice president, Bassichi's Company, on July 31, 1991). Another system uses an upward air flow to blow light material away from the glass as it passes across a vibrating screen.

Glass Crushers and Grinders. After the glass is separated from the extraneous waste, it is ready to be crushed or ground into cullet. Impact and jaw crushers are commonly used (personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991).

Screens. Cullet passes onto a vibrating screen that allows smaller glass fragments to pass through to the next stage of the recovery process. Larger pieces, including any contaminants, are conveyed back to the sorters, magnetic separators, or crushers and grinders for reprocessing. Cullet is screened and reprocessed through the separators and crushers and grinders until it meets size specifications (personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991). This process may be repeated three or four times before the cullet reaches the desired size.

Aluminum Separators. Most processing facilities use an electrostatic or eddy-current magnet to remove aluminum fragments from screened cullet (personal communication between TRC Environmental Corporation and Bill Boxell, corporate process manager, Foster-Forbes, Inc., on August 28, 1991).

4.5.4. Paper

4.5.4.1. *Composition of Paper Recyclables*

In 1988, recycled wastepaper in the United States was made up of newspapers (16.2 percent), corrugated (49.8 percent), mixed papers (11.0 percent), and high-grade deinking paper (8.5 percent), with additional volumes of in-plant pulp substitutes (14.5 percent). In total, wastepaper contributed approximately 25 percent of new supply production in 1988 (Franklin Associates Ltd., 1990).

Paper is predominantly made of cellulose fibers from wood and cotton and other sources. Mechanical or chemical techniques reduce hardwood and softwood to fiber-rich pulp. Chemical methods may use caustic soda, sodium sulfate, and various sulfides. In addition to fiber, paper consists of numerous coatings, sizing agents, and colorants. Coatings, used to make paper strong and smooth, include clay, titanium oxide, calcium carbonate, zinc sulfide, talc, and synthetic silicates. Sizing agents make paper water resistant and include rosin, hydrochemical and natural waxes, starches, glues, and cellulose derivatives. Colorants are made of a wide range of inorganic elements. The most commonly used pigments are carbon black (black) and titanium oxide (white).

Inks are another major constituent of paper recyclables. They generally consist of pigment and a vehicle. Carbon-derived black pigments are the most common. Other common pigments include titanium oxide, zinc sulfide, and zinc oxide. Although the vehicle is not actually applied to the paper with the pigment, vehicle residues may remain on the paper. Printing vehicles include a variety of oils, waxes, and solvents. Letterpress and lithographic inks, which print well on newsprint, make use of mineral oil, resin, and solvent vehicles. Xerographic, UV-cured, and laser printing inks use solvent, acrylic, and polyester-based vehicles (Carr, 1991). Flexographic inks, a relatively new category, have wide applications and are gaining in popularity. These inks use numerous solvents as the printing vehicle.

4.5.4.2. *Process Technologies*

Plants that recycle postconsumer wastepaper receive it from commercial collectors, wastepaper dealers, or directly from municipal collection programs. When paper arrives at the facility, it is inspected and passed through a series of sorting stages to remove gross contaminants. Many contaminants are found in the wastepaper stream that must be removed manually or by screens or filters throughout the process. Contaminants are listed in Table 4-6 by the paper grade. Next, the paper is pulped, and the pulp is cleaned, deinked, and bleached. Processes used in wastepaper recycling plants vary depending on the paper grades accepted (Table 4-7). Pulp used in low-grade products such as brown paper bags and cardboard often requires no deinking and little bleaching, whereas pulp used in high-grade products may undergo more thorough cleaning. Most facilities include some combination of the following types of steps and equipment:

TABLE 4-6

Typical Wastepaper Contaminants

	Hot melt glues	Pressure-sensitive adhesives	Poly-styrene foam	Plastic films	Waxes	Wet strength resins	Latex	Asphalt	Synthetic fiber	Starches and gums	Coatings	Poly-ethylene	Clays	Inks
Pulp substitutes	X					X				X	X			
Deinking		X			X	X					X	X	X	X
Newspaper	X			X	X		X	X	X					
Mixed	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Corrugated	X	X	X	X	X	X	X	X						

Source: Amoth et al., 1991.

TABLE 4-7

Specific Processes Associated With Wastepaper Categories

Wastepaper category	Process	Finished products
Pulp substitutes (in-plant scrap)	Pulping	Fine paper
		Tissue
Deinking grade paper	Pulping	Tissue
	Screening	Fine paper
	Cleaning	
	Deinking	
Newspaper	Pulping	Newsprint
	Screening	Folding cartons
	Cleaning	
	Deinking	
Mixed papers	Pulping	Packing
	Screening	Packaging
	Cleaning	Molded products
Corrugated	Pulping	Corrugating medium
	Screening	Linerboard
	Cleaning	Kraft towels

Source: Broeren, 1989.

- Material inspection and storage
- Manual sorting
- Magnetic separators
- Trommel screens
- Pulpers
- Screens
- Separators (deinking)
  - Flotation
  - Washing
- Bleaching
- Dewaterer/thickener
- Wastewater clarification
- Effluent treatment
- Sludge disposal
- Paper milling

Figure 4-6 depicts the generalized process flow of a paper recycling plant.

Material Inspection and Storage. Wastepaper must be carefully inspected for quality before it can be used as a pulp supply. Levels of contaminants, aging, and water damage must be evaluated when the wastepaper arrives at the recycling facility. Aged or water-damaged papers are often discolored, which limits their use in high-quality end products. With current technology, roughly 70 percent of the mixed wastepaper that enters a facility can be used for recycled paper, and 20 to 30 percent must be discarded, usually landfilled or incinerated (Patrick, 1990).

The inspection and storage area is generally arranged much like the tipping floor of an MRF. Trucks deliver loads of loose or baled wastepaper and dump them on a concrete receiving floor. Paper is stored in piles or in concrete bins or compartments. Bucket-loaders and forklifts are used to move the paper around the facility.

Manual Sorting. Unless a consistently high-quality wastepaper stream is available (i.e., in-plant scrap), most paper plants perform some degree of sorting before pulping. Sorting wastepaper by quality, color, or grade is essentially a manual operation. The wastepaper stream is usually sorted by workers along a conveyor belt. Both positive and negative sorting techniques are used to remove contaminants and sort paper by grade (Andrews, 1990). See Section 4.4.2 for more discussion of sorting methods.

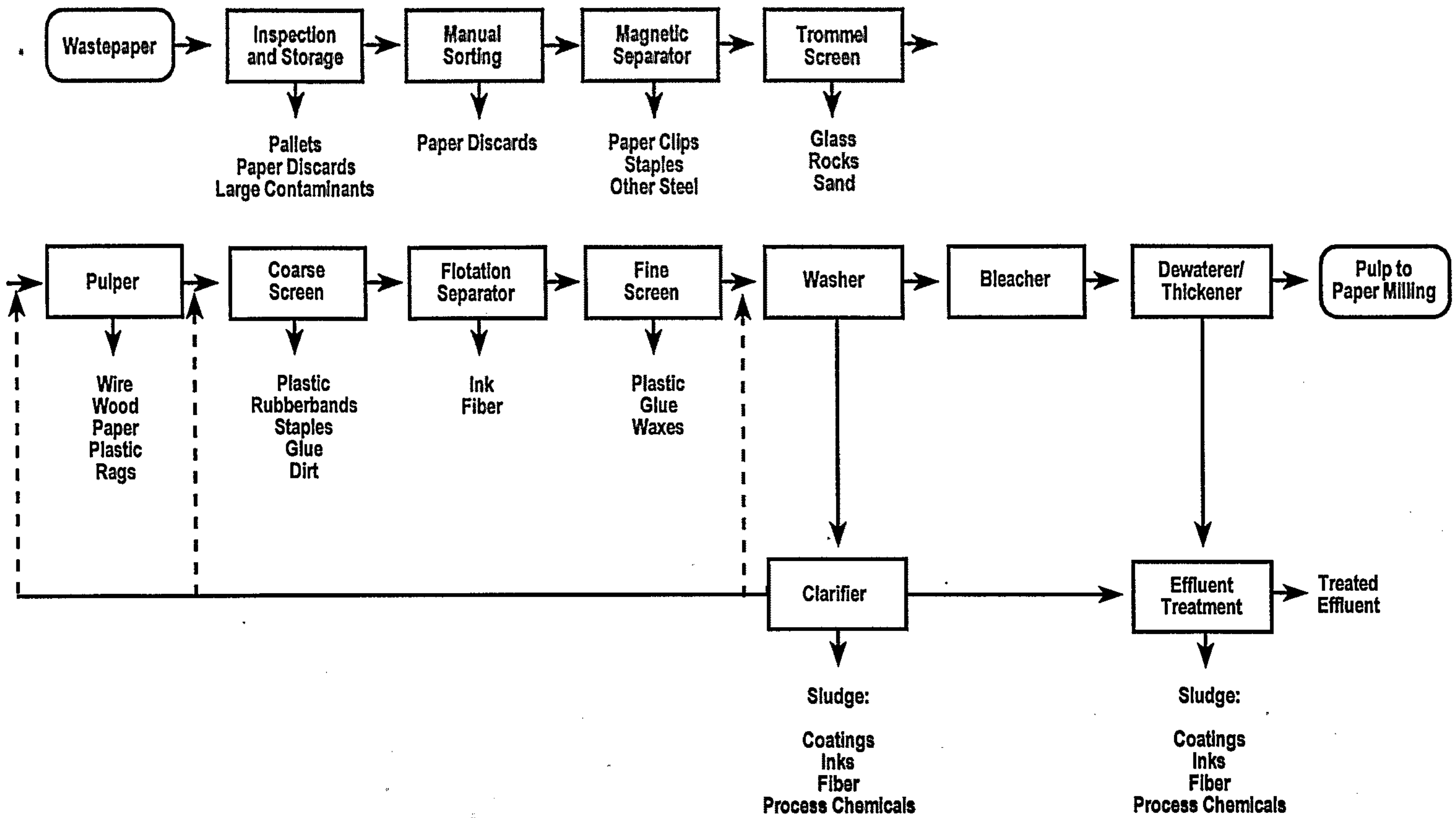


FIGURE 4-6

Generalized Paper Recycling Process

Source: Carroll and Gojda, 1990; Schriver, 1990

Magnetic Separators. Magnetic separators are used in some wastepaper processing facilities to separate ferrous metal contaminants (e.g., paper clips, staples, wire) from papers. In general, magnetic separators in paper plants employ a suspended magnet to remove ferrous metals from a conveyor belt passing beneath it (Morgan, 1987). See Section 4.4.1 for more discussion of magnetic separator technology.

Trommel Screens. Trommels are inclined screen cylinders that are used to sort fine materials such as glass fragments from the wastepaper stream. See Section 4.4.2 for a description of their use.

Pulpers. After passing through some combination of the processes discussed above, wastepaper enters the pulper. Pulpers generally consist of a large mixing vat with spinning paddles or blades that churn the paper in a water-based slurry to "fiberize" it and break down contaminants with a minimal amount of fiber degradation. Wastepaper bales that have been broken apart are evenly fed to open pulping vats. Some pulpers use metal rotors and disks to grind the paper to fibers, and others rely on fiber-to-fiber contact to break down the paper. Heated water (generally below 150°F) and caustic chemicals such as sodium hydroxide are added to facilitate the pulping process. A number of process-enhancing chemicals may also be added to the system at the pulper to ensure complete mixing with wastepaper (Table 4-8). The pH of pulper slurry is raised to between 10 and 12, which swells fibers and releases inks into suspension. The alkalinity also hydrolyzes ink vehicles and binders. Some screening of large contaminants takes place as the pulp is drained from the pulper and the pulp slurry, or "stock," is carried by pipes to subsequent process steps.

Recently, high-consistency pulpers have gained popularity. These pulpers rely on a higher fiber concentration (roughly 15 percent) to break down the paper. High fiber concentrations are obtained by using less water. This method reduces the amount of chemicals and energy required and permits larger contaminant

TABLE 4-8

Deinking Chemicals

Deinking chemical	Structure/formula	Function	Dosage (% of fiber)
Sodium hydroxide	**NaOH**	Fiber swelling Ink breakup Hydrolyzes Ink dispersion	3-5
Sodium silicate	**Na_2SiO (hydrated)**	Wetting Peptization Ink dispersion Alkalinity ledger and buffering Peroxide stabilization	3-5
Sodium carbonate	**Na_2CO_3**	Alkalinity Buffering Water softening	3-5
Sodium or potassium	**(NaPO3)n=15 Hexametaphosphate $Na_5P_3O_{10}$ Tripolyphosphate Tetrasodium pyrophosphate**	Metal iron sequestrant Ink dispersion Buffering Alkalinity Detergency Peptization	0.2-1.0
Nonionic surfactants	**Ethoxylated linear alcohol Ethoxylated alkyl phenols**	Ink dispersion Wetting Emulsification Solubilizing Ink removal	0.2-2.0
Solvents	**C_1-C_{14} aliphatic saturated hydrocarbons**	Ink softening Solvation	0.5-2.0
Hydrophilic	$CH_2CHC=OOH(Na)n$	Ink dispersion	0.1-0.5

TABLE 4-8 (continued)			
Deinking chemical	Structure/formula	Function	Dosage (% of fiber)
Polymers	Polyacrylates	Antiredeposition	0.1-0.5
Fatty acid soap	$CH_3(CH)_{16}COOR$ Stearic acid	Ink flotation acid	0.5-5.0
Hydrogen peroxide	H_2O_2	Bleach	1.0
Sodium hydrosulfite	$Na_2S_2O_4$	Bleach	0.5-1.0
Chlorine	Cl_2	Bleach	0.2-1.0

Source: Amoth et al., 1991.

particles to remain unbroken in the pulp, which facilitates subsequent flotation separation.

Stake Technology Ltd. (StakTeck) of Ontario, Canada, has developed a steam explosion pulping method that pressurizes shredded paper and water by using a screw press. The pulp is released under high pressure against a rotating blade, causing an explosion-like reaction and chopping the pulp into small bits. The system operates at temperatures as high as 400°F and pressures as high as 400 psi (Stinson, 1991). The process can replace standard pulping, and StakTeck claims it requires substantially less water and energy (MSW Management, 1991).

Screens. Most plants include a number of screening steps. Screens varying in coarseness are used to remove a range of progressively finer contaminants from pulp. Rotors may be used to press pulp through the screens.

Separators. Separation, often referred to as deinking, is the process that removes ink particles from pulp. Flotation and washing are the primary deinking technologies. Systems that float large ink particles from pulp slurry have traditionally been popular in Europe; systems that wash dissolved inks from pulp have been more common in the United States. Recent advances in flotation technology have led to its increased popularity in the United States. Both techniques generate ink-laden residue, which is either in the form of a froth or is dissolved in wastewater. Table 4-8 lists additives used in the deinking process. These chemicals are added at many points throughout the system, depending on the technology used and the degree of pulp quality required for end products. Chemical additives remaining in washwater and sludge are handled by onsite wastewater and sludge treatment systems.

Flotation Separators. Small ink particles are agglomerated into larger clusters that float to the surface attached to bubbles of air, which has been injected into the bottom of the flotation tank. The resulting inky foam or slurry is mechanically skimmed from the surface and usually dewatered before disposal.

For flotation to work effectively, ink must be stabilized as insoluble particles. Fatty acids are added to the pulp to form calcium soaps that act as stabilizers (Schriver, 1990). Fatty acid soaps and ethoxylates are commonly used along with calcium chloride, which assists the fatty acid conversion to insoluble soap. Typical concentrations are approximately 80 pounds of surfactant per ton of dry pulp produced (Basta et al., 1991). In addition, clay enhances the process of ink removal and is frequently added to flotation systems.

Washing Separators. Washing separation systems operate by dispersing ink into tiny particles that can be washed from the pulp. Classes of alkylphenol ethoxylates and linear alcohol ethoxylates are commonly used as dispersants in washing systems (Schriver, 1990). A variety of washing systems are available. The most common types of washers are described below (Horacek, 1983):

> <u>Sidehill screens</u> are, in simple terms, inclined troughs lined with a screen. Pulp released at the top of the screen gradually tumbles to the bottom under its own weight. Water passes from the fiber and through the screen into a collection tank below.
>
> <u>Gravity deckers</u> use spinning horizontal screen drums that accept a coating of pulp slurry. Water drains to the center of the drum and is removed. The pulp cake is scraped off the drum as it dries.
>
> <u>Inclined screw extractors</u> use a screw to pull the pulp slurry up and through an inclined screen cylinder. Water drains away as the pulp rises in the cylinder.
>
> <u>Vacuum filters</u> draw water from the slurry by pulling the pulp against screens.
>
> <u>Screw presses</u> extract water from the slurry by compacting the pulp in an enclosed chamber with a large screw. Water is forced from the pulp through perforations in the chamber walls.

All of these types of equipment are enclosed systems, except for the sidehill screen. Wastewater drawn from the pulp is usually sent to a clarifier for treatment. Because of required chemicals and water volumes, it is not practical to use clean water during washing. Instead, recycled wastewater streams are commonly used throughout washing systems (Horacek, 1983).

Bleaching. A majority of paper recycling plants bleach pulp fibers to improve their brightness for end products. Bleaching is accomplished by adding bleaching agents to pulp before it enters a mixer. After mixing, the fiber and bleach mixture is often allowed to soak or react in a holding tank or tower. Water flowing from the reaction is clarified and reused or released.

Chlorine-based bleaches, such as hypochlorite, are commonly used throughout the paper industry. A 1987 survey of paper mills by U.S. EPA Region V revealed that 12 of 14 deinking facilities surveyed used chlorine bleaching (Barney, 1987). Concerns about the use of chlorine-based bleaching agents has spurred the use of alternative bleaching agents. Hydrosulfite, peroxide, and oxygen-based bleaches are frequently used as alternatives when lower brightness levels are acceptable.

Dewatering Equipment/Thickeners. Some deinking facilities operate in conjunction with a papermaking mill, in which case pulp can be sent directly to the paper mill. Otherwise, pulp must be stored or transported before being used in paper production. To reduce the volume and weight of the pulp, it is processed through a dewaterer. There are numerous dewaterer designs. They use screens, screws, presses, and vacuum systems to draw water from the pulp.

Wastewater Clarification. Process wastewater is commonly treated and reused to conserve process chemicals. Wastewater from washing and flotation operations is discharged to the clarifier where ink and other contaminants are removed. The clarified liquid can then be reused throughout the recycling process to wash and dilute the pulp. Paper facilities generally pass unclarified water backward through the process. Cleaner water passes from the final washing stage to earlier and dirtier stages. The water is drained when it reaches the first washer and is then sent to the clarifier, where it is treated and reused. A large percentage of the liquid and solid plant wastes is generated at the clarifier.

Most clarifiers are designed as large open vats or enclosed tanks. Filtration is often the first clarification stage, to reduce the loss of fiber and remove large contaminants. During washing, dispersants break inks into tiny particles. Clarification reverses this process by adding flocculants to reagglomerate the ink into larger particles that can then be floated or settled and removed. Low-molecular-weight cationic liquid polymers and high-molecular-weight anionic polymers are used as flocculants depending on the wastewater makeup (Schriver, 1990). Dissolved air flotation is generally used to float the flocculated particles to the surface of the clarifier. The flotate is skimmed from the surface by a center-mounted scoop mechanism that slowly circles the tank. A sediment sump draws heavy material from the bottom of the tank. Skimmed material and sludge are usually thickened and incinerated or landfilled. Wastewater is reused within the plant or treated and released.

Effluent Treatment Systems. Water is an integral part of wastepaper processing and, as a result, large quantities of wastewater are generated. Pulp generally consists of between 2 and 15 percent fiber; the rest is primarily water. During washing, dewatering, and other processes, depending on the system configuration, large quantities of water are removed from the pulp. Plantwide wastewater streams are collected and often sent to an onsite treatment facility to stabilize pH, remove suspended solids, improve biochemical oxygen demand, and remove significant hazardous chemicals. Many paper processing facilities have had to install effluent treatment plants to meet effluent quality standards. Systems are similar to those in standard wastewater treatment plants. They commonly employ primary as well as secondary treatment using clarifiers and conventional biologic methods such as aerated stabilization basins and activated sludge.

Sludge Disposal. Sludge disposal is a significant issue for paper recycling facilities. Several wastepaper treatment processes (e.g., washing, flotation, and screening) as well as effluent treatment systems generate a waste sludge. A deinking plant processing 250 tons of pulp per day, operating at 75 percent fiber yield, can generate approximately 70 tons of sludge per day (Carroll and Gajda, 1990). Sludge received from a variety of sources throughout the facility is usually dewatered before disposal. The effluent from this process can be sent to the facility's effluent treatment system.

The primary sludge management options are landfilling, incineration, reuse, and landfarming. Landfilling is the disposal of dewatered sludges directly into a landfill designed to accept pulp and paper industry sludge. Incineration reduces sludge volumes, but the high inorganic content of deinking plant sludges (50 or 60 percent from inks) results in only a 20 to 30 percent volume reduction during incineration (Sixour, 1991). Reuse includes incorporating sludge in building products and other applications, but reuse of the sludge occurs infrequently. Landfarming, in which sludge is applied to forests and agricultural crops as a soil supplement, is also done on a limited basis. Drawbacks to this technique include the large tracts of land that are required, concern about heavy metals, and other technical problems.

Paper Milling. Paper milling is the process of forming paper from pulp. Pulp is filtered, dewatered, rolled, and pressed into a pulp mat. Paper milling may occur at the facility where deinking takes place, or it may be done at a completely separate plant. The two processes are not interdependent. Secondary fiber is commonly added to virgin feedstock and run on standard paper-milling equipment.

Some plants that run high percentages of secondary fiber have encountered problems with adhesives, or "stickies," and other contaminants that have not been adequately removed from the pulp during deinking. Stickies adhere to the filter screens and mill felts, which must be cleaned regularly. Caustic solvents are used to dissolve stickies when they begin to hamper production. The solution is sprayed from a batch tank using a spray boom. Solvent runoff is often diverted directly to the wastewater sewer. Air emissions are removed and vented by exhaust stacks that operate continuously to remove warm, moist air from the paper machines.

4.5.5. Plastic

4.5.5.1. *Composition of Plastic Recyclables*

As defined in Appendix B, there are six industry-defined categories of recyclable thermoplastic resins, commonly known as PET, HDPE, LDPE, PVC, PP, and PS. A seventh category, "Other," includes multiresin and multimaterial plastic products. Tables 4-9 and 4-10, respectively, present primary feedstock chemicals and additives used in producing thermoplastic resins. Table 4-11 defines the characteristics and uses of the principal additive categories. The plastic recyclable stream also includes packaging material (labels, adhesives, inks) and container residues.

4.5.5.2. *Process Technologies*

Resins are purchased by reprocessors as single (homogeneous) or mixed resins (heterogeneous). In general, recyclable plastics are separated into pure resin streams before being used as supplements to virgin feedstocks. The need for separation is primarily due to differences in melt characteristics. Commingled plastics recycling represents the significant exception to this rule. This technology allows a mixed stream of plastic wastes to be manufactured into dense products such as plastic lumber for outdoor applications. This section presents an overview of the general processing steps necessary to reclaim plastics. Subsequent sections detail resin-specific processes and describe commingled resin processing.

TABLE 4-9

Primary Feedstock Chemicals Used in Commonly Recycled Thermoplastic Resins

Resin	Feedstock chemicals
Polyethylene terephthalate (PET)	Dimethyl terephthalate Ethylene glycol Terephthalic acid Titanium oxide Triaryl phosphites Phenolic compounds
High-density polyethylene (HDPE)	Butane Ethylene Polypropylene
Low-density polyethylene (LDPE)	Butane I-Butane Ethylene Octane Propane Vinyl acetate
Polyvinyl chloride (PVC)	Acetylene Acrylic esters Acrylonitrile Butadiene Cetyl vinyl ether Chlorotrifluoroethylene Divinylbenzene Ethylene Methacrylic esters Propylene Vinyl chloride Vinylidene chloride
Polypropylene (PP)	Ethylene Propylene

TABLE 4-9 (continued)	
Resin	Feedstock chemicals
Polystyrene (PS)	Acrylonitrile
	Acrylamide
	Acrylic acid
	Alkyl esters
	Aromatic acids
	Benzene
	Methacrylic acid
	N-vinyl-z-pyrolidone
	Styrene
	Vinyl chloride

Source: Enviro Control, Inc., 1978; Radian Corporation, 1985; U.S. EPA, 1990.

TABLE 4-10

Categories of Additives Used in Plastics, Use Concentrations, and Major Polymer Applications (1987)

Additive		Additive concentration in plastic products[a] (lb additive/100 lb resin)	Largest polymer markets
Fillers		High, 10-50	PVC
Inorganics	Mica		
Minerals	Other minerals		
Calcium carbonate	Other inorganic		
Kaolin and other	Natural		
Talc			
Plasticizers		High, 20-60	PVC
Phthalates	Phosphates		
Dioctyl (DOP)	Polymerics		
Diisodecyl	Dialkyl adipates		
Diethyl	Trimellates		
Dimethyl	Others		
Others	Oleates		
Epoxidized oils	Palitates		
Soya oils	Stearates		
Others			
Reinforcing agents		High, 10-40	Various
Fiber glass	Cellulose		
Asbestos	Carbon		

TABLE 4-10 (continued)

Additive		Additive concentration in plastic products[a] (lb additive/100 lb resin)	Largest polymer markets
Flame Retardants		High, 10-20	Various
Additive Flame Retardants	Others		
Aluminum trihydrate	Reactive flame retardants		
Phosphorous compounds	Epoxy reactive		
Antimony oxide	Polyester		
Bromine compounds	Urethanes		
Chlorinated compounds	Polycarbonate		
Boron compounds	Others		
Colorants		Low, 1-2	Numerous
Inorganics	Organic reds		
Titanium dioxide	Organic yellows		
Iron oxides	Phthalo greens		
Cadmium	Others		
Chrome yellows (includes lead)	Dyes		
Molybdate orange	Nigrosines		
Others	Oil solubles		
Organic pigments	Anthroquinones		
Carbon black	Others		
Phthalo blues			

TABLE 4-10 (continued)			
Additive		Additive concentration in plastic products[a] (lb additive/100 lb resin)	Largest polymer markets
Impact modifiers		High, 10-20	PVC
Acrylics	CPE		
MBS	Ethylene-vinyl acetate copolymers		
ABS	Others		
Lubricants		Low, <1	PVC, PS
Metallic stearates	Fatty acid esters		
Fatty acid amides	Polyethylene waxes		
Petroleum waxes			
Heat stabilizers		Moderate, 1-5	PVC
Barium-cadmium	Calcium-zinc		
Tin	Antimony		
Lead			
Free radical initiators[b]		Low, <1	LDPE, PS, PVC, PE
Antioxidants		Low, <1	PS
Sterically hindered phenols	Others		
Chemical blowing agents		Moderate, 1-5	PVC, PP, PS
Azodicarbonides	High temperature CBSs		
Oxbissulfonylhydrazide	Inorganic		

TABLE 4-10 (continued)			
Additive		Additive concentration in plastic products[a] (lb additive/100 lb resin)	Largest polymer markets
Antimicrobial Agents		Low, <1	PVC, PE
Antistatic Agents		Low, <1	PVC
Quaternary ammonium compounds	Fatty acid ester derivatives		
Fatty acid amides and amines	Others		
Phosphate esters			
UV Stabilizers		Low, <1	PE, PP, PS, PVC
Benzotriazoles	Malonates		
Benzophenes	Benzilidenes		
Salicylate esters	Others		
Cyanoacrylates			
Catalysts[c]		Low, <1	Numerous
Others		Low, <1	

[a]Estimates refer to concentrations in those products where the additive is used.
[b]Includes organic peroxides only, as reported by source.
[c]Includes urethane catalysts only, as reported by source.

Source: U.S. EPA, 1990.

TABLE 4-11

Characteristics and Uses of Plastics Additives

Additive	Examples or types	Purpose	Typical applications for products with additive
Antimicrobials	Oxybisphenoxarsine, isothiazalone	Increase resistance of finished product to microorganisms	Roof membranes, pond liners, appliance gaskets, outdoor furniture, trash bags
Antioxidants	Phenolics, amines, phosphites, thioesters	Prevent deterioration of appearance and physical properties during processing and long-term use	Numerous
Antistatic agents	Amine salts, phosphoric acid esters, polyethers	Control static buildup during processing or in final product	Films, bottles, electronics and computer room furnishings, medical equipment
Blowing agents	Azobisformamide, chlorofluorocarbons, pentane	Add porosity to produce foamed plastics	Food trays, insulation, cushions, clothing, mattresses
Catalysts and curing agents	Numerous	Facilitate polymerization or curing of resin	Numerous
Colorants	Organic and inorganic pigments, dyes	Enhance appearance and consumer appeal of end product	Consumer products
Fillers	Minerals, e.g., calcium carbonate wood flours	Add hardness or other properties, lower production costs	Coatings, composites, flooring
Flame retardants	Aluminum trihydrate, halogenated hydrocarbons, organphosphates, antimony oxide	Reduced combustibility of plastic	Consumer, electrical, transportation and construction
Free radical initiators	Peroxides, azo compounds	Assist in polymerization or curing	Numerous
Heat stabilizers	Organotin mercaptides, lead compound and barium, cadmium and zinc soaps	Prevent heat degradation or improve heat resistance of polyvinyl chloride	Construction pipe, bottles, wire and cable coatings, film, sheet and upholstery
Impact modifiers	Methacrylate butadiene styrene, acrylic polymers, chlorinated PE, ethylene vinyl acetate	Improve strength and impact-resistance	Rigid PVC applications, building and construction (pipe and siding)
Lubricants and mold release agents	Fatty acids, alcohols and amides, esters, metallic stearates, silicones, soaps, waxes	Improve viscosity of plastic or reduce friction between plastic and surrounding surfaces, including molds	Molded and extruded consumer products

TABLE 4-11 (continued)

Additive	Examples or types	Purpose	Typical applications for products with additive
Plasticizers	Phthalates, trimelitates, aliphatic di- and tri-esters, polyester, phosphates	Soften and flexibilize rigid polymers	Garden hose and tubing, floormats, gaskets, coatings
Reinforcers	Glass fibers, wood flours	Improve physical properties of resin	Laminates
UV stabilizers	Sterically hindered amines, carbon black, hydroxybenzophenones, hydroxybenzotriazoles	Prevent or inhibit degradation by UV radiation	Building materials, agricultural films

Source: U.S. EPA, 1990.

Plastics reclamation systems vary widely depending on the type of raw materials processed, the degree of processing, and the specific technology used. Regardless of the materials accepted at a reclamation facility or the physical condition of the waste, plastics are generally processed using some combination of the following steps:

- Manual sorting
- Shredders and grinders
- Washers
- Separators
  - air classifiers
  - flotation tanks
  - hydrocyclones
- Dryers
- Aluminum separators
- Extruders

Because soda bottles are some of the most frequently recycled postconsumer plastic products, the discussion that follows generally describes their reclamation. Figure 4-7 presents an overview of a plastics recycling system with process inputs and outputs.

Because of their large volume, more and more plastics arrive at processing centers either shredded, in bales, or in some other compacted form. A hydraulic bale breaker or piece of heavy machinery can be used to break bales apart. Some facilities prefer to receive unaltered containers because of unique sorting and separation methods.

Manual Sorting. Because few reliable automated sorting technologies exist for separating plastics by resin and color, the first processing step performed at many plastics recycling facilities is hand sorting, except when plastics are received preshredded. Facilities accepting presorted or homogeneous plastics may use hand sorting to remove contaminants. Manual sorting systems are usually arranged as picking lines, a series of workers stationed along a moving conveyor or carousel that carries a steady stream of recyclables. Depending on the configuration of the sorting system, workers remove either desirable or undesirable materials and drop

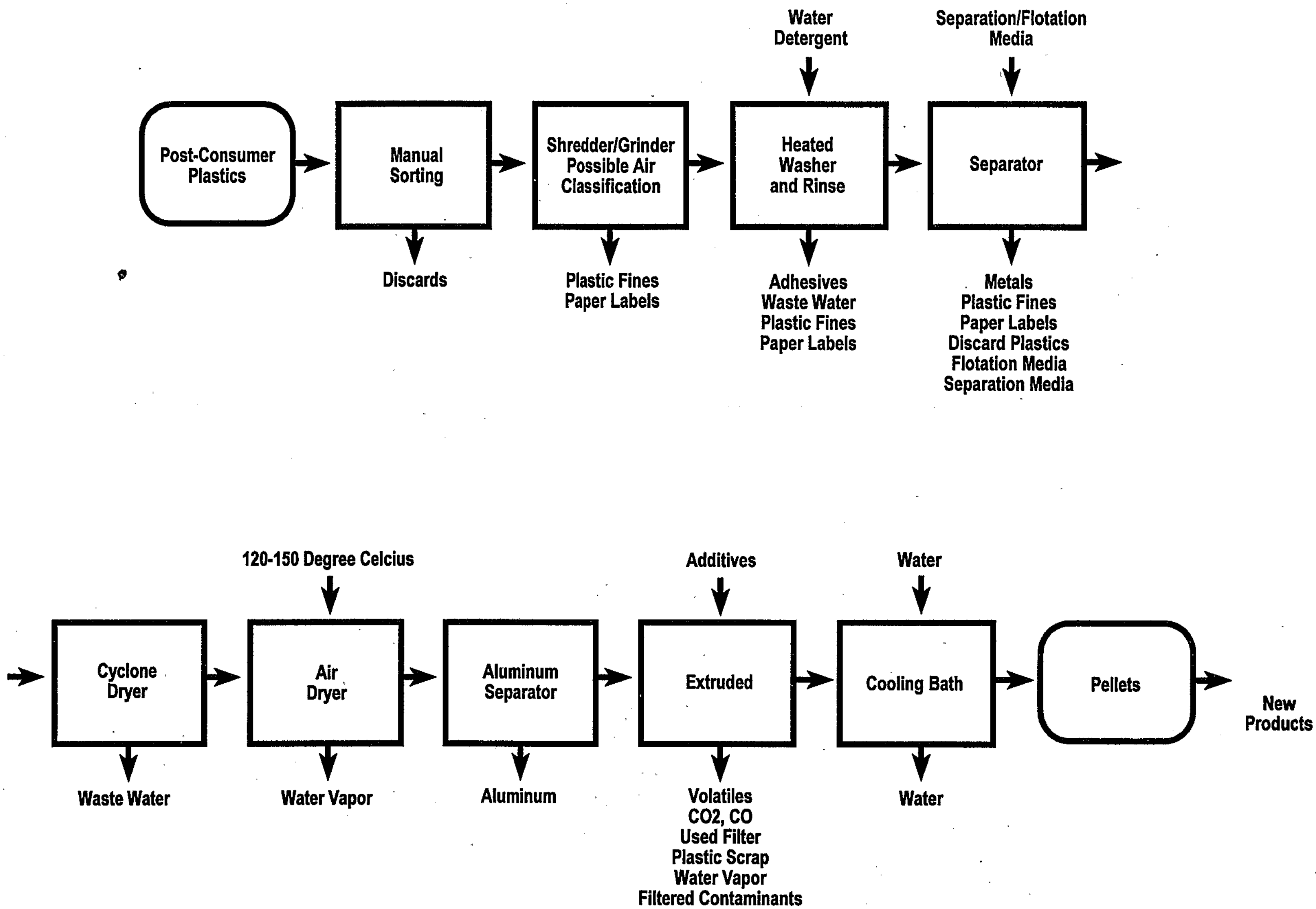


FIGURE 4-7

Overview of Plastics Recycling Process

them in bins or on other conveyors. Workers are required to handle large quantities of the waste stream at a constant rate. For example, at Plastics Recycling Alliance (PRA) plants in Chicago and Philadelphia, workers hand sort between 300 and 375 pounds of waste per hour on average (Schut, 1990).

Shredders and Grinders. Most plastics processors convert raw plastic waste into a stream of plastic flakes of uniform size (0.25 to 0.50 inch on a side) that can be accepted by cleaning and separation equipment. Plastics are generally "flaked" by using one of a variety of grinders, shredders, or granulators. Shredding allows caps, labels, HDPE base cups, security closure rings, and other impurities to be separated from the bulk of the container during washing and automated separation. A second grinding stage may be employed after initial shredding for some processes requiring smaller particles. When flakes are reduced to the target dimensions, they either fall through a screen or are blown from the shredder or grinder to transport ducts.

Some recently developed grinding systems process film scrap (e.g., plastic bags and sheeting) and other particularly dirty plastic waste streams with a wet grinding method (Modern Plastics, 1988). This technology uses a stream of water to wash film scrap as it is carried past cutting knives. The water both washes impurities from the plastic flakes and minimizes temperatures in the grinder chamber.

Washers. Washing usually occurs after the plastics are shredded to facilitate the removal of labels and other impurities. Certain systems under development do some washing before shredding (Modern Plastics, 1988). Washing methods vary depending on the type of plastic being cleaned, the degree of contamination, and the specific machinery being used. However, most systems consist of a water bath, a mechanical or air agitator, and possibly a solvent rinse. Wash water may be heated to temperatures as high as 160°C to dissolve label adhesives and other contaminants. A mild caustic detergent may also be added to remove labels and kill bacteria. Such detergents can be effective in concentrations as low as 1 percent. For example, a vinyl recycling operation in Akron, Ohio, uses a 1 percent solution of Electrosol automatic dishwasher detergent agitated in hot water (Summers et al., 1990). Mechanical paddles or air streams are used to accelerate cleaning. Washed plastics are frequently rinsed in one or more water rinse steps.

Separators. One of three separation methods is typically used to generate a clean, single-resin product: air classifiers, flotation tanks, or hydrocyclones. In facilities using flotation tank or hydrocyclone systems to separate mixed resins, plastic containers must first be reduced to a single-resin chip or flake that can be skimmed from the surface or scraped from the bottom of a tank.

Air Classifiers. Air classification systems separate wastes by using an air stream. This technology can be used to isolate a lightweight target material by removing it from the waste stream or to remove lightweight impurities from a heavier resin. Polystyrene or plastic film wastes are often separated from heavier contaminants with air classification.

Flotation Tanks. Flotation is an effective means of separation because of differences in resin densities. Flotation can also be used to separate contaminants from the target resin. Most flotation systems use water as the separation medium. A stream of mixed plastics is added to the flotation tank. Lighter fractions, polyethylene film for example, can be mechanically skimmed from the water surface, and heavier components scraped from the bottom. Solutions such as calcium nitrate are sometimes used to adjust the specific gravities of the flotation bath to separate the target material from the contaminant (Summers et al., 1990). A surfactant may also be added in low concentrations to prevent plastic flakes from adhering to the equipment or to each other. Figure 4-8 illustrates how a

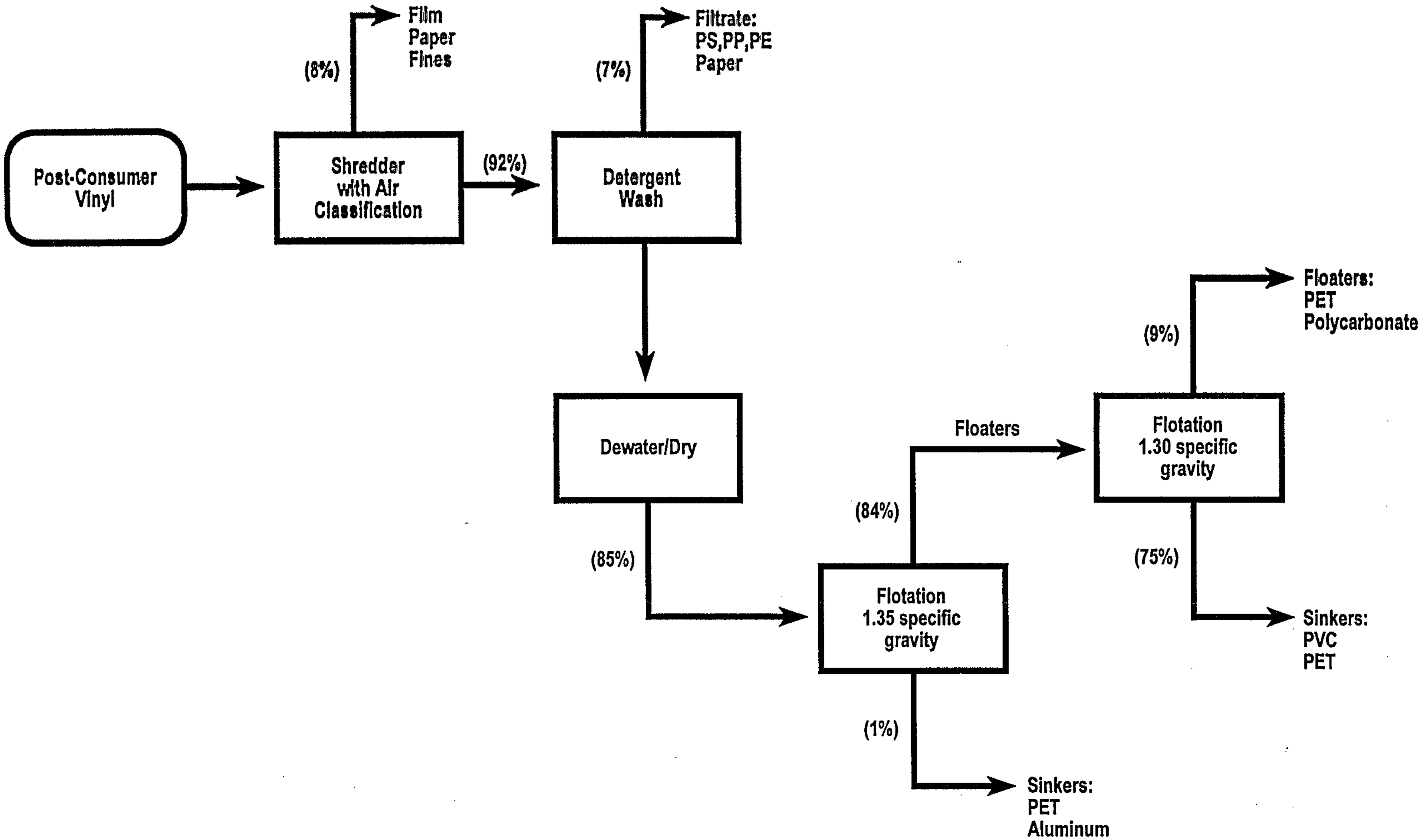


FIGURE 4-8

Post-Consumer Vinyl Purification Process and Percentage of Byproducts from Akron, OH Facility

Source: Summers, 1990

processing system incorporating flotation technology can be used to purify a PVC resin stream.

Because materials separation represents one of the greatest hurdles to recycling the large variety of resins being manufactured, separation technology is constantly under development. Research is under way at Rochester Polytechnic Institute on an advanced flotation system that uses a heated chemical bath to dissolve and separate mixed resins (personal communication between TRC Environmental Corporation and George Heath of Chem Systems, Inc., of Tarrytown, NY, on November 29, 1990). A batch of mixed resins is heated to the melting point of the most unstable resin. The molten resin is then removed from the bath. The bath temperature is raised to the next lowest melting point and that resin is removed. The process continues until all recoverable resins are isolated. This method requires a solvent filtration and recirculation system to process a waste stream consisting of solvents and various resin wastes.

Hydrocyclones. Hydrocyclone technology, adapted from the mining industry, has been recently applied to MSW handling. The equipment is essentially a centrifuge that separates plastic wastes and contaminants based on their specific gravities. Air, water, or oil is used to enhance the separation process. The separation medium can be filtered and reused. The fluid requirements are generally less than for flotation separation systems.

Dryers. Plastic flakes must be dried before they can be extruded into pellets or packaged for shipping. Cyclone driers are often used initially to dewater plastics. This may be followed by an air drying system that dries flakes as they pass under a stream of hot air on a conveyor. Air hopper dryers are also used. Heated air streams in the range of 120 to 160°C are common to most drying systems. Some systems also incorporate industrial dehumidifiers.

Aluminum Separators. Many PET reprocessing systems grind soda bottles together with their aluminum caps and safety rings. The aluminum fragments must be removed from the plastic flakes to a concentration of <100 ppm. Aluminum removal is commonly accomplished with an electrostatic separator.

Extruders. The form and composition of recycled resins required by end-product processors vary widely. Plastics scrap processors commonly supply cleaned or separated resins as flakes or pellets depending on the needs of the buyer. Although plastic flakes can be added directly to virgin feedstocks, extruded pellets are generally preferred for the following reasons: (1) pellet extrusion involves additional filtration that results in a higher quality end product; (2) necessary compounding agents can be added during extrusion; and (3) extruded pellets can be tailored to match the size, density, and composition of virgin feedstocks to which they are to be added.

Typical extruder designs include a screw-shaped mechanism that uses friction to heat and melt the feedstock of plastic flakes in a closed chamber. The plastic is softened and compounded with additives as it passes through the chamber. Brydson (1990) indicates that as the flakes or granules melt, they fuse together, trapping air and possible chemical degradation products. Such gases must be forced from the melt before it reaches a mold or pelletizer. Once pellets have been formed, they are commonly cooled in a recirculated water bath.

4.5.5.3. *Resin-Specific Processing*

Plastics reclamation alternatives vary by resin type. Recycling options for the seven industry-defined resin categories include some combination of the technologies discussed above. Resin-specific characteristics (i.e., melt temperatures, source products, process techniques) are summarized in Table 4-12.

TABLE 4-12

Resin-Specific Processing Issues

Resin type	Source products	Uses of recycled resin	Reclamation process	Process temperatures	Resin-specific issues
Polyethylene terephthalate (PET)	Beverage containers, film, tape	Molded products, clothing, insulation, carpeting	Standard steps shown in Figure 4-7.	Decomposes at temperatures approaching 300°C.	Most recycled resin in U.S. Degrades more when wet.
High-density polyethylene (HDPE)	Packaging, medical and construction products	Oil and detergent bottles, thick-walled products	Standard steps shown in Figure 4-7.	HDPE can be extruded between 170 and 220°C. Decomposes near 400°C.	Considered a nontoxic compound. Burns easily with a very smokey flame.
Low-density polyethylene (LPDE)	Bags and other film applications	Numerous packaging applications	Standard steps shown in Figure 4-7. Wet grinders have been used successfully to clean LDPE film waste.	LPDE can be extruded between 120 and 160°C. It oxidizes at 150°C and decomposes at roughly 400°C.	Because of its flexibility, it is a desirable reclamation feedstock. It is often used as a matrix resin in the manufacture of products from commingled feedstock.
Vinyl (V)	Cooking oil and water bottles, pipe, shrink wrap	Pipe, siding, other building materials	Standard steps shown in Figure 4-7. Sophisticated flotation, X-ray, and optical sorting systems are under development.	PVC decomposes at temperatures above 100°C.	PVC is the primary postconsumer vinyl being recycled and showing potential to produce significant volumes of recycled scrap. The similar specific densities of PVC and PET make separation difficult.
Propylene (PP)	Packaging, furnishings, battery cases, drinking straws	Matrix for commingled applications	Standard steps shown in Figure 4-7. Separation is a technical hurdle.	Decomposes at temperatures approaching 240°C	The thermal stability of PP in the absence of oxygen is high. Relatively high decomposition temperature makes PP desirable for commingled applications.
Polystyrene (PS)	Packaging, foam insulation, consumer products	Construction products	Standard steps shown in Figure 4-7. Air classification is often used to separate expanded foam PS products from other.	PS can be extruded at temperature approaching 150°C. It will ignite between 245 and 300°C.	PS comes in both rigid and expanded foam forms.
Other	A wide range of products	Commingled applications	Additional separation/ purification steps may be necessary.	Varies	The number of specialized resins is constantly growing. The various melt characteristics complicate reclamation.

4.5.5.4. *Commingled Plastics*

Commingled plastics recycling, although limited in its end-market application, offers a relatively simple and flexible reprocessing alternative to sorting and cleaning mixed plastics. Most programs that collect plastics for recycling concentrate their efforts on one or two resins, but the opportunity to collect large quantities of multiresin materials exists. Separating this growing variety of plastics presents a significant technical challenge.

A number of ventures have successfully applied extruder and compression mold technology to the reprocessing of unsorted, mixed plastics into dense products such as lumber, automobile curbstops, and playground equipment. Generally, higher solid contaminant levels and decreased tensile strengths restrict this process to the manufacture of thick-walled end products.

Several commingled plastics processing systems currently are used in the United States. Most facilities use extruder technology that incorporates the same basic features discussed in the previous section. These systems are capable of handling a wide range of unsorted and uncleaned or moderately cleaned scrap. Most systems also use one segregated resin, preferably polyethylene, as a base or matrix to which the unsorted scrap is added as filler. The resin mixture is shredded, mixed, and extruded into molds. Because multiple resins, each with distinct melt temperatures, may be used in commingled processing, process temperatures must be carefully monitored to prevent overheating and decomposition of any of the resins.

Additives are often used to improve the quality and expand the range of products manufactured from commingled plastic wastes. Recent research has explored the use of wood and glass fibers, calcium carbonate and mica crystals, and reinforced plastics to strengthen these products (Salas et al., 1990). In addition, colorants, impact modifiers, flame retardants, UV stabilizers, and compounding agents may be added to meet the desired end-product specifications. These additives are similar to those used in the manufacture of products from virgin feedstock (see Tables 4-9 and 4-10).

4.5.6. Steel/Tin

4.5.6.1. *Composition of Ferrous Metal Scrap*

This section focuses on steel food containers and beverage cans, which constitute the largest single source of ferrous metal scrap recovered from MSW when durables (e.g., white goods) are excluded. The grouping of steel containers in one category incorporates bimetal cans, tin-plated cans, and all-steel cans. Bimetal cans contain aluminum ends attached to a steel body that may or may not be tin-plated.

The tinplating used in steel can construction is composed of 99 percent steel and 1 percent tin (Carlin, 1989). Steel is an alloy of iron that contains <1 percent carbon and is produced by oxidizing carbon, silicon, phosphorous, manganese, and other impurities present in molten iron and steel scrap to specified minimum levels (U.S. EPA, 1982). Tinplate is produced either by passing steel sheets through a bath of molten tin or by electroplating in a continuous process (Grayson and Echroth, 1980). The tin coating on steel cans protects the container's contents by creating a layer between the steel and the contents, eliminating the possibility of reactions between the two.

Steel cans include labels, adhesives, associated inks and pigments, and container residues. In many recycling programs, either consumers or collection facilities are responsible for removing labels and cleaning containers. However, contaminants may still remain on recyclables received by reclamation facilities. Cans may also include surface coatings that contain both organic and inorganic chemicals.

The quantity of steel can scrap that can be used for iron and steel fabrication depends on the product to be manufactured; the facility's ability to handle the scrap; the density, chemical composition, and the tin content of the bales; and the amount of tin in the facility's other scrap (Copperthite, 1989). The most important parameter is the quantity of tin in the can scrap. If the steel cans have not been detinned, the scrap can contribute only 1 to 4 percent of the steel mill's scrap mix. If the can scrap has been detinned, the quantity of steel cans used may rise to 10 to 20 percent, depending on the tin content of the remainder of the mix and the product that is to be manufactured.

4.5.6.2. *Processing Technologies*

The industrial processes that steel cans follow during reclamation include iron and steel manufacturing and detinning. Iron and steel manufacturers and detinning facilities acquire steel cans from the collection and sorting facilities discussed earlier. The steel cans that arrive at these facilities may be baled, shredded, flattened, or unaltered. Because the steps involved in the recycling of steel cans are distinctly different for each of the two industries, this section discusses the processes separately.

Iron and Steel Manufacturing. The iron and steel manufacturing industry in the United States uses two furnace types, the basic oxygen furnace and the electric arc furnace, to produce iron and steel. The basic oxygen furnace, which is used to produce about 60 percent of the steel in the United States, uses an average of 30 percent scrap feedstock, whereas the electric arc furnace, which produces about 40 percent of the steel, uses virtually 100 percent scrap (Heenan, 1991). The methods used to introduce (charge) ferrous metal scrap to the furnace, where it mixes with virgin materials, vary slightly for each type of furnace and are discussed separately. Despite the differences in the furnace charging steps, the equipment used and raw material charged are comparable.

Basic Oxygen Furnace. A basic oxygen furnace is a large, open-mouthed vessel lined with a refractory material. The furnace is mounted on trunnions that allow it to be rotated 360 degrees in either direction. A typical vessel is 12 to 14 feet across and 20 to 30 feet high. The furnace receives a charge composed of scrap and molten iron. The feedstock is composed primarily of virgin materials (at least 70 percent molten iron) (U.S. EPA, 1982). Iron is produced in a blast furnace using iron ore and other materials. Steel scrap is added to the furnace by dumping it from a large "charge box" or container that is loaded in the scrap yard (U.S. EPA, 1980a). Steel is produced in the furnace by introducing a high-speed jet of pure oxygen, which oxidizes the carbon and the silicon in the molten iron (U.S. EPA, 1980b). Emissions including metallic oxides, particles of slag, carbon monoxide, and fluoride are typically released from this process.

Electric Arc Furnace. Electric arc furnaces consist of a cylindrical vessel made of heavy welded plates, a bowl-shaped hearth, and a dome-shaped roof. Three graphite or carbon electrodes are mounted on a superstructure located above the furnace and can be lowered and raised through holes in the furnace roof. The electrodes carry the energy for melting the scrap charge. Bladders located at the holes in the furnace roof cool the electrodes and also minimize the gap between the openings in the roof and the electrodes to reduce emissions, noise, heat losses, and electrode oxidation. When the electrodes are raised, the furnace roof can be swung aside so that charge materials may be deposited in the furnace. Ferrous scrap is added to the furnace from a large bucket, where it is typically placed following removal from railroad cars or other forms of transport. Any required alloying agents are added to the furnace through the side or slag door. Alloying agents used in the electric arc furnace include ferromanganese, ferrochrome, high carbon chrome, nickel, molybdenum oxide, aluminum, and manganese-silicon (U.S. EPA, 1982).

Detinning. The chemical detinning process, which removes tin from tinplate scrap and tin-coated food and beverage cans, is the only significant domestic source of tin metal in the United States (Grayson and Echroth, 1980). This section describes the following primary steps involved in detinning:

- Unloading of tin-plated scrap
- Shredders
- Air classifiers and magnetic separators
- Chemical detinning

- Separation
- Tin removal

The chemical detinning and separation steps take place at all detinning facilities, whereas the other steps are not always performed. Figure 4-9 illustrates the primary processing steps involved in detinning plated scrap. The more efficient, continuous process is used at most modern detinning facilities, although older facilities may use a batch process.

Unloading of Tin-Plated Scrap. Heavy equipment is used to unload tin cans from incoming vehicles and place them on a conveyor system that feeds the shredding mill. Equipment most commonly used to load and unload tin cans are cranes equipped with magnets and grapples. Once placed on the conveyor system, the tin cans are automatically fed into a shredder.

Shredders. Tin cans must be shredded for two reasons. First, shredding loosens and separates contaminants such as paper, glue, lacquer, plastic, organics (e.g., food residues, dirt), and aluminum ends from the bimetal food and beverage cans so they can be removed during magnetic separation and air classification. Second, shredding exposes a greater area of the tin cans to chemicals used to remove tin from the cans. The area exposed may be up to one square acre per ton of tin cans (personal communication between TRC Environmental Corporation and Jerry Bailey of Proler International Corporation on July 31, 1991). See Section 4.4.2 for further discussion of shredders.

Air Classifiers and Magnetic Separators. Once shredded, the cans are carried by a conveyor system to an air classifier, a magnetic separator, or both to remove contaminants. These contaminants, depending on their density, either fall or are blown into disposal containers, which are then transported to a landfill. Industry sources have reported that the combination of shredding, magnetic

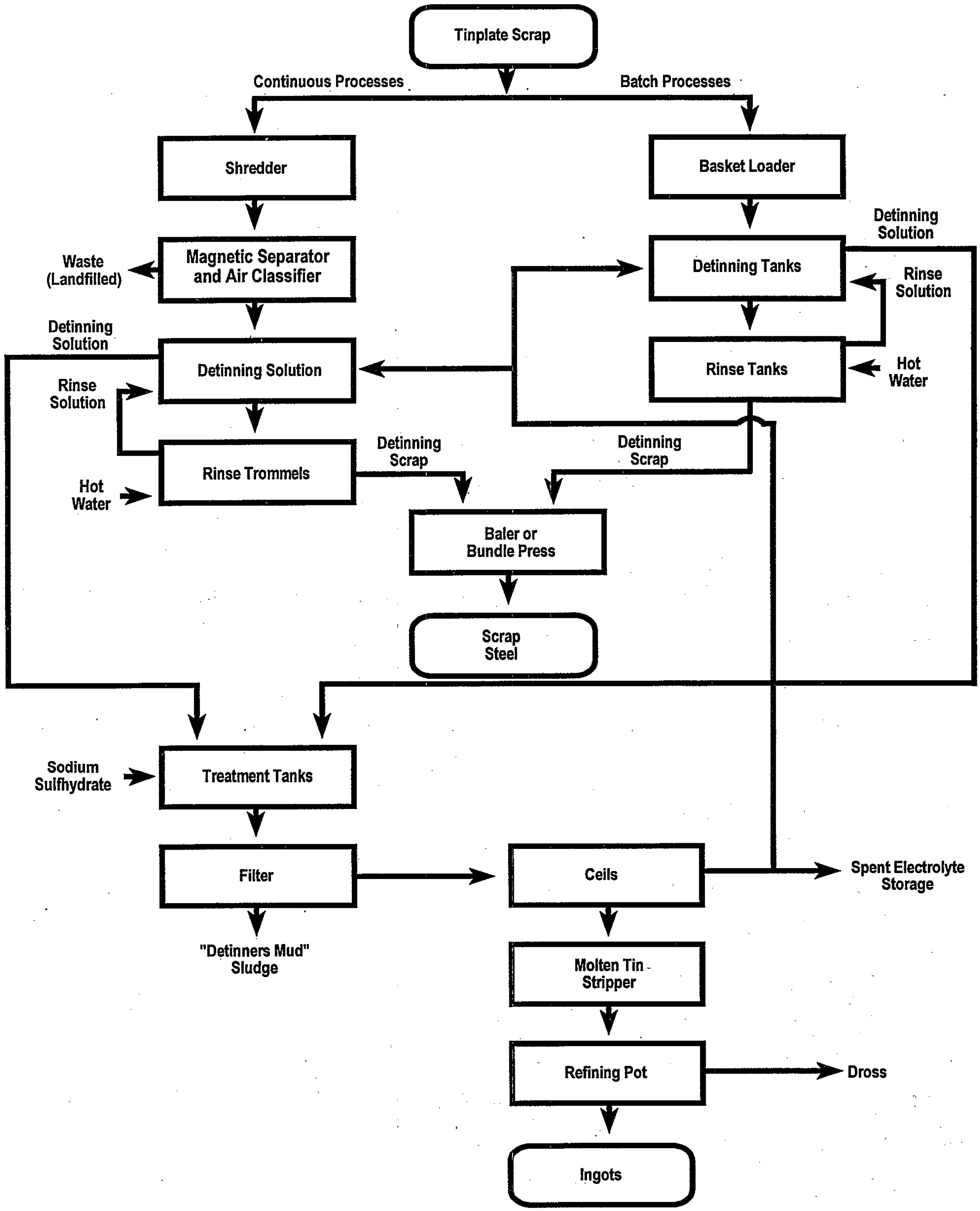


FIGURE 4-9

Detinning Process Utilizing Caustic Soda separation, and air classification removes 98 percent of nonmetallic contaminants and 99 percent of the aluminum (Process Engineering, 1989). See Section 4.4.2 for further discussion of air classifiers and magnetic separators.

Chemical Detinning. After tin cans have passed through the shredder, air classifier, and magnetic separator, they are considered clean and have enough surface area exposed to increase the efficiency of the chemical detinning step. Detinning is accomplished by treating cans with a hot alkaline solution, usually caustic soda, which contains an oxidizing agent to dissolve the tin and precipitate it as sodium stannate (Grayson and Echroth, 1980). This step also removes any contaminants remaining on the scrap such as paints and glues. The cans are placed in the detinning solution by steel baskets lowered into solution tanks (typical of batch processes) or a tube-like device that works like a screw conveyor (Watson, 1989).

Separation. Detinned cans are separated from the detinning solution by rinse trommels (cylindrical rotating screens). The cans are rinsed with hot water that is recycled into the detinning tanks. The residual tin remaining on the surface of the detinned scrap is usually <0.06 percent (Watson, 1989). The detinned scrap is baled and sold to iron and steel manufacturers for use in new products.

Tin Removal. Tin remaining in the detinning solution is removed through an electroplating process, which uses electricity to turn the sodium stannate back into tin metal (Watson, 1989). The tin is then melted off the plates and cast into ingots that are sold. In older detinning plants, process residues, the spent caustic soda, and "detinner's mud" are recovered and used by other industries, and any rinse water is treated and reused. In newer facilities, the spent caustic soda is also reused by the system. The detinner's mud or sludges are usually sold to tin smelters as low-grade ore (CBNS, 1988).

5. SAFETY CONCERNS ASSOCIATED WITH RECYCLING AND MITIGATION OPTIONS

5.1. INTRODUCTION

This section considers each of the public health, occupational safety, and environmental hazards that are associated with the recycling practices and processes summarized in Chapter 4. The hazard-specific discussions address the following:

- Sources of the hazard
- Nature of the hazard
- Prevention/mitigation options

Narratives for each hazard are supported by tables that provide a comprehensive list of the process steps or technologies that are potential sources of a particular hazard and summarize the prevention and mitigation options. In addition, the tables indicate the relative significance (low, medium, high) of the hazards, based on a qualitative assessment of the following criteria:

- The frequency or severity of the hazard
- The ability to control the hazard
- The ability to regulate the hazard
- The prevalence of the hazard in related industries

It should be stressed that the ranking is based on a database that is incomplete. Much information available to characterize recycling hazards is anecdotal in nature. Measures of hazard magnitude are generally unavailable.

Many prevention and mitigation options discussed in this section reflect the requirements of Federal, state, and local regulations. Such regulations may affect facility, process, and equipment design as well as day-to-day work practices and procedures. Properly implemented, they may reduce direct hazards to workers and facility-related hazards to public health and the environment, which range from traffic accidents to facility emissions.

Compliance with certain regulations and implementation of safe work practices may be reflected in facility operating plans used at MRFs and other processing facilities. Although operating plans vary from facility to facility, they may incorporate the following:

- Functions of employees
- Operation of equipment
- Fire contingency
- Contaminant isolation and removal
- Staffing contingencies
- Medical emergencies
- Personal protective equipment
- Summaries of applicable regulations

5.2. REGULATIONS APPLICABLE TO RECYCLING OPERATIONS

Occupational health and safety and environmental protection are two broad regulatory categories that apply to the recycling industry to prevent and mitigate the hazards addressed in this section. Because of the industry's relative infancy, there are few laws that specifically target recycling. However, there are significant Federal, state, and local laws that apply to operations commonly used in recycling. Some of the more important regulations that serve to control or prevent recycling hazards are outlined below.

5.2.1. Occupational Regulations

The safety of workers employed in the recycling industry falls under the auspices of the U.S. Occupational Health and Safety Administration (OSHA), established in 1970. As defined in 29 CFR 1910, OSHA health and safety standards apply to workers employed by private sector businesses. OSHA regulations do not cover the occupational safety of public employees, who are employed by Federal, state, county, municipal, and other government bodies

(Council on Environmental Quality, 1987-1988). Many municipalities operate their own recycling programs rather than contracting the work to the private sector; therefore, the population of workers not covered by Federal regulations is potentially large. One survey indicates that municipal employees collect recyclables in 33 of the 50 largest U.S. cities that have recycling programs (Smith and Hopkins, 1992). Some states have established their own occupational health and safety regulations. State legislation may extend health and safety coverage under these programs to include government workers. Volunteer workers, however, also a potentially large population, may be beyond the jurisdiction of both Federal and state occupational health and safety regulations.

OSHA regulations are grouped into specific categories by equipment type, operation type, or hazardous material (Table 5-1), along with a small number of industry-specific rules (e.g., pulp, paper, and paperboard mills). Much of the machinery used in recycling is common equipment that has been adapted from other industries and is covered under general OSHA regulations. There is no OSHA rule that specifically targets the recycling industry or its workers. Some recycling program managers have expressed concern over the fact that there are no recycling-specific rules, whereas others feel current general regulations are broad enough to cover most hazardous activities that would be encountered in the recycling industry (Combs, 1992).

Additional regulations and guidelines that may have a bearing on worker health and safety have been issued by the following organizations and associations:

- American National Standards Institute (ANSI)
- American Society of Mechanical Engineers (ASME)
- American Society of Testing Methods (ASTM)
- National Solid Waste Management Association (NSWMA)
- National Fire Protection Association (NFPA)
- National Institute of Occupational Safety and Health (NIOSH)

TABLE 5-1

OSHA Health and Safety Standards Applicable to the Recycling Industry

OSHA standard	Coverage
Part 1904	Record Keeping
Part 1910	Safety and Health Standards
Subpart C	Access to Employee Medical Records
Subpart D	Walking and Working Surfaces * Floor and wall openings * Stairs and ladders * Scaffolds (proposed changes include falls)
Subpart E	Means of Egress
Subpart F	Manlifts and Platforms
Subpart G	Environmental Control * Ventilation * Noise
Subpart H	Hazardous Materials * Acetylene * Flammable liquids * Others
Subpart I	Personal Protective Equipment * Eye and face protection * Respiratory protection * Head protection * Foot protection * Electrical protective devices
Subpart J	General Environment * Signs and tags * Hazard identifications
Subpart K	Medical and First Aid

TABLE 5-1 (continued)	
OSHA standard	Coverage
Subpart L	Fire Protection * Fire suppression equipment * Fire protection systems
Subpart M	Compressed Air Systems
Subpart N	Materials Handling and Storage * General rules * Servicing vehicles * Trucks * Cranes
Subpart O	Machines and Guarding * General rules * Power presses * Mechanical transmission apparatus
Subpart P	Portable Power Equipment
Subpart Q	Welding, Cutting, and Brazing
Subpart R	Special Industries * Pulp, paper, and paperboard
Subpart S	Electrical * Systems * Work protectors * Maintenance
Subpart Z	Hazardous Substances * Airborne contaminants * Asbestos * Bloodborne pathogens * Hazard communication standard

Source: Combs, 1992; 29 CFR 1910.

5.2.2. Environmental Regulations

Most environmental regulations that apply to recycling facilities are based on Federal regulations that are administered by state or local agencies or offices. Local laws and ordinances regarding issuance of permits to facilities may also apply.

5.3. SHARP OBJECTS

Source Activity: Opportunities to contact sharp objects are greatest at points where recyclables are manually separated from MSW, sorted by material, or otherwise handled (e.g., cleaned, crushed, transported, or stored) are shown in Table 5-2. The extent of handling required of the consumer and the waste worker varies depending on program-specific collection and sorting methods. Programs that require consumers to separate, clean, and sort recyclables may present a higher potential for public contact with sharp objects than those that collect commingled recyclables and sort them at an MRF.

The degree and type of mechanization employed in collecting and sorting also affect the potential for workers to contact sharp objects. Glass sorting, a process that has proven difficult to automate, routinely exposes workers performing manual sorting to sharp objects. Some forms of mechanization may increase the occurrence of sharp objects such as broken glass and shredded metal. During collection, for example, compactor trucks and elevated loading systems that dump recyclables into bins from above can cause higher percentages of broken glass (Glenn, 1990; O'Brien, 1991). Shredding and slicing equipment used in aluminum, rigid plastics, and steel processing produces a sharp-edged flake or chip.

Hazard Type: Sharp objects found among recyclables fall into two primary categories: process fragments and contaminants. Rigid recyclables (i.e., glass, plastic, steel) broken or shredded during collection, sorting, or processing frequently result in sharp-edged fragments. Hypodermic needles and razor blades are among the sharp contaminants found mixed with recyclables. Injuries that can result from contact with sharp objects include cuts, lacerations, punctures, and

TABLE 5-2

Sharp Objects Hazards

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Separation in the home Drop-off centers Buy-back centers	Public education Personal protective equipment	Low
Occupational	Curbside sorting Dumping Tipping floor Bag breakers Conveyor systems Sorting stations Slicers Front-end separation at transfer stations, landfills, waste-to-energy plants	Public education Worker training System and equipment design Personal protective equipment	Medium
Material processing			
Occupational	AL - Drying and delacquering GL - Manual sorting PA - Manual sorting S/T - Unloading scrap S/T - Air classification S/T - Magnetic separation	Public education Worker training System and equipment design Personal protective equipment	Low

AL - Aluminum processing
GL - Glass processing
PA - Paper processing
S/T - Steel and tin processing

abrasions. These injuries are primarily an occupational hazard, especially to workers handling recyclables during collection or sorting operations, but may also be a public health hazard.

Any break in the skin caused by sharp objects can become the site of infection following exposure to bacteria, viruses, fungi, or parasites (Clayton and Clayton, 1991). Risk of infection, although uncharacterized, may be significant in cases where container residues exist. In addition, the Center for Plastics Recycling Research reports that workers regularly find hypodermic needles inside HDPE milk jugs (personal communication between TRC Environmental Corporation and Wayne Pearson, executive director of Plastics Recycling Foundation, on February 11, 1992). Although potential for puncture wounds is the greatest hazard associated with needle exposure, exposure to infectious agents cannot be precluded.

Prevention and Mitigation Options: Contact with sharp objects can be minimized through the use of personal protective equipment such as gloves, hard hats, boots, safety glasses, and overclothes. This equipment must be available to workers and its use required. Automated sorting systems as well as practicable design controls effectively reduce sharp object hazards, because there is less human contact with broken materials. Education is the most effective method to warn consumers about potential sharp object hazards associated with recycling, because it is not realistic to expect all consumers to use protective equipment in the home. In addition, educating the public to avoid mixing sharp contaminants with recyclables can reduce potential worker exposures during collecting and sorting operations. Process and facility modifications can limit the generation of sharp recyclables and the degree to which they must be handled. For instance, recent trials with collection vehicles fitted with internal nets and baffles designed to catch falling glass during loading have been found to reduce breakage. Within the MRF, wooden floors, drop chutes at conveyor ends, and rubber bumper guards on steel sorting tables have reduced glass breakage (Keller, 1992).

5.4. ERGONOMIC AND LIFTING INJURIES

Source Activity: Table 5-3 summarizes collection and sorting activities that often require repeated lifting and twisting motions, a common source of ergonomic injuries. The public may sustain injuries while carrying heavy bins of recyclables to the curb for collection. Worker injuries that occur during collection result from lifting and dumping heavy bins, twisting and reaching during curbside sorting, and repeatedly climbing in and out of vehicles. Manual sorting activities that occur at an MRF commonly require reaching, lifting, and twisting motions. A 1988 study of working conditions in Danish MRFs reported that inappropriate and monotonous working conditions at conveyor belts resulted in ergonomic strain (Malmros and Petersen, 1988). Falls and other miscellaneous ergonomic injuries may occur throughout MRFs, drop-off centers, or other material processing facilities. Elevated platforms, floor-mounted conveyor belts, and sunken bins or dumpsters increase the opportunity for falls.

Hazard Type: The potential for ergonomic injuries is a significant occupational concern for numerous recycling activities. Poorly designed work stations and improper manual materials handling and lifting practices can result in various injuries or disorders. These problems are not generally associated with a single accident, but with repeated, low-level insults to a localized body region. The back and upper extremities are the most commonly affected areas (Levy and Wegman, 1988). For example, manual lifting and loading of waste materials into trucks or containers can result in lower back injury and pain. Driving-related injuries include back injuries as well as vibrational fatigue. Frequent or repetitive forceful hand motions with awkward posture can affect the musculoskeletal system or the peripheral nervous system at the fingers, hand, wrist, elbow, forearm, and shoulder resulting in inflammation of tendons and joints and nerve compression. The following are examples of repetitive motion disorders (Clayton and Clayton, 1991; Levy and Wegman, 1988):

TABLE 5-3

Ergonomic and Lifting Injuries

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Separation in the home Drop-off centers Buy-back centers	Public education Equipment design	Low
Occupational	Curbside sorting Loading and dumping of collection vehicles Transportation during curbside collection Tipping floor Conveyor systems Sorting stations Balers Drop-off centers Buy-back centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Worker training System and equipment design Rotating worker activities Personal protective equipment	Medium
Material processing			
Occupational	GL - Manual sorting PA - Manual sorting PL - Manual sorting S/T - Unloading scrap Lifting Equipment operation	Worker training System and equipment design Rotating worker activities Personal protective equipment	Low

GL - Glass processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

- Carpal tunnel syndrome (nerve disorder of the wrist)
- Degenerative joint disease
- DeQuervain's disease (inflammation of the tendons of the thumb)
- Trigger finger
- Epicondylitis ("tennis elbow")
- Rotator cuff tendinitis (shoulder)
- Tension neck syndrome
- Pain in the upper extremity and neck

Prevention and Mitigation Options: Poorly designed collection vehicles and other equipment that require workers to make repeated awkward motions during collection and sorting increase the possibility of ergonomic injuries. In many cases, these hazards can be successfully eliminated through design improvements. Truck-mounted automated lift systems, for instance, are now available to hoist and dump containers of recyclables into collection vehicles. The distance workers must reach to sort recyclables at the curbside is minimized on newer collection truck bodies designed with "low-profile" sorting bins. The lower bin position on these models reduces lifting heights, making sorting safer and more efficient. Taller driver compartments with lowered floors and full-length doors allow workers to step from the vehicle to the curb more easily.

Within the MRF, the potential for ergonomic injuries during material sorting can be minimized substantially through the redesign of equipment and methods. Stations where workers manually sort recyclables can be engineered to lessen the range of motion required of the workers. Head-on sorting stations are believed to minimize the physical strain during sorting, which often results from reaching and twisting across a conveyor belt. The head-on method balances the workers' range of motion to both sides, minimizes motion extremes, and eliminates the need to stretch across the belt. Adjusting the height of conveyor belts or working surfaces to meet worker dimensions also has been shown to reduce strain at sorting stations and other operations (Solomon-Hess, 1991). To limit ergonomic stress during sorting, some recycling firms rotate workers to other activities on a regular basis (Powell, 1992). Cushioned floors in working areas and elevated foot rests effectively reduce the strain on workers' legs. The potential for falls can be minimized by using guardrails, warning tape, and signs.

As new materials are recycled and members of the public become more efficient recyclers, larger bins will be required to separate and store recyclables in the home. Some consumer recycling bins already are designed with wheels to facilitate moving recyclables from the home to the curb.

5.5. FIRES AND EXPLOSIONS

Source Activity: The sorting and storage of combustible paper products and the presence of flammable chemical residues pose the primary fire and explosion hazards associated with recycling (Table 5-4). Large volumes of paper stored in the home or MRF are a fire hazard whether wet or dry. Dry paper easily can be ignited in areas where it is stored or processed. Explosions may occur in shredder chambers, slicers, crushers, and balers when residues of flammable or explosive substances (e.g., gasoline, propane, cleaning solvents, mineral spirits, batteries) are ignited (Kohn, 1989; Nollet, 1989a, b; Engineering News Record, 1990). Explosions are more likely when an unsorted mixture of MSW is shredded. Many of the heating methods and chemicals used in reprocessing recyclables also can cause fires or explosions. When aluminum is melted, for example, moisture trapped in the melt has been known to explode.

Hazard Type: Hazards associated with fire or explosions are primarily occupational and environmental. Burns are the greatest hazard posed by a fire or an explosion and can vary in severity from minor superficial burns to deep tissue damage. Explosions can result in damaging noise exposure (Section 5.8). Environmental impacts include fire-related air emissions.

Prevention and Mitigation Options: Frequent collection and processing reduces combustible paper stockpiles in the home and MRF. Because loose paper is more flammable than baled, baling can minimize the potential for fires. Storing baled paper in a dry, well-ventilated location reduces the chance of spontaneous combustion. Shredder explosions can be avoided by visually inspecting and using

TABLE 5-4

Fire and Explosions

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Storage in the home Drop-off centers	Proper storage Public education Frequency of collection (paper)	Low
Occupational/ Environmental	Curbside handling Sorting stations Shredders Drop-off centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Public education Frequency of collection and processing (paper) System design (e.g., ventilation, equipment isolation) Emergency response equipment/ procedures Flammables removals during sorting	Medium/low
Material processing			
Occupational/ Environmental	AL - Smelting PA - Material storage PL - Shredding and grinding S/T - Shredding	Public education Frequency of collection and processing (paper) System design (e.g., ventilation, equipment isolation) Emergency response equipment and procedures Flammables removals during sorting	Low

AL - Aluminum processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

magnetic detectors and separators to identify potentially dangerous metal containers (e.g., propane tanks, aerosol cans) within the recyclable stream so that they can be removed before shredding. Auxiliary ventilation systems that exhaust flammable vapors and circulate fresh air through the shredder chamber also can reduce explosion hazards. Locating shredders in dedicated, sealed rooms designed to contain an explosion is an additional precaution that isolates the equipment and protects workers throughout the facility. Adequate fire detectors, sprinkler systems, and firefighting equipment should be installed in all recycling facilities.

5.6. FLYING AND FALLING DEBRIS

Source Activity: Debris can fly or fall during most stages of processing (Table 5-5). Flying materials can result at drop-off centers where the public is often required to sort recyclables by throwing or dropping them into uncovered bins or dumpsters. Recyclables may fall on workers during operations when the recyclables are being loaded into collection vehicles, sorted in overhead booths, or conveyed through an MRF by belts or cranes. Collection vehicles fitted with automated hoist loaders, for instance, lift bins high over the side of the truck where recyclables are dumped and possibly fall onto workers below. In many MRFs, it is customary for workers performing manual sorting to drop or throw sorted recyclables down chutes into collection bins located below. Fast-moving equipment commonly used in MRFs and other processing centers (i.e., bag breakers, metal and plastic shredders, glass crushers and grinders) can throw recyclables from the equipment at high velocities. For example, it is reported that glass is frequently projected from the top of crushing or grinding equipment (personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991). Heavy bales of recyclables also represent potential falling object hazards when they are transported or stacked precariously.

Hazard Type: Flying and falling objects may lead to a variety of occupational injuries to unprotected workers. Items accidentally dropped from

TABLE 5-5

Flying and Falling Debris

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Drop-off centers	Public education Equipment design	Low
Occupational	Loading and dumping collection vehicles Tipping floor Sorting stations Air classifications Magnetic separators Glass crushers Slicers Shredders Drop-off centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Worker training System and equipment design (e.g., equipment isolation, shielding) Personal protective equipment	Medium
Materials processing			
Occupational	AL-Shredding GL-Crusher and grinder PA-Manual sorting PA-Magnetic separators PL-Shredding and grinding	Worker training System and equipment design (e.g., equipment isolation, shielding) Personal protective equipment	Medium

TABLE 5-5 (continued)			
Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Occupational (continued)	S/T - Iron and steel manufacture S/T - Separation		

AL - Aluminum processing
GL - Glass processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

overhead may cause head, neck, and shoulder injuries, such as fractures, concussions, and lacerations (Levy and Wegman, 1988). Objects also can be dropped during material handling (lifting or carrying) and cause injuries to feet and toes, such as crushing injuries, fractures, and contusions. Flying objects can cause cuts and lacerations or strike unprotected eyes and result in eye injuries, including blindness. To a lesser extent, the general public is susceptible to similar hazards as recyclables are handled at drop-off centers.

Prevention and Mitigation Options: Personal protective equipment such as hardhats and safety glasses helps prevent injuries from both flying and falling debris. In addition, establishing and maintaining safety zones beneath elevated equipment and in dumping areas are an effective means of limiting worker exposure to falling objects. Objects hurled from processing equipment can be contained by proper guards and housing on shredders and other equipment. Most new equipment is sold as completely enclosed units; however, custom-made or adapted equipment may lack adequate housings. In some cases, additional plastic sheeting or other guards added to the mouth of a shredder will help to contain flying objects. Employees should be trained to use equipment only when all guards are in place. Physically isolating equipment that can produce flying or falling objects in a separate room whenever possible will further reduce hazards to workers.

5.7. TEMPERATURE AND PRESSURE EXTREMES

Source Activity: Recycling operations potentially expose workers to temperature extremes during outdoor collection activities and indoor processing at facilities with inadequate climate controls (Table 5-6). Indoor temperature extremes are a particular concern because operations frequently occupy large buildings, have numerous delivery doors and openings, and are therefore difficult to heat and cool adequately. Because of prohibitively high costs, it is not uncommon for small municipalities to operate facilities without a climate control system in place. A variety of recyclable reprocessing techniques may expose workers to temperature and pressure extremes. The primary concerns are heated liquids

TABLE 5-6

Temperature and Pressure Extremes

Type of hazard	Source of activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Occupational	Tipping floor Drop-off centers Collecting and sorting on route	Worker training Facility design (e.g., climate control systems) Personal protective equipment	Low
Material processing			
Occupational	AL - Dying and delacquering Al - Smelting AL - Casting and cooling PA - Pulper PL - Washing PL - Separation PL - Extrusion S/T - Chemical detinning	Worker training System and equipment design (e.g., shielding, equipment isolation) Process modifications Personal protective equipment	Low

AL - Aluminum processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

generated during container washing, plastic separation, or pulping operations and hot machine parts such as extruder blades or aluminum and steel furnaces. Plastic extruders and some paper pulping equipment also operate at high pressures.

Hazard Type: Exposure to high or low ambient temperatures and contact with hot materials are primarily occupational hazards. Processes that involve heating of materials or wash water (temperatures can be at least 160°F) can result in burns. Many facilities have inadequate or no climate control, thus potentially exposing workers to extreme temperatures. Prolonged exposure to high ambient temperatures (e.g., in or around furnace or kiln areas or collection activities during warm times of the year) may result in heat-related illnesses. Susceptibility to heat stress also is dependent on physical fitness, the level of exertion required, and clothing. Heat-related illnesses include heat exhaustion, heat cramps, and heat stroke (Zenz, 1988).

Heat Exhaustion: Heat exhaustion occurs from increased stress on various body organs. Signs and symptoms include general weakness and dizziness, excessive perspiration, cool moist skin, and a weak pulse.

Heat Cramps: Heat cramps are caused by heavy sweating with inadequate water and electrolyte replacement. Heat cramps are characterized by pain in the hands, feet, and abdomen as well as muscle spasms.

Heat Stroke: Heat stroke, which is the most serious form of heat stress, occurs when the body's temperature regulation mechanism fails and the body's temperature rises to critical levels. Symptoms include hot dry skin, severe headache, nausea, dizziness, and a strong rapid pulse. Left untreated, heat stroke can lead to coma and death.

Exposure to severe or prolonged cold temperatures (in unheated process areas) also can result in various adverse health effects. Cold weather injuries include the following:

Frostnip and Frostbite: Frostnip is characterized by sudden blanching or whitening of the skin. Superficial frostbite results in firm, waxy, or white skin with the tissue beneath remaining resilient. Deep frostbite results in cold, pale, and frozen tissue.

Hypothermia: Hypothermia is a fall in the deep core temperature of the body. Symptoms generally appear in five stages: severe shivering; apathy, drowsiness, and rapid cooling of the body to less than 95°F; unconsciousness, glass stare, slow pulse, and slow respiratory rate; freezing of the extremities; and death, if left untreated.

Prevention and Mitigation Options: Exposures to indoor temperature extremes can be controlled through the installation of adequate climate control systems. A popular solution to the challenge of heating or cooling a large, open-air building is to isolate workers within small enclosed booths. Sorting workers, for instance, can be housed within a climate-controlled booth within the larger facility. Collection workers can be encouraged to wear appropriate clothing and provided with training on the symptoms and prevention of thermal stress. Training, in addition to guards, shields, and personal protective equipment, also can prevent exposure to temperature and pressure extremes associated with processing equipment. Process modifications that minimize the use of temperature extremes also can be implemented. One plant in Alabama has developed an aluminum melting process that drastically reduces its use of high temperatures, minimizing the potential for worker exposures (personal communication between TRC Environmental Corporation and Mitch Chow of Alabama Reclamation of Sheffield, AL, on August 7, 1991).

5.8. MOVING EQUIPMENT AND HEAVY MACHINERY

Source Activity: Stationary as well as mobile equipment present hazards to workers in recycling facilities (Table 5-7). Examples of stationary equipment include balers, conveyors, crushers, shredders, slicers, overhead cranes, and an assortment of reprocessing equipment such as plastic extruders, paper pulpers, and steel furnaces. Moving mechanical parts on this equipment, even under normal operating conditions, present potential hazards. To meet the unique processing

TABLE 5-7

Moving Equipment and Heavy Machinery

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Drop-off centers On-route collection	Personal protective equipment Worker training Public education Facility design	Low
Occupational	Loading and dumping collection vehicles Operation of heavy equipment Tipping floor Bag breakers Conveyor systems Sorting stations Slicers Shredders Balers Drop-off centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Worker training System and equipment design (e.g., shielding, emergency shut-off, safety zones, emission controls, ventilation)	Low
Material processing			
Occupational	AL - Balers and compactors AL - Bale breaking AL - Shredding AL - Dying and delacquering AL - Casting and cooling	Personal protective equipment Worker training System and equipment design (e.g., shielding, emergency shut-off, safety zones, emission controls, ventilation)	

TABLE 5-7 (continued)			
Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Material processing			
Occupational (continued)	GL - Manual sorting GL - Magnetic separation GL - Velocity trap and air classifier GL - Screening PL - Material storage PL - Conveyor systems PL - Screening and cleaning PL - Separators PL - Manual sorting PL - Shredders and grinders PL - Washing PL - Separation PL - Drying PL - Aluminum separation PL - Extrusion S/T - Iron and steel manufacture S/T - Unloading scrap S/T - Shredding S/T - Air classification S/T - Magnetic separation		Low

AL - Aluminum processing
GL - Glass processing
PL - Plastic processing
S/T - Steel and tin processing

and handling demands of recyclables, recycling operations often adapt equipment from farming or other uses. Safety attachments may be removed or hazardous equipment configurations created in customizing equipment of processing systems.

Mobile equipment includes vehicles used during collection and transport and within an MRF or other facility. Dedicated recyclable collection vehicles now include a variety of hoists and loading mechanisms that increase hazards such as pinch points and the opportunity for a vehicle to contact overhead trees and electrical wires. Standard waste collection vehicles pose similar physical hazards. Within recycling facilities, the close interaction of workers and equipment (e.g., forklifts, loaders), particularly on the tipping room floor, poses a considerable accident hazard. The public also can be put at risk at drop-off centers if access to areas where machinery is used is not strictly controlled.

Workers may endanger themselves if they do not take proper precautions when they perform equipment maintenance. Balers, conveyor belts, shredders, moving parts on collection vehicles, and other types of equipment can become jammed with recyclables (e.g., plastic or metal containers, broken glass, paper). Dislodging jams and other on-the-spot repairs may endanger worker safety because of accidental start-ups if proper electrical lock-out procedures are not followed.

Hazard Type: Moving equipment and heavy machinery pose primarily occupational safety hazards, although accidents can occur when consumers handle recyclables at drop-off centers. Injury can be caused by the crushing, squeezing, or pinching of a body part between a moving object and a stationary object or between two moving objects (Levy and Wegman, 1988). Examples of such injuries include catching fingers and other body parts in conveyor belts (Martin, 1991), workers falling onto conveyors and being killed in a shredding machine (UPI, 1989), and workers contacting moving parts by climbing into trucks or bailer chamber bins to dislodge jammed material (Keller, 1989).

Another hazard related to recycling equipment includes accidents (tipovers) and emissions associated with forklift and loader operations (carbon monoxide [CO] and particulates). A study conducted at the Langard Demonstration Project (a resource recovery facility in Baltimore, Maryland) measured carbon monoxide levels of 100 ppm to 900 ppm on the facility's tipping floor when more than two trucks were present (STC, 1979). The OSHA permissible exposure limit for CO is 35 ppm. Early signs of CO poisoning include headache, weakness, lassitude, and mental confusion. If exposure is prolonged, CO prevents the normal uptake and distribution of oxygen in the body and may ultimately have lethal effects (Section 5.12 "Gaseous Releases").

Prevention and Mitigation Options: Injuries associated with material processing and handling equipment can be avoided through the appropriate placement of guards and shields. Consideration of equipment interfacing is especially important because unique hazards can exist when equipment of various makes are integrated.

Injuries during equipment maintenance can be reduced by positioning multiple emergency power shut-off buttons, cords, and switches along process lines that include hazardous equipment (e.g., balers, conveyor belts, shredders). As a result of incidents of crushing injuries associated with balers, easily accessible safety switches are now being placed within baler chambers (Dessoff, 1991). Strictly observed electricity lockout practices during the maintenance of automated equipment limit the possibility of accidental start-ups.

Training regimens stressing safety practices for the use of specialized equipment help prevent injuries resulting from equipment misuse. Safety zones and warning signs alerting employees to hazardous areas and equipment also help prevent accidents.

Proper ventilation and vehicle emission controls can help reduce worker exposures to vehicle emissions during loading and unloading operations.

5.9. NOISE

Source Activity: A summary of recycling activities that generate significant levels of noise, including collection, sorting, and general material handling, is provided in Table 5-8. Aside from the noise associated with equipment motors and

TABLE 5-8

Noise Hazards

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Consumer drop-off at collection centers Curbside collection Transportation during processing	Vehicle and equipment design Collection and transport scheduling	Low
Occupational	Tipping floor Air classification Magnetic separators Aluminum separators Glass crushers Slicers Shredders Front-end separation at transfer stations, landfills, waste-to-energy plants Residential drop-off at collection centers Curbside collection Transportation during processing	Vehicle and equipment design System design (e.g., equipment isolation, shielding) Personal protective equipment	Medium
Material processing			
Occupational	AL - Shredding GL - Manual sorting GL - Crushers/grinders PA - Magnetic separators	Vehicle and equipment design System design (e.g., equipment isolation, shielding)	Low

TABLE 5-8 (continued)			
Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Occupational (continued)	PL - Shredders and grinders S/T - Shredders	Personal protective equipment	

AL - Aluminum processing
GL - Glass processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

engines, significant noise is generated by contact between aluminum, glass, and steel containers when they are loaded on a collection vehicle, dumped on the tipping floor, or transported on conveyor belts. Specific processing equipment such as air classifiers, metal and plastic shredders, and glass crushing and grinding equipment are also noisy. Noise may result from the use of heavy trucks, compactors, and automated loaders and compactors during neighborhood collection.

Hazard Type: Excessive noise is primarily an occupational hazard but also can be a public health concern associated with certain collection activities. The effects of noise on the ear are related to the duration of exposure and the intensity of the noise. Noise can have direct effects on both the middle and inner ear. The current OSHA standard for continuous noise for 8 hours is 90 dBA, with higher levels permissible for shorter periods of time. The American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value is 85 dBA. Noise levels above these standards are considered damaging. One study of noise levels measured throughout the front-end processing stages at a resource recovery plant revealed levels ranging from 85 to 90 decibels on the tipping floor and at the shredders. Levels between 90 and 100 decibels were measured at the primary and secondary shredders and at the magnetic separator (Mansdorf et al., 1981).

The primary health effect associated with noise exposure is noise-induced hearing loss (NIHL). There are three categories of NIHL (Levy and Wegman, 1988; Zenz, 1988; Clayton and Clayton, 1991): (1) acoustic trauma, which can be the effect of a single intense noise followed by ringing in the ear and a shift in the hearing threshold; there also can be damage to the eardrum if peak exposure levels exceed 160 dBA; (2) temporary threshold shift (TTS), which is temporary hearing loss with recovery within a few hours or days following removal from the noise if the noise has not been too loud or the exposure too long; the cumulative effect of noise levels of less than 85 dBA also can lead to TTS; and (3) permanent threshold shift (PTS) can result if the noise is of sufficient intensity and duration to damage the sensory cells in the inner ear. Diminished ability to understand speech in a setting with noisy background is a pronounced effect of NIHL. Some individuals also experience ringing ears and headaches in addition to their hearing loss.

Prevention and Mitigation Options: A simple and inexpensive means of reducing worker noise exposure is to require the use of earplugs or headphone-style protectors. Another option is the use of engineered controls that reduce the levels of noise generated. Using soundproof sorting booths as a means of isolating workers from noisy operations is gaining popularity in MRFs nationwide. Sound-deadening panels and dividers also can be used effectively to separate areas where noise is generated, such as the tipping floor, from areas where workers are stationed. Noisy equipment (e.g., shredders and grinders) can be fitted with sound-deadening attachments, or it can be isolated in a separate room or enclosure. Selecting quieter collection vehicles or reducing the number of vehicle trips to collect all MSW can minimize noise effects on the public.

5.10. AESTHETIC IMPACTS

Source Activity: Collection vehicles and recycling facilities can constitute aesthetic impacts themselves or generate other impacts including overall appearance effects, odors, and litter (Table 5-9).

In general, the release of litter is a concern more during recyclable materials collection than it is during MSW collection (personal communication between TRC Environmental Corporation and Alan Watts, recycling coordinator for Solid Waste Services, a division of the Environmental Conservation Services Department, Austin, TX, in August 1991). Drop-off centers can be a source of litter and often have an unkempt appearance because they are frequently unmanned. Discarded items frequently are left on the ground when bins are full or the items are not recyclable. In addition, people scavenging recyclables for profit can leave a drop-off center in disarray. Odors may be emitted from unclean recyclables during storage or reprocessing. For example, plastics that have absorbed butyric acid have been known to emit an acrid odor on exposure to heat during extrusion (Hernandez et al., 1988).

TABLE 5-9 Aesthetic Impacts			
Type of hazards	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Consumer collection Curbside collection Drop-off centers Transportation during processing MRFs	Public education Facility design (e.g., screening elements, secure storage areas, fences)	Low

Hazard Type: Aesthetic impacts are primarily a public health concern. Although aesthetic impacts do not directly impair health, indirectly they affect the psychologic confidence of individuals. Excessive odors and litter can diminish the public's support and result in complaints and opposition to MSW programs.

Prevention and Mitigation Options: Visual impacts can be minimized through the thoughtful use of screening elements (e.g., bushes, fences, walls, trees, earth berms). New facilities can be designed with greater attention paid to aesthetic quality. Litter and odors can be controlled by avoiding the use of uncovered, outdoor material storage areas. Odors can be reduced by effective washing of recyclables. Perimeter fences also can help to control windborne litter. Stationing an overseer at drop-off facilities or restricting access to the facility during nonstaffed hours will limit inappropriate dumping and scavenging. Garbage containers placed at drop-off facilities will help decrease litter.

5.11. TRAFFIC

Source Activity: Traffic hazards are attributable to trucks collecting recyclables at the curbside, private vehicles delivering recyclables to drop-off and buy-back centers, and vehicles (e.g., trucks, trains, barges) transporting recyclables between processing and within facilities. Traffic hazards are summarized in Table 5-10. Specifics of program organization and equipment type dictate the nature of traffic hazards. A drop-off or buy-back operation may have a higher occurrence of vehicle accidents involving private vehicles, whereas a curbside program may have a higher rate of accidents involving collection trucks.

Hazard Type: Traffic poses public health, occupational, and environmental hazards. Vehicular accidents (including pedestrian accidents), release of materials from collection vehicles, emissions (hydrocarbons, NO_x, carbon monoxide, and particulates) and maintenance-generated wastes, and noise are all traffic related hazards.

Workers collecting recyclables may be subject to traffic-related hazards during collection and truck-loading activities. Two-sided sorting may result in a

TABLE 5-10 Traffic Hazards			
Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Drop-off centers Buy-back centers Consumer drop-off at collection centers Curbside collection Transportation during processing	Public education Vehicle design (e.g., emission controls, safety features) System design (e.g., traffic flow) Collection and transport scheduling	Low
Occupational	Drop-off centers Buy-back centers Front-end separation at transfer stations, landfills, waste-to-energy plants Curbside collection Transportation during processing	Worker training Vehicle design (e.g., emission controls, safety features) System design (e.g., traffic flow) Collection and transport scheduling Personal protective equipment	Low
Environmental	Drop-off centers Buy-back centers Front-end separation at transfer stations, landfills, waste-to-energy plants Curbside collection Transportation during processing Vehicle maintenance	Vehicle design (e.g, emission controls) Proper waste handling Vehicle equipment	Low

higher accident rate because it has the potential to place workers in the path of traffic (personal communication between TRC Environmental Corporation and Pamela Harris, director of Loss Control Services for Browning Ferris International [BFI], Houston, TX, on September 13, 1991).

Although it is difficult to draw conclusions from the limited existing data on traffic accidents associated with recycling operations, statistics from a program in Austin, Texas, suggest that recycling vehicles can be more prone to accidents than other MSW collection vehicles. Statistics from 1986 and 1987 reveal that recycling vehicles accounted for approximately 30 percent of accidents involving collection vehicles and approximately 20 percent of the total vehicles in the collection fleet (personal communication between TRC Environmental Corporation and Sergio Martinez, safety specialist for Solid Waste Services, a Division of the Environmental Conservation Services Department, Austin, TX, in August 1991). Specific vehicle design and route organization features (e.g., truck size, loading design, number of workers assigned to each collection crew) are possible factors contributing to these higher rates.

Prevention and Mitigation Options: A thorough, safety-conscious traffic-flow plan can minimize potential accident hazards at all types of recycling facilities. Traffic safety zones can be established within which no vehicles are allowed. A well-organized collection strategy that anticipates and avoids periods and routes of high traffic will help reduce road accidents. Conducting safe-driver training, recognizing good drivers, and installing safety signs, mirrors, and other equipment can reduce traffic hazards at facilities and on the road.

Emerging collection strategies such as those that utilize efficient, lightweight collection vehicles that unload to larger vehicles for distance driving have the potential to reduce energy use and emissions. The type of truck chassis and engine used and the amount of stop-and-go driving required during collection influence fuel efficiency and related vehicle emissions. Keeping vehicles well maintained reduces emissions.

5.12. PROCESS CHEMICALS AND CONTAINER RESIDUES

Source Activity: A summary of process chemicals and residues of hazardous chemicals in recyclable containers that pose direct hazards at a number of processing points (Sections 5.13 through 5.18 for indirect hazards associated with these chemicals and other residues and contaminants) is provided in Table 5-11. Examples of common process chemicals include chlorine and other paper bleaching and pulping agents, aluminum fluxing agents and compounds, plastics additives, and equipment cleaning solvents. In some cases (e.g., paper deinking and pulping), chemicals are used in open vats or other containers from which splashing may endanger workers.

Container residues may include insecticides, herbicides, and other lawn and garden products; paints, stains, and construction products; automotive oils and cleaners; gasoline, kerosene, and other fuels; and miscellaneous household cleaning products. Individuals may be exposed to these residues during collection, cleaning (rinsing), and storage of recyclables in their homes. Workers are exposed to residues primarily during collection, sorting, and washing steps. For example, elevated pesticide levels also have been reported in wash water resulting from pesticide-saturated paper labels (personal communication between TRC Environmental Corporation and George Pisacano of the Center for Plastics Recovery Research, Rutgers University, on February 12, 1992). Certain container and label materials may be more likely than others to absorb and retain chemical residues.

Hazard Type: Mishandled or mismanaged process chemicals or residues can cause adverse effects to workers and the public. Direct skin contact, inhalation, and incidental ingestion exposures are possible. The health hazards associated with the chemicals and residues that may be encountered are summarized below.

Process Chemicals: Chlorine and fluorine, process chemicals used to remove magnesium from aluminum cans, are strong eye and respiratory irritants (Sittig, 1991). Fluoride compounds also are associated with central nervous system and skin disorders. Certain chemicals used in the deinking process could result in adverse health effects if proper controls are not in place. Repeated

TABLE 5-11

Process Chemicals and Container Residues
(Direct Impacts)

Type of hazards	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Consumer collection	Public education	Low
Occupational	Curbside sorting Dumping Bag breakers Sorting stations Drop-off centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Public education Worker training Personal protective equipment System and equipment design (e.g., storage practices, ventilation)	Medium
Material Processing			
Occupational	AL - Smelting PA - Pulper PA - Screening and cleaning PA - Clarifier PA - Bleaching PA - Effluent treatment PA - Sludge disposal PL - Manual sorting PL - Washing PL - Separation PL - Extrusion S/T - Chemical detinning	Public education Worker training Personal protective equipment System and equipment design (e.g., storage practices, ventilation)	Medium

AL - Aluminum processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

exposure to corrosive alkaline solutions such as sodium hydroxide can cause dermatitis.

Chemicals used during plastics processing are not generally hazardous. Difficulty in handling and disposing of hazardous solvents is one reason why more benign detergents usually are used in washing steps. Plastic resins and container labels can absorb organic residues such as pesticides. Health effects associated with exposure to pesticides include primarily skin and central nervous system disorders. Long-term exposures to certain pesticides can cause liver and kidney damage. Some pesticides are carcinogens.

Container Residues: Potential effects associated with container residues vary widely according to the type of residue. Possible effects range from short-term irritant effects to long-term toxicity and cancer. Hazardous constituents banned or reduced in concentration in current products may be present in old containers collected for recycling. Potential health and safety issues associated with residues are addressed under the regulatory authority of the Food and Drug and Cosmetic Act. Fire and explosion hazards associated with chemical residues are discussed in Section 5.5.

Prevention and Mitigation Options: Personal protective equipment including glasses, gloves, and aprons is recommended for reducing chemical exposures. Requiring workers to shed dedicated work uniforms before leaving the facility also will help reduce exposures to chemical spills (Solomon-Hess, 1991). In addition, showers and eyewash stations can help to minimize contamination. Adequate enclosures on processing vats, secure storage practices, and enhanced ventilation systems also prevent worker exposures to process chemicals. To minimize a release in the event of a chemical spill, some recycling facilities have installed separate run-off collection systems that are designed to collect and treat water contaminated with oil and other waste substances (Combs, 1991). Both occupational and public health exposures can be prevented by educating the public to avoid recycling containers with exceptionally hazardous contents and to properly wash or decontaminate containers before disposal.

5.13. GASEOUS RELEASES

Source Activity: Gases released are summarized in Table 5-12. Aside from occasional gaseous releases attributable to container residues (Section 5.12.), releases from recycling operations often are associated with heating or melting process stages or gases or volatile chemicals used to clean or refine recycled materials (Sections 5.8. and 5.11. contain information on emissions from equipment and vehicles). Potential release may vary with the material processed. Emissions from aluminum delacquering processes that burn paint and coatings may include organic contaminants and heavy metals such as lead and cadmium. Steel melting and demagging operations typically release metallic oxides and chlorides as well as acid and chlorine gases. Heavy metals contained in label inks also may be released. Bleaching agents (e.g., chloroform and chlorine) are released from processing and wastewater treatment operations associated with wastepaper recycling.

Plastics processing involving heating, particularly drying and extrusion molding operations, has the potential to release gaseous degradation products such as acids, volatile organic compounds (VOCs), carbon dioxide, and carbon monoxide (Allen, 1983). When most resins are melted, there is the possibility of releasing small quantities of unreacted monomer as well as any additives, dyes, and compounding agents. HDPE extruder operations have been found to release 0.63 kg of VOCs per mg of resin processed (Radian Corporation, 1985). One study has confirmed that some degradation of HDPE resin can occur during heating (Gibbs, 1990). Melting polystyrene above 280 degrees also has been shown to produce styrene monomer emissions (Brighton et al., 1979). Plastic degradation from overheating, scorching, and burning usually occurs by accident and is usually caused by equipment malfunctions, operator error, or improper equipment maintenance. Commingled plastics processing also raises the likelihood of exceeding resin degradation temperatures because it can involve simultaneously heating resins with different melt temperatures.

TABLE 5-12 Gaseous Releases			
Type of hazard	Sources	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health/ environmental	MRFs Front-end separation at transfer stations, landfills, waste-to-energy plants Consumer drop-off at collection centers Curbside collection Transportation during processing	System and equipment design (e.g., emission controls, chemical reuse)	Low
Occupational	Shredders Front-end separation Transfer stations, landfills, waste-to-energy plants Consumer drop-off at collection centers Curbside collection Transportation during processing	System and equipment design (e.g., emission controls, ventilation, chemical reuse) Personal protective equipment	Low
Material processing			
Public health/ occupational/ environmental	AL - Drying and delacquering AL - Smelting PA - Screening and cleaning PA - Bleaching PA - Milling PL - Extrusion	System and equipment design (e.g., emission controls, ventilation, chemical reuse) Personal protective equipment	Low

TABLE 5-12 (continued)			
Type of hazard	Sources	Prevention/mitigation	Significance of hazard
	S/T - Iron and steel manufacturing S/T - Shredding		

AL - Aluminum processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

Hazard Type: Gaseous releases associated with various recycling operations may result in potential exposure of workers, the public, and environmental receptors to a variety of toxic substances if proper controls are not employed. The magnitude of releases from recycling facilities that can affect the public and the environment is difficult to characterize.

In a remanufacturing facility, organic and metal oxide contaminant releases are possible during the delacquering and smelting of aluminum to remove impurities such as paints, coatings, and container residues. Exposure to metal oxides, including zinc, copper, magnesium, aluminum, antimony, cadmium, copper, iron, manganese, nickel, selenium, silver, and tin, may result in a flu-like condition known as metal fume fever. The symptoms of metal fume fever include chills, increased sweating, nausea, weakness, headache, muscle pain, and cough. The fever often begins with thirst and a metallic taste in the mouth (Levy and Wegman, 1988). In general, acute effects of solvent exposure include irritation of the respiratory tract, skin irritation, and central nervous system effects. Long-term health effects associated with organic compound exposure include liver, kidney, and gastrointestinal disorders. Certain solvents that may be used in or generated during certain recycling processes are classified by EPA as potentially carcinogenic to humans. In the paper deinking process, use of chlorine-based bleaches has been associated with the releases of dioxins and chloroform, both of which are potentially carcinogenic to humans. Exposure to dioxins also is associated with disorders such as chloracne, nervous system disorders, and liver damage (Sittig, 1991).

Many of the emissions from thermal decomposition of plastic resins are similar to those associated with the processing of virgin feedstock and include various classes of organic compounds. Possible acute health effects associated with worker exposure to organic compounds include irritation of mucous membranes and the respiratory system, dermatitis, and central nervous system effects (U.S. Department of Health and Human Services, 1990). Long-term exposures may cause liver, kidney, and gastrointestinal damage.

Prevention and Mitigation Options: Public exposure can be minimized through emission control technologies that are available to reduce gaseous releases from recycling facilities. Depending on their size and complexity, systems can reduce worker exposures by venting gases outdoors or eliminating harmful emissions altogether. Cost is the primary factor that limits the application of state-of-the-art air filtration systems, particularly at small, start-up operations with limited capital reserves. Fixed carbon-bed absorbers, electrostatic precipitators, distilling equipment, and fractionalizers all can be used effectively to reduce air emissions. For example, the acidic degradation byproducts of PVC processing can be neutralized using a sodium hydroxide mist (personal communication between TRC Environmental Corporation and Brian Doty, plant manager, Innovative Plastic Products, Inc., Greensboro, GA, on July 29, 1991). Wet scrubbers can be used to control gaseous emissions from drying and delacquering operations. In the absence of emission control systems, personal protective equipment such as respirators will reduce worker exposures.

5.14. PARTICULATE RELEASES

Source Activity: Virtually every operation within an MRF or processing facility generates some airborne particulates. A summary of particulate releases is provided in Table 5-13. Sorting activities, trommel screens, air classifiers, glass crushers, shredders, and other equipment that moves or manipulates recyclables are potential dust sources. Shredding and blowing equipment tends to generate the most particulates. Studies conducted at the Langard resource recovery facility in Baltimore, Maryland, identified high dust levels in the material receiving area (STC, 1979).

Certain materials produce more particulates, or particulates that are more hazardous, when they are shredded or processed. Paper, because of its fibrous nature, generates significant dust when it is sorted or shredded. Other dusts include fine glass shards from crushing or grinding, plastic fines from shredding, and aluminum and steel bits from shredding and demagging and detinning. The

TABLE 5-13

Particulate Releases

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health/ environmental	Drop-off centers MRFs Front-end separation at transfer stations, landfills, waste-to-energy plants Curbside collection Transportation during processing Most other processing facilities	System and equipment design (e.g., emission controls)	Low
Occupational	Tipping floor Trommel screens Air classifiers Shredders Drop-off centers Front-end separation at transfer stations, landfills, waste-to-energy plants Curbside collection Transportation during processing	System and equipment design (e.g., emission controls, ventilation) Personal protective equipment	Medium

TABLE 5-13 (continued)			
Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Material processing			
Public health/ occupational/ environmental	AL - Drying and delacquering AL - Smelting GL - Crusher and grinder GL - Screening GL - Aluminum separation PA - Trommel screens PL - Shredding S/T - Iron and steel manufacture S/T - Shredding S/T - Separation	System/equipment design (e.g., emission controls, ventilation) Personal protective equipment	Low

AL - Aluminum processing
GL - Glass processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

processing technique, material processed, and the ventilation conditions all affect the amount of airborne particulate material. Although some recycling facilities report dust to be a significant problem, an inspection conducted by the Vermont Health Department in a facility that regularly grinds PVC scrap found nuisance dust to be below allowable levels (personal communication between TRC Environmental Corporation and Fred Satink of the Vermont Department of Health on July 29, 1991).

Hazard Type: Particulate releases from recycling activities may pose potential public health, occupational, and environmental hazards. Uncontrolled dust may be inhaled or swallowed with food or saliva. In general, the principal potential health effects of particulate exposure include the aggravation of asthma or other respiratory or cardiorespiratory symptoms, increased cough and chest discomfort, and increased mortality. In addition, the toxic action of some gases may be enhanced when they are adsorbed to respirable particles. The health effects associated with inhalation of particles is dependent on the location and extent of their deposition in the respiratory system. Several factors influence particle deposition, retention, and clearance, including the anatomy of the respiratory tract, particle size, and breathing patterns. Children are considered to be more susceptible to particulate pollution. Environmental effects of particulate emissions include soiling and deterioration of building materials and other surfaces, cloud formation, and interference with plant photosynthesis (Clayton and Clayton, 1991). Dust levels measured in studies at resource recovery plants have ranged from 118 to 202 mg/m^3 in the vicinity of a shredder to as low as 38 mg/m^3 (Diaz et al., 1981). The OSHA Permissible Exposure Limit (PEL) for inert or nuisance dusts is 15 mg/m^3 for total particulates and 5 mg/m^3 for the respirable fraction.

Some dusts generated during certain recycling activities contain metal fines. Acute exposure to metal dusts can cause irritation of the upper respiratory system and eventually severe pulmonary irritation (Levy and Wegman, 1988). Heavy metals reported in air emissions from MRFs include cadmium, chromium, nickel, lead, and mercury (Visalli, 1989). Cadmium, chromium (hexavalent), lead, and nickel are carcinogenic to animals and humans when inhaled. Chronic exposure to mercury and lead can result in adverse effects to the central nervous and gastrointestinal systems; lead is also a probable carcinogen.

Exposure to fine glass particles can result in the development of silicosis because silica is a primary component of glass. Particles less than one micron in diameter present the greatest danger because they can penetrate to respiratory bronchioles and alveoli (Last and Wallace, 1992; Zenz, 1988). Such particle sizes are typically associated with grinding or sandblasting glass. Crushing of glass during recycling activities is not likely to produce particles that small.

Prevention and Mitigation Options: Ventilation and filtration systems and personal protective equipment are two approaches to controlling dust and protecting workers from elevated levels of airborne particulates. Filtration systems collect contaminated air and feed it to a bag house or an air scrubber system that removes contaminants. The latter method has proved effective for removing glass and other particulates from ambient air (U.S. EPA, 1977). Building-wide, negative air flow systems also have been used to draw air to a central filtration unit, but these systems are difficult to implement in large facilities like MRFs with many openings. An alternative is dust collection hoods on specific pieces of equipment that generate dust (e.g., shredders, air classifiers, plastics grinders). Operating equipment such as shredders at slower speeds has been found to further reduce dust generation rates (Toensmeir, 1987). The use of isolated booths to house sorting workers in a climate-controlled environment also is gaining acceptance as a method for limiting exposures to airborne contaminants. Dust masks and respirators can reduce the hazard to workers; however, the equipment must be properly selected, consistently used, and replaced when necessary. Workers often do not use masks because they are uncomfortable and considered a nuisance.

5.15. WATERBORNE RELEASES

Source Activity: Wastewater is generated by recycling operations ranging from washing containers in the home to industrial paper pulping and plastic washing systems (Table 5-14). The public generally washes food and paper particles down the drain. MRFs and other facilities that receive recyclables and commingled wastes can generate effluents containing a variety of liquids from container residues to rain water. Run-off from the tipping floor and other processing areas within a recycling facility often is discharged to the storm or sanitary sewer.

Water-based cleaning and sorting processes have the potential to generate large volumes of wastewater. For example, water is used extensively at several stages of wastepaper pulping and cleaning. Effluents containing chlorine and its byproducts, inks, and dyes are generated by screening, bleaching, washing, and filtering operations. The levels of chemical and physical contaminants vary depending on the type of paper being processed and the degree of wastewater treatment that takes place before release. Several types of plastics shredding or grinding, cleaning, and separation equipment also use water to wash and transport plastic flakes. A B.F. Goodrich vinyl recycling operation in Akron, Ohio, adds a 1-percent solution of dishwasher detergent to hot-water wash solutions (Summers et al., 1990).

Another source of facility effluents is water-based air filtration systems (e.g., wet scrubbers) used to control air emissions. Air filtration skimming and scrubbing processes are frequently used at aluminum and steel facilities. Contact cooling waters also can include a number of contaminants.

Hazard Type: Process wastewater and effluents from emission control systems result in primarily environmental hazards. Wastewater from aluminum processing may contain metals, phenolics, oil and grease, and suspended solids. Wastewater from paper processing may include chlorine-derived dioxins, PCBs, and heavy metals and solvents from inks. Although toxic constituents in manufactured goods are increasingly regulated, recycling of older products can contribute to the release of these contaminants. These substances exhibit both carcinogenic and noncarcinogenic health effects in humans. The primary environmental concerns are BOD loading of receiving waters and toxic effects on aquatic organisms.

TABLE 5-14

Waterborne Releases

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health/ environmental	Separation in the home Tipping floor	System and equipment design (e.g., collection, treatment, reuse)	Low
Material processing			
Public health/ environmental	AL - Scraping, drying, and delacquering AL - Smelting AL - Casting and cooling PA - Separators PA - Clarifiers PA - Bleaching PA - Dewatering and thickening PA - Milling PA - Separation PA - Washing PL - Separation PL - Washing S/T- Iron and steel manufacture	System and equipment design (e.g.,collection, treatment, reuse)	Low

AL - Aluminum processing
PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

Prevention and Mitigation Options: Dedicated systems can be installed to collect and treat facility effluents before release. Standard treatment techniques include primary and secondary clarifiers, neutralization, activated sludge, aerated stabilization, and anaerobic processes. Certain anaerobic processes can reduce BOD by as much as 95 percent (Amoth et al., 1991). The use of alternative chemicals such as nonchlorine bleaches and other nonhazardous process chemicals has reduced the quantity of dioxins released by secondary paper plants. Most wastewaters from cleaning, sorting, reprocessing, or air filtration also can be recycled to minimize effluent discharges. For instance, paper recycling plant effluents have been successfully filtered and recycled (Horacek, 1983).

5.16. SOLID WASTE AND SLUDGE

Source Activity: Residual material is generated as a result of sorting and refining operations that purify waste materials for remanufacture (Table 5-15). An assortment of gross solid discards and sludge byproducts generated as recyclables is initially processed at the MRF. More rigorous sorting, filtering, and refining that occur during subsequent processing generate a variety of sludges and finer contaminants. These discards are generally landfilled, incinerated, landfarmed, or discharged with wastewater.

A survey of 41 operating and proposed MRFs found residue generation rates ranging from less than 1 to 25 percent of the material entering a facility. Most of the discards from the MRFs generating more than 10 percent waste were found to be mixed-color cullet (Glenn, 1989). The remainder of the residue is difficult to categorize and is not generally salvageable.

Aluminum reprocessing generates both solid and sludge discards. Fabric filters used to collect aluminum fines, slag and dross collected during skimming, and demagging residues captured by emission control equipment are examples of aluminum reprocessing wastes.

Paper recycling generates large quantities of sludge and a variety of solid discards including plastic, bindings, cellophane, rubber bands, staples, and paper

TABLE 5-15

Solid Waste and Sludge

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health/ environmental	Front-end separation at transfer stations, landfills, waste-to-energy plants MRFs	Process and system design (e.g., careful sorting, reuse of waste, glass breakage reduction) Treatment and disposal facility design	Low
Material processing			
Public health/ environmental	PA - Manual sorting PA - Magnetic separators PA - Trommel screens PA - Pulper PA - Screening and cleaning PA - Separators PA - Clarifier PL - Washing PL - Separation PL - Extrusion S/T - Air classifiers S/T - Magnetic separation S/T - Tin removal	Process and system design (e.g., careful sorting, reuse of waste, glass breakage reduction) Treatment and disposal facility design	Low

PA - Paper processing
PL - Plastic processing
S/T - Steel and tin processing

clips (Sixour, 1991). It is estimated that deinking and pulping operations will produce as much as 700,000 tons of sludge in 1995 (Usherson, 1992). This is caused primarily by fiber losses and high clay and ink content of certain waste paper grades. Heavy metals, PCBs, and dioxins are contaminants of concern in paper processing sludges.

Plastics cleaning, sorting, and filtration often generate soil, rocks, off-specification plastics, metals, labels, detergent, and solvents. Filtrate quantities vary widely depending on the type and quality of the plastic being processed. A filtration system that uses a coarse wire screen on an extruder for processing PET bottles may collect 4 to 5 chips of aluminum (averaging 3 mm^2 in size) per 10 kg of PET processed (Wissler, 1990). One plastics recycling facility reported landfilling more than 16,000 pounds of wet filtrate (as much as 50 percent water) for every 5 to 10 cubic feet of plastics processed (personal communication between TRC Environmental Corporation and Garry Thompson. M. A. Industries, Inc. Peachtree City, GA, in July 1991).

Hazard Type: Many of the process chemicals and contaminants found in effluent streams also can occur in sludge. Trace quantities of heavy metals, PCBs, dioxins, and other chlorinated organic compounds are found in recycling plant sludge. Metals measured in deinking sludges are listed in Table 5-16. As mentioned previously, exposure to these contaminants can result in both carcinogenic and noncarcinogenic toxic effects. Extent of exposure and the bioavailability of chemicals in the waste and sludge will affect the potential for adverse effects. Public health and environmental hazards can result from releases during solid waste and sludge treatment and disposal.

Prevention and Mitigation Options: Solid waste and sludge residues from recycling processes usually are landfilled or incinerated. Because there are no completely satisfactory methods to dispose of these wastes, limiting the quantity that must be discarded is the most effective alternative. Some communities have begun to write contract clauses requiring waste haulers to limit the percentage of

TABLE 5-16

Heavy Metal Concentrations in Deinking Sludges (ppm)

Municipal heavy metal	Lowest concentration	Highest concentration
Cadmium	0	<0.02
Chromium	16.0	118
Copper	31.0	400
Lead	3.0	210
Manganese	31.0	880
Nickel	1.0	25
Zinc	36.0	1,000

Source: Hoekstra, 1991.

residue per volume of recyclables processed. Such agreements encourage contractors to perform more careful sorting, which results in fewer residuals.

To reduce glass residue discards, MRFs are being designed to include fewer handling steps for glass containers. At a large facility in Las Vegas, Nevada, glass that has been sorted at the curbside is dumped from the truck directly into sorting bins, which are delivered to the processor. This system not only limits the mixing of glass types at the MRF, it also requires that each container be handled only once when it is collected at the curbside (Combs, 1991).

Another modification that reduces the amount of broken glass is the installation of wooden floors in glass-handling areas (Salimando, 1989). Recently developed equipment (glass beneficiation systems) has been aimed at purifying glass residues to create a higher percentage of reusable product.

In some cases, wastes are reclaimed because of the value of certain constituents. For example, detinning sludges are often reused for their high alkali content (Grayson and Echroth, 1980). Reuse of other wastes such as paper mill sludges, which may contain heavy metals, can be more difficult. Paper mill sludges traditionally have been landfilled or incinerated; however, 58 percent of sludges were landfarmed in 1990 (Diehn, 1991). Recently, landfarming has become a popular sludge disposal method, but concerns about heavy metal concentrations remain. Developing alternative uses for typical waste materials (e.g., the use of mixed cullet in glasphalt) can reduce the quantity of residue that must be disposed of.

5.17. MICROBIOLOGIC HAZARDS

Source Activity: Microorganisms such as bacteria, fungi, and viruses often grow within recyclable containers or on paper products. A summary of source activities is listed in Table 5-17. Newspapers used in animal litter boxes provide a growth medium for microbes. Infectious agents also can be present on hypodermic needles that contaminate the recyclable waste stream. Microbiologic agents are of particular concern when recyclables are mixed with MSW before sorting, but

TABLE 5-17

Microbiologic Hazards

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Separation in the home Drop-off centers Buy-back centers	Public education Frequency of collection and processing	Low
Occupational	Curbside sorting MRFs Drop-off centers Buy-back centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Public education Frequency of collection and processing Personal protective equipment Vehicle and equipment cleaning Worker training (cleanliness)	Medium

separated recyclables also provide suitable substrate for microorganisms. The public can be exposed to these hazards when dirty recyclables are stored in the home for extended periods of time. Operations that increase the risk of worker exposure to microbiologic hazards include commingled MSW and recyclable collection, the use of the same vehicles to collect both MSW and recyclables, bag breakers and other equipment that stir up contaminated materials and potentially disperse microorganisms, and manual sorting operations that require workers to handle recyclables and remove putrescible wastes. Facilities that wash plastic materials, however, report no significant bacterial problems (personal communication between TRC Environmental Corporation and Garry Thompson, M. A. Industries, Inc., Peachtree City, GA, in July 1991).

Hazard Type: Although the public may be exposed to microorganisms on recyclables, exposure potential appears to be greatest among workers. Individuals may be exposed to microorganisms in aerosols, on dust particles, or on objects they contact. Pathogenic microorganisms of concern include coliform bacteria species such as *Escherichia coli* and fungi such as *Aspergillis* (Pahren, 1987). The most common health problems associated with these pathogens include respiratory infections, diarrhea, and skin diseases. Contact dermatitis can occur from contact with fungi.

Worker illnesses have been reported at indoor waste processing facilities where microbial densities tend to be higher. A 1987 study evaluated dust and biologic airborne contaminants at Danish waste processing plants and measured "demonstrated endotoxins (poisonous substances produced by bacteria) in excess of recommended normal values for air content" (Malmros and Petersen, 1988). Half the staff members at these facilities were found to suffer from some type of respiratory system ailment. Additional symptoms included flu-like symptoms, fever, and eye and skin irritation.

Prevention and Mitigation Options: Teaching the public to wash containers before recycling will reduce microbial growth. Washing vehicles and other processing equipment regularly also minimizes the build-up of microorganisms.

Frequent collection minimizes public exposure in the home. Personal protective equipment such as water-resistant gloves have been shown to effectively protect workers (personal communication between TRC Environmental Corporation and Pamela Harris, director of Loss Control Services for Browning Ferris International, Houston, TX, on September 13, 1991). Respiratory protection reduces occupational inhalation exposures to airborne pathogens.

5.18. PESTS

Source Activity: Pests such as insects and rodents may be attracted to containers and other recyclables as a food source or nesting medium. A summary of the source activities is provided in Table 5-18. Pests are a concern when recyclables are stockpiled in the home or at a recycling facility before collection or processing. Recyclables contaminated with food residues are particularly susceptible to pest infestation. Home refuse containers with accumulated residues have been shown to produce more than 1,000 fly larvae per week (Chanlett, 1979).

Hazard Type: Insects and rodents represent both an occupational and public health hazard. Flies are contaminated with hundreds of species of pathogenic microorganisms that can be transmitted to humans (Last and Wallace, 1992). Some culex mosquitoes are wastewater breeders and will breed in dirty water pools, including rainwater accumulated in stored cans and bottles and other discarded items (Chanlett, 1979). Rats harbor the pathogens for leptospiras, rat-bite fever, and salmonellosis (Chanlett, 1979).

Insect bites usually present nuisance conditions such as localized swelling, itching, and minor pain. However, a hazard and common cause of fatalities from insect bites--particularly bees and wasps--is a sensitivity reaction. Anaphylactic shock from stings can include severe reactions by the circulatory, respiratory, and central nervous systems, which may lead to death.

Prevention and Mitigation Options: Educating the public to avoid mixing garbage and recyclables and to thoroughly clean containers before storage or

TABLE 5-18

Hazards From Pests

Type of hazard	Source activity	Prevention/mitigation	Significance of hazard
Collection and sorting			
Public health	Separation in the home Drop-off centers	Public education Frequency of collection and processing	Low
Occupational	Curbside sorting MRFs Drop-off centers Buy-back centers Front-end separation at transfer stations, landfills, waste-to-energy plants	Public education Frequency of collection and processing Personal protective equipment Vehicle and equipment cleaning	Low

collection reduces pest hazards. Frequent and regular collection and processing reduces excessive recyclable stockpiling, limiting pest habitats and food sources. Pesticides also can be used to eliminate rodent and insect pests, although their use is discouraged because of their deleterious environmental effects.

6. SUMMARY AND CONCLUSIONS

This report presents an overview of the practices and processes used to recycle municipal solid waste and the associated public health, occupational safety, and environmental concerns. Aluminum, glass, paper, plastics, and steel and tin recyclables are tracked through collecting, sorting, and processing. Many safety concerns identified are generic to the overall handling of MSW, regardless of whether the materials are recycled or whether the recycling program includes simple community drop-off centers or automated systems with state-of-the-art collection vehicles and sorting facilities. Other recycling hazards are specific to the material or product type being recycled.

Solid waste managements methods, including recycling, pose physical, chemical, and biologic hazards to workers, the public, and the environment. Workers typically encounter physical hazards when they handle recyclables during the collection and sorting stages and also during material-specific processing. Contact with sharp objects, moving parts, or flying or falling debris can cause physical injury. Ergonomic injuries can result from poorly designed collection vehicles or the repetitive motions required of workers at sorting stations within MRFs. Traffic noise is a safety concern when recycling programs increase the number of vehicle trips. Noise levels within some MRFs also are known to exceed OSHA standards. Fires and explosions, although infrequent, are physical hazards in addition to affecting property.

Chemical hazards can result from airborne (gaseous and particulate), waterborne, and sludge and solid releases at recycling facilities. Postconsumer recyclables can contain chemical residues or contaminants. The chemical composition of the recyclable itself, the coatings and paints applied to products and packaging, or other additives and process chemicals can contribute to chemical releases during processing.

Microbes and pests present biologic hazards. Microbiologic agents can enter MSW directly as a result of consumers discarding contaminated materials such as newspapers from pet litter boxes. Container residues and recyclables composed of materials that provide suitable substrate present indirect means for the introduction of opportunistic microorganisms. Rodents and insects are common pests encountered at facilities handling MSW, regardless of whether the facilities are for recycling.

Preventive and mitigative options exist to control most hazards encountered in the recycling industry. Many specific hazards and their sources (equipment or activities) are not unique to recycling and exist in other industries or in the collection and disposal of MSW by other options. Although existing standards of practice do not specifically target the recycling industry, Federal (OSHA, EPA), state, and other standards apply to many practices and processes used in recycling and serve to reduce or prevent hazards.

Pollution control technologies exist for most processing operations, but the extent to which controls are used is difficult to quantify. There are documented cases in which failure or lack of control equipment has resulted in unacceptable worker exposures (e.g., noise, fugitive dust). In addition, it is difficult to control occupational hazards occurring at the initial material-handling stages because some manual sorting of recyclables is inevitable. Advanced sorting technologies have the potential to limit worker exposure to recyclable materials and their byproducts, but as yet the technologies are not widely applied.

Safety procedures, emission control devices, wastewater treatment systems, and responsible solid waste management practices reduce many of the public health, occupational, and environmental hazards. In addition, public and worker education is essential to implementing a safe and successful program.

The significance of hazards identified in this report is summarized in Tables 6-1, 6-2, and 6-3. Each table presents ratings for hazards that occur during collection and sorting and material-specific processing. The overall processing of recyclables appears to contribute to increased occupational hazards because of excessive worker contact through handling and separation of recyclables. The types of occupational hazards appear to be reasonably similar between material

TABLE 6-1 Summary of Public Health Concerns		
	Activities	
Public health concerns	Collection and sorting	Material-specific processing
Sharp objects	Low	NMS
Ergonomic and lifting injuries	Low	NMS
Fires and explosions	Low	NMS
Flying and falling debris	Low	NMS
Moving heavy machinery	Low	NMS
Noise	Low	NMS
Aesthetic impacts	Low	NMS
Traffic	Low	NMS
Process chemicals and container residues	Low	NMS
Gaseous releases	Low	Low
Particulate releases	Low	Low
Waterborne releases	Low	Low
Solid waste and sludge	Low	Low
Microbiologic	Low	Low
Pests	Low	Low

NMS = The hazard identified is not specific to any particular material.

TABLE 6-2

Summary of Occupational Safety Concerns

Safety concerns	Activities	
	Collection and sorting	Material-specific processing
Sharp objects	Medium	Low
Ergonomic and lifting injuries	Medium	Low
Fires and explosions	Medium	Low
Flying and falling debris	Medium	Medium
Temperature and pressure extremes	Low	Low
Moving equipment and heavy machinery	Low	Low
Noise	Medium	Low
Traffic	Low	NMS
Process chemicals and container residues	Medium	Medium
Gaseous releases	Low	Low
Particulate releases	Medium	Low
Microbiologic	Low	NMS
Pests	Low	NMS

NMS = The hazard identified is not specific to any particular material.

TABLE 6-3

Summary of Environmental Safety Concerns

Environmental concerns	Activities	
	Collection and sorting	Material-specific processing
Fires and explosions	Low	Low
Traffic	Low	NMS
Gaseous releases	Low	Low
Particulate releases	Low	Low
Waterborne releases	Low	Low
Solid waste and sludge	Low	Low

NMS = The hazard identified is not specific to any particular material.

types. Available data suggest that the number of hazards potentially affecting public health and the environment is smaller than that potentially affecting workers. The separation and sorting of recyclables in the home is a popular collection strategy. However, programs that require the public to handle and store recyclables, especially containers and their contents, increase public health hazards. Moreover, the additional preparation of recyclables that is required to meet market specifications generates solid discards and cleaning byproducts (e.g., material rejects, detergents, effluents).

Generally, recycling increases the number of vehicle trips necessary to collect MSW. Training and new truck designs can be used effectively to reduce certain hazards and to increase efficiency.

Lack of data to characterize recycling hazards results from the newness of recycling programs and certain processes, the proprietary nature of technologies, and chemical formulations. Occupational health studies and databases on workplace hazards will permit the significance of occupation hazards to be assessed. More data to characterize and quantify emissions and effluents leaving recycling facilities are required to estimate the magnitude of many public health and environmental hazards.

7. ADDITIONAL RESEARCH NEEDS

Insufficient data exist to fully characterize the nature and significance of MSW recycling hazards. The lack of data is caused in part by recent increases in recycling activities and innovations in recycling technologies and the corresponding lag in time required to conduct studies and collect information. The following research activities would assist in filling key data gaps.

- Characterize the air quality within recycling facilities (e.g., MRFs) and emissions from these facilities.
- Study pollution and safety control devices and systems to determine the frequency with which they are being implemented and their applicability, effectiveness, and cost to the industry.
- Study the ergonomic effects of various practices and processes in recycling programs. For example, evaluate curbside collection versus drop-off centers or manual versus automated sorting stations within MRFs.
- Characterize and quantify wastewater discharges from various types of recycling facilities to ambient waters.
- Evaluate the impacts of waste-handling facility capacity on the magnitude of facility-related activities.
- Conduct an epidemiologic study of workers with acute and chronic exposures attributable to recycling activities.
- Monitor changes in health biomarkers and the associated health status of workers.
- Identify sources of microbial hazards associated with recycling facilities, especially mixed waste processing facilities.
- Conduct a quantitative risk assessment for workers with microbial exposures.
- Identify inhalation and dermal risks attributable to infectious agents in MSW.

- Develop databases of occupational injuries and chemical exposures in recycling.

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APPENDIX A
GLOSSARY

Recycling is a rapidly evolving industry in which numerous technical terms are used, many with several meanings or interpretations. The following list of definitions is provided to assist the reader of this report.

Additive - A substance added to another material (e.g., plastic) in relatively small amounts to impart or improve desirable properties or suppress undesirable properties.

Alloy - A mixture or solid solution of two or more metals.

Baler - A machine used to compress recyclables into bundles to reduce volume.

Bottle bill - A law requiring deposits on beverage containers.

Buy-back facilities - A facility where consumers bring recyclables for payment.

Charge - The quantity of a material to be used or consumed that is loaded at one time into an apparatus (e.g., furnace).

Commingled - Two or more recyclable materials or objects mixed together.

Cullet - Broken glass used to manufacture new glass.

Curbside collection - A MSW management program option in which materials are collected at the curb and brought to processing facilities.

Drop-off facilities - A collection or processing facility to which consumers bring recyclables.

Dross - The solid layer that forms on the surface of a molten or melting metal largely as a result of oxidization or the rising of contaminants and impurities to the surface.

Ferrous - Types of metal containing iron.

Flux - A substance used to promote fusion of metals by removing impurities or contaminants.

Hazard - A source or condition that can create or increase the potential for danger.

Incinerator - A facility in which combustion of solid waste takes place.

Landfill - An engineered structure designed to isolate waste from man and minimize environmental risk.

Municipal solid waste - A mixture of household, commercial, and institutional solid waste.

Nonferrous - Types of metal containing no iron (e.g., aluminum).

Plastic - Any complex synthetic or natural organic compound formed by polymerization.

Polymer - Any of numerous natural or synthetic compounds consisting of linked molecules. The words plastic and polymer are used interchangeably.

Recover - The process to regain useable material from waste.

Recyclable - A component of municipal solid waste that can be collected and reused or processed for use in new products.

Recycling - The process during which an item is subjected to physical or chemical alterations between the time it is separated from waste and processed into its final form.

Resin - A class of solid or semisolid organic substances derived from plants or synthetic materials.

Resource recovery facility or waste-to-energy plant - A facility that accepts and combusts municipal solid waste as a means of generating energy.

Reuse - An activity in which a material is subjected to small or no alterations in its physical form and is employed in the same function for which it was originally designed or built.

Risk - The quantitative estimate of injury, disease, or death under specific circumstances.

Scrap - Fragments or small pieces of recyclables (generally refers to metals).

Separation - Segregation of recyclables from municipal solid waste.

Slag - A substance that floats on molten metal during refining, protects the metal from oxidation, and removes contaminants.

Smelting - Purifying or separating alloys or ores by melting.

Sort - To manually or automatically select specific recyclable materials and place them into homogeneous material streams.

Trommel screen - A large, rotating cylindrical screen that is used in MRFs and paper sorting facilities to remove small and heavy contaminants (e.g., sand, rocks, paper clips) from a material stream.

APPENDIX B

COMMON RECYCLABLES: AMOUNTS AND MARKETS

INTRODUCTION

Aluminum, glass, paper, plastics, and steel and tin represent a large percentage of the MSW generated in the United States. In 1988, these recyclables accounted for approximately 63 percent (113 million tons) of the MSW generated (Table B-1). A report by Franklin Associates (1990) states that in 1988, 19.5 percent (22.3 million tons) of recyclables generated, 12.4 percent of total MSW, was recovered. Table B-1 lists the material-specific recovery rates. The remainder was landfilled or incinerated. Recyclables that were disposed of in landfills accounted for 68 percent of landfill volume. The 1988 recycling rate (12.4 percent) was nearly twice the 1960 rate of 7 percent. It is estimated that recovery rates will approach 30 percent by the year 2000 (Franklin Associates, 1990). Given recovery rate increases, markets must expand to absorb recovered materials. To date, however, market growth for recyclables has not kept pace with recycling rates. As states continue to pass legislation mandating recycling (see Appendix C), the supply of recyclables will continue to increase. Although some market development has occurred, recyclable markets are weak for some materials. This creates supply excesses that lower the market prices paid for recyclables, making their collection less desirable.

ALUMINUM AMOUNTS AND MARKETS

Amounts

Aluminum has many commercial applications, including beverage and other containers, foil, closures, siding, window frames, roofing, mobile home awnings and canopies, heating and ventilation applications, curtain walls, copper and aluminum radiators, and appliances. In 1988, more than 4.3 million tons of aluminum was produced, and an additional 2.4 million tons of scrap aluminum was reused.

TABLE B-1 Materials Recovery From Municipal Solid Waste, 1988				
	Weight generated (in millions of tons)	Weight recovered (in millions of tons)	Percent recovered of each material	Discards (in millions of tons)
Paper and paperboard	71.8	18.4	25.6	53.4
Glass	12.5	1.5	12.0	11.0
Metals				
Ferrous	11.6	0.7	5.8	10.9
Aluminum	2.5	0.8	31.7	1.7
Other nonferrous	1.1	0.7	65.1	0.4
Total metals	15.3	2.2	14.6	13.0
Rubber and leather	4.6	0.1	2.3	4.5
Textiles	3.9	0.0	0.6	3.9
Wood	6.5	0.0	0.0	6.5
Other	3.1	0.7	21.7	3.1
Total nonfood product wastes	132.1	23.1	17.5	109.6
Other wastes				
Food wastes	13.2	0.0	0.0	13.2
Yard wastes	31.6	0.5	1.6	31.6
Miscellaneous	2.7	0.0	0.0	2.7
Inorganic wastes				
Total other wastes	47.5	0.5	1.1	47.5
Total MSW	179.5	23.4	13.1	157.1

Source: U.S. EPA, 1990.

Aluminum recycling is widespread because of several factors. Deposit laws and dealers who purchase aluminum scrap provide an incentive for the public to recycle. Aluminum manufacturers prefer recycled aluminum because less than 5 percent of the energy required to make aluminum from bauxite (the principal aluminum ore) is used to recycle aluminum (Copperthite, 1989; ISRI, 1990a,b; ALCOA, 1991).

Although aluminum has many applications, the only items recycled in significant quantities from municipal solid waste are used beverage cans (UBC) and foil and closures (Franklin Associates, 1990). UBC comprises more than 90 percent of all aluminum recovered from municipal solid waste. Table B-2 shows that in 1988, 55 percent of beverage cans and 5 percent of foil and closures were recovered from MSW.

Markets

The recycling of UBC is a closed loop because its predominant market is new aluminum beverage containers. Although aluminum is not plagued by the chronic oversupply problems of other recyclables, recent increases in supply have exceeded the capacity of remelting mills (Misner, 1991). UBC prices are more dependent on the worldwide price of virgin aluminum ingot than their own supply and demand because ingot prices reflect the supply and demand atmosphere for aluminum-can sheet that is produced from UBC (Misner, 1991).

GLASS AMOUNTS AND MARKETS

Amounts

Postconsumer glass can be classified into functional groups depending on the method used to form it. Three groups, container glass (bottles and jars), flat glass (window glass, plate glass, float glass, tempered glass, and laminated glass), and pressed and blown glass (ornamental glass and stemware), constitute virtually all glass produced (U.S. EPA, 1979). As of 1988, 6.9 percent (12.5 million tons)

TABLE B-2

Generation and Recycling of Aluminum Products in MSW, 1988

Product category	Weight generated (in thousand of tons)	Weight recovered (in thousand of tons)	Percent recovered	Discards (in thousands of tons)
Major appliances	107	0	0	107
Furniture and furnishings	89	0	0	89
Miscellaneous durables	280	0	0	280
Miscellaneous nondurables	240	0	0	240
Beverage cans	1,439	791	55	648
Other cans	67	0	0	67
Foil and closures	324	16	5	308
Total	2,546	807	32	1,739

Source: Franklin Associates, Ltd., 1990.

of all MSW generated in the United States consisted of glass products, 92 percent of which was container glass (Table B-3).

Nearly 100 percent of the glass recycled from MSW was container glass. Plate glass does not provide a consistent market for recyclers, and little is recycled because of the intended durability of the product. Pressed and blown glass also generally is formed into items considered to be "durable goods."

The most common types of glass are soda-lime, borosilicate, lead silicate, and opal. Approximately 77 percent of all glass manufactured is soda-lime glass, which is used exclusively in the production of food and beverage containers because of the ease and efficiency with which it is produced. Three colors of soda-lime glass, clear (flint), green, and amber, are commonly produced and recycled. Green and amber glass are produced by adding minerals such as chromium trioxide, iron oxide, and cupric oxide for green glass and sodium sulfide for amber glass to a flint batch (Grayson and Echroth, 1980). Recyclers generally segregate by color because clear glass can be used in any batch, whereas colored glass generally is used to produce recycled products in a specific color.

Markets

The major market for recycled glass (cullet) is glass container manufacturers, which receive approximately 70 percent of the cullet processed in the United States. They maintain strict specifications regarding the cullet color and the amount of contaminants present. In general, only a small amount of green or amber glass can be added to a batch of flint glass. In the same regard, manufacturers regulate the amount of off-specification glass in green and amber batches.

Although glass container manufacturers have promoted their products as 100 percent recyclable, the current supply created by proliferating collection programs is far exceeding domestic furnace capacity. In addition, relatively high transportation costs associated with cullet, given its high weight-to-volume ratio, may make export of the material unprofitable. Green glass imported from Canada

TABLE B-3

Generation and Recycling of Glass in MSW, 1988

Product category	Weight generated (in millions of tons)	Weight recovered (in millions of tons)	Percent recovered	Discards (in millions of tons)
Durable goods[a]	1.2	Negligible	Negligible	1.2
Containers and packaging				
Beer and soft drink bottles	5.4	1.1	20.0	4.3
Wine and liquor bottles	2.0	0.1	5.0	1.9
Food and other bottles and jars	3.9	0.3	7.7	3.6
Total glass containers	11.3	1.5	13.3	9.8
Total glass	12.5	1.5	12.0	11.0

[a]Glass as a component of appliances, furniture, consumer electronics, etc.

Source: Franklin Associates Ltd., 1990.

is not taken back by the only manufacturer in that country, Consumers Glass, because it feels the supply of green bottles to Canadian bottlers by U.S. manufacturers creates a balanced net flow of green glass across the border (Apotheker, 1991; personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991).

Fiberglass insulation and sandblasting material represent new markets for green and mixed cullet. Although the fiberglass industry produces 1.4 million tons of insulation per year, the market dislocation for green and mixed-color cullet probably meets or exceeds that entire quantity (Apotheker, 1991; personal communication between TRC Environmental Corporation and Steve Apotheker, journalist, *Resource Recycling* Magazine, on August 14, 1991). One industry representative estimates that the sandblasting market could absorb about 200,000 tons of cullet annually, although only about 10,000 tons are absorbed currently (personal communication between TRC Environmental Corporation and Roger Hecht, vice president, Bassichi's Company, on July 31, 1991).

PAPER AMOUNTS AND MARKETS

Amounts

Wastepaper grades have been defined by the U.S. Bureau of Census into five major grades: old newspaper (ONP), mixed paper (MP), old corrugated containers (OCC), high-grade deinking (HGD), and pulp-substitutes (PS) (Amoth et al., 1991). PS are basically in-plant scrap and require little or no preparation aside from repulping before being used as a fiber source. ONP, MP, OCC, and HGD may require cleaning and deinking, but they are still valuable sources of secondary fibers.

The major source categories of paper in MSW include corrugated boxes, newspapers, office paper, and books and magazines. Of the 71.8 million tons of paper waste generated in 1988, these items accounted for 49 million tons. These items also accounted for the bulk of the paper that was recycled. Table B-4 lists

TABLE B-4

Generation and Recycling of Paper and Paperboard in MSW, 1988

	Weight generated (in millions of tons)	Weight recovered (in millions of tons)	Percent recycled	Discards (in millions of tons)
Nondurable goods				
Newspaper	13.3	4.4	33.3	8.9
Books and magazines	5.3	0.7	13.2	4.6
Office papers	7.3	1.6	22.5	5.7
Commercial printing	4.1	0.6	14.6	3.5
Tissue paper and towels	3.0	Negligible	Negligible	Negligible
Paper plates and cups	0.7	Negligible	Negligible	Negligible
Other nonpackaging paper[a]	5.2	Negligible	Negligible	Negligible
Total paper and paperboard nondurable goods	38.9	7.4	18.9	31.5
Containers and packaging				
Corrugated boxes	23.1	10.5	45.4	12.6
Milk cartons	0.5	Negligible	Negligible	Negligible
Folding cartons	4.4	0.3	7.7	4.1
Other paperboard packaging	0.3	Negligible	Negligible	Negligible
Bags and sacks	2.9	0.2	7.0	2.7
Wrapping papers	0.1	Negligible	Negligible	Negligible

TABLE B-4 (continued)				
	Weight generated (in millions of tons)	Weight recovered (in millions of tons)	Percent recycled	Discard (in millions of tons)
Other paper packaging	1.5	Negligible	Negligible	Negligible
Total paper and paperboard containers and packaging	32.9	11.0	33.5	21.9
Total paper and paperboard	71.8	18.4	25.6	53.4

[a]Includes tissue in disposable diapers, paper in games and novelties, posters, tags, cards, etc.

Source: Franklin Associates, Ltd., 1990.

the various constituents of waste paper in 1988 and the extent to which they were recycled.

Markets

Historically, the use of recycled fibers, or secondary fibers, in the production of new paper and paper products has been common practice. The contribution of secondary fibers to paper production has increased steadily to constitute approximately 25 percent of new paper production in 1988 (Franklin Associates, 1990).

Repulping or grinding paper into reusable fibers uses well-established technologies. Removing the ink from newsprint and other inked papers, commonly called deinking, is one of the primary technical challenges presented by paper recycling.

A growing number of municipal recycling programs have boosted the amount of newsprint collected and increased the demand for deinking capacity. Federal and state legislation suggesting or mandating the use of secondary fibers in new products has begun to play a role in the rise in secondary fiber utilization. It is estimated that the use of deinked fibers will grow to 5.8 million tons in the next 10 years. Most of this will be used in newspaper production. If collection rates continue to grow and deinking capacity expands as expected, it is estimated that wastepaper utilization rates will rise to nearly 30 percent by 1995 (Franklin Associates, 1990). Alternative developing markets for waste paper include the following:

- Animal bedding
- Egg and fruit boxes from old cartons
- Egg and fruit cartons for wastepaper pulp
- Building material
- Asphalted roofing sheets
- Insulating material
- Fuel

Export is one outlet for the domestic oversupply of recycled paper. In fact, many dealers or processors export nearly all their waste paper (Misner, 1991). For example, various grades of paper from the United States are imported by countries in Asia, where lower labor costs allow more economical paper processing. The export of waste paper is dependent on the availability of shipping containers (Misner, 1991).

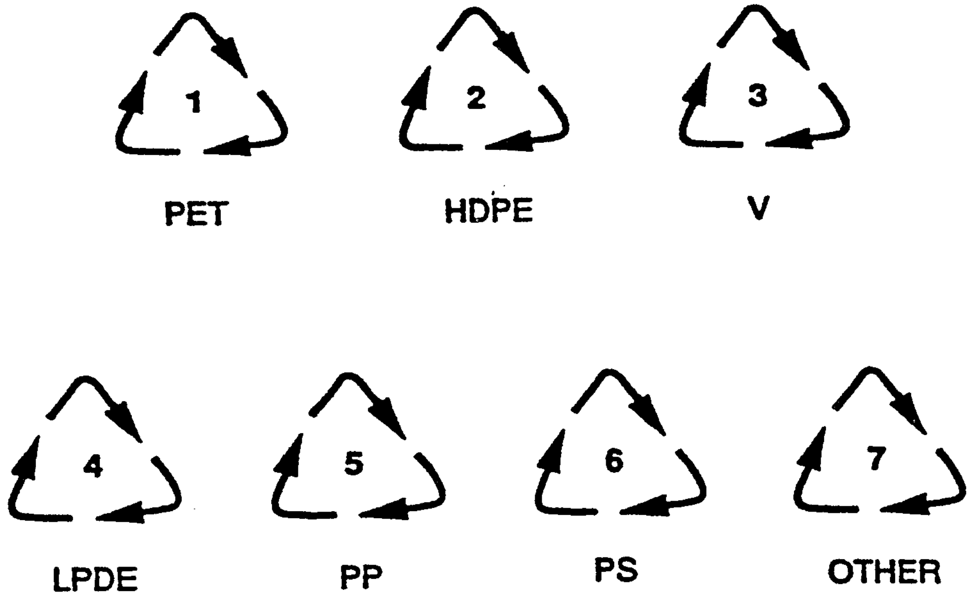
PLASTIC AMOUNTS AND MARKETS

Amounts

Plastics are broadly classified by their polymer structure as either thermoplastic or thermoset resins. Thermoplastics are commonly recycled because they can be melted and reformed, whereas the cross-linked polymers of thermoset resins cannot.

In the late 1980s, the Society of the Plastics Industry (SPI) voluntarily devised and implemented a system of seven codes (Figure B-1) to facilitate the identification and separation of common thermoplastic resins used in packaging applications (SPI, 1988). The symbols usually appear on the bottoms of containers and other disposable plastic items. Most postconsumer recycling programs focus their efforts on reclaiming categories one through six.

Table B-5 lists the various plastic goods recycled in 1988 and their contributions to recycling of plastics in general. At present, containers made from polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are the postconsumer plastics recycled in significant quantities. Both resins are recycled at higher rates because of their frequent use in packaging. PET is used to manufacture carbonated beverage containers, 21 percent of which were recycled in 1988. The high recycling rate is attributable to high collection levels in states with bottle-bill legislation. HDPE is used in base cups for PET bottles and milk and bottled water containers. HDPE is easily recyclable and is considered a resin of choice for numerous applications.



1. Polyethylene terephthalate
2. High-density polyethylene
3. Vinyl
4. Low-density polyethylene
5. Polypropylene
6. Polystryene
7. Other, including multilayer

FIGURE B-1

Society of the Plastics Industry Coding System for Plastic Resins

TABLE B-5

Generation and Recycling of Plastics in MSW, 1988

Product category	Weight generated (in millions of tons)	Weight recovered (in millions of tons)	Percent recycled	Discards (in millions of tons)
Durable goods[a]	4.1	<0.1	1.5	4.1
Nondurable goods				
Plastic plates and cups	0.4	0		0
Clothing and footwear	0.2	0		0
Disposable diapers[b]	0.3	0		0
Other Misc. nondurables	3.8	0		0
Total plastics nondurable goods	4.7			4.7
Containers and packaging				
Soft drink bottles	0.4	0.1	25.0	0.3
Milk bottles	0.4	Negligible	<1.0	0.4
Other containers	1.7	Negligible	Negligible	1.7
Bags and sacks	0.8	Negligible	Negligible	0.8
Wraps	1.1	Negligible	Negligible	1.1
Other plastic packaging	1.2	Negligible	Negligible	1.2
Total plastics containers and packaging	5.6	0.1	1.7	5.5
Total plastics	14.4	0.2	1.3	14.3

[a] Appliances, toys, furniture, etc.
[b] Does not include nonplastic materials in diapers.

Source: Franklin Associates, Ltd., 1990.

Limitations of collection and sorting systems and other factors have hindered reclamation of the other coded resins, which include low-density polyethylene (LDPE), vinyl (V), polypropylene (PP), polystyrene (PS), and others. These resins appear in a range of products from building materials and luggage to egg cartons and garbage bags. In 1990, these resins together represented more than 34 billion pounds of potentially recyclable plastics, 8.9 billion pounds of which were used in packaging (Modern Plastics, 1991).

Markets

In a study of recycled plastics markets (Bennett, 1989), the Center for Plastics Recycling Research (CPRR) indicated that current PET markets include the following:

- Civil engineering--geotextiles and urethane foam
- Recreational--skis, surfboards, and sailboat hulls
- Industrial--carpeting, fence posts, fiberfill, fuel pellets, industrial paints, strapping, unsaturated polyester, and paint brushes

Based on the CPRR report, current HDPE markets exist in the following areas:

- Agriculture--drain pipes and pig and calf pens
- Marine engineering--boat piers (lumber)
- Civil engineering--building products, curb stops, pipe, signs, and traffic-barrier cones
- Recreational--toys and golf bag liners
- Gardening--flower pots, garden furniture, and lumber
- Industrial--drums and pails, kitchen drainboards, matting, milk-bottle carriers, pallets, soft-drink base cups, and trash cans

In addition to evaluating the markets for PET and HDPE, CPRR evaluated the potential markets for mixed plastics, that is, recycled plastic consisting of several resin types. Six potentially significant markets were identified:

- Treated lumber
- Landscape timbers
- Horse fencing
- Farm pens for poultry, pigs, and calves
- Roadside pots
- Pallets

Although the diversity of potential plastics markets appears great, the development of these markets is not occurring fast enough, creating an oversupply of recycled plastics. Industry representatives indicate that curbside collection programs create a steady supply of recycled resins regardless of the ability of end-users to utilize the material (Misner, 1991). Export of recycled plastics may assist in absorbing the oversupply (Goldberg, 1990).

STEEL AND TIN VOLUMES AND MARKETS

Amounts

The broad category of ferrous metal scrap consists of all alloyed or unalloyed ferrous materials containing iron or steel as the principal component (Schottman, 1985). In the model that Franklin Associates, Ltd. (1990) used to calculate MSW ferrous metal scrap generation and recovery rates, only durable goods (e.g., white goods, furniture, tires) and steel containers and packaging are considered. Durable goods are usually collected separately from common recyclables and sent to automobile processing facilities for shredding (U.S. EPA, 1989). This report excludes durable goods and focuses instead on food and beverage containers.

In addition to iron and steel, tin can be a significant component of ferrous scrap. The main source of tin in MSW is the tinplate that is used for steel food and beverage containers. Excluding white goods and other durables, tinplated steel cans constitute the largest single source of ferrous metal scrap (approximately 60 percent) recovered from MSW (personal communication between TRC Environmental Corporation and Gregory L. Crawford of the Steel Can Recycling Institute on August 13, 1991). The remaining 40 percent falls into a category called other ferrous scrap, which may include a number of discarded items such as old, broken, or worn out toys, tools, and automobile parts.

According to Franklin Associates, Ltd. (1990), approximately 11.6 million tons of ferrous metals in MSW (including durable goods as well as steel containers and packaging) were generated in 1988, of which an estimated 400,000 tons was recovered from steel containers and packaging (Table B-6) (Franklin Associates, Ltd., 1990). This figure indicates a recycling rate of 13.8 percent for steel containers and packaging. The Steel Can Recycling Institute (Heenan, 1991) reported that the steel-can recycling rate for 1990 had increased to 24.6 percent.

Markets

In general, ferrous metals markets are the most established of all recyclable markets. Ferrous metals have been recycled for more than 50 years into a variety of products. Most steel industry experts expect the domestic market for recycled steel cans to be consistent because of continued growth in the scrap-consuming minimill sector of the steel industry (Goldberg, 1990). It is expected that this growth will accommodate anticipated increases in the amount of steel cans collected from MSW.

TABLE B-6

Generation and Recycling of Ferrous Metal in MSW, 1988[a]

Product category	Weight generated (in million of tons)	Weight recovered (in million of tons)	Percent recovered	Discards (in million of tons)
Durable goods				
Ferrous metals[b]	8.8	0.3	3.4	8.5
Containers and packaging steel				
Beer and soft drink cans	0.1	Negligible	Negligible	0.1
Food and other cans	2.5	0.4	16.0	2.1
Other steel packaging	0.2	Negligible	Negligible	0.2
Total containers and packaging steel	2.8	0.4	16.0	2.4
Total ferrous metals	11.6	0.7	6.0	10.9

[a]Numbers may not add to totals because of rounding.
[b]Ferrous metals in appliances, furniture, tires, and miscellaneous durables.

Source: Franklin Associates, Ltd., 1990.

APPENDIX C

FEDERAL, STATE, AND MUNICIPAL INVOLVEMENT

FEDERAL INVOLVEMENT

In response to the 1976 passage of the Resource Conservation and Recovery Act (RCRA), EPA developed guidelines that outline requirements and recommendations for the recycling activities of Federal agencies, state and local governments, and the private sector.

Throughout the 1980s, EPA made several proposals to encourage the establishment of recycling programs. In February 1988, EPA created the Municipal Solid Waste Task Force to specifically address MSW problems and, 1 year later, presented its suggestions in a final report titled *The Solid Waste Dilemma: An Agenda for Action*. The task force recommendations are summarized in the concept of "integrated waste management." This concept encourages recycling as the preferred waste management option, second only to source reduction. EPA, therefore, established a national goal of 25 percent source reduction and recycling by 1992. The guidelines EPA set forth to achieve this goal include the following:

- Stimulation of markets for secondary materials
- Enhancement of separation, collection, and processing of recyclables
- Establishment of a national recycling council
- A review of the incentives and disincentives of liability potentially affecting recycling industries

The report suggested that all levels of government and the private sector participate in establishing these guidelines to achieve the 25 percent source reduction and recycling goal (U.S. EPA, 1989).

Aside from EPA, other Federal agencies also have begun to address recycling issues. The U.S. Food and Drug Administration continues to evaluate the use of recycled plastic in food packaging materials.

STATE INVOLVEMENT

Because RCRA placed the responsibility for MSW management on state governments, the majority of laws passed in the United States regarding recycling have occurred on the state level. An annual nationwide survey conducted by the journal *Biocycle* indicates that the first state law to have a significant effect on recycling efforts was Oregon's "Opportunity to Recycle " Act of 1983 (Glenn and Riggle, 1991). This law banned many recyclables from landfills and incinerators and required municipalities to provide recycling services. Connecticut, Rhode Island, and New Jersey passed similar legislation several years later. In addition to the requirements mentioned above, Rhode Island and New Jersey mandated citizen and business participation. State recycling laws proliferated between 1987 and 1989, with 22 states enacting comprehensive recycling laws (National Solid Waste Management Association [NSWMA], 1989). NSWMA defines a comprehensive recycling law as one providing a framework for statewide recycling and mandating local government and citizen participation in some cases.

In 1990, new recycling legislation focused less directly on recycling and more on waste reduction goals. Requirements of various laws can be separated into three categories. The first type requires local governments to pass ordinances mandating citizens and businesses to source separate and recycle. Connecticut joined the District of Columbia, New Jersey, New York, Pennsylvania, and Rhode Island in enacting this type of law. The second type of legislation requires municipalities to provide recycling programs without making participation mandatory. Arizona was the only state to pass such legislation in 1990, joining nine other states that already had such laws. The third type, which is generally combined with one of the first two types, requires municipalities to reach a specified waste reduction goal. Alabama, California, Maryland, Minnesota, North

Carolina, Vermont, and Virginia added this type of legislation to mandatory source separation ordinances. New Jersey and Rhode Island added goals to mandatory participation requirements. Florida, Georgia, Illinois, Iowa, Louisiana, and Ohio passed waste reduction goals alone (Glenn and Riggle, 1991). Table C-1 lists state recycling goals as well as whether the states have made these goals mandatory and the deadlines for meeting goals.

Land disposal bans are another method states use to encourage recycling of MSW. In 1990, only Massachusetts and Wisconsin passed land disposal bans on traditional constituents of MSW. Connecticut removed disposal bans in favor of mandating recycling of the once-banned items.

Aside from mandating the establishment of recycling programs, many states encourage recycling by financing market development. Four types of financial incentives exist: tax credits, low-interest loans, grants, and tax exemptions. As the promulgation of new recycling legislation waned in 1990, so did the enactment of financial incentives for market development. Virginia was the only state to enact a tax credit program in 1990, joining California, Colorado, Maryland, New Jersey, North Carolina, and Oregon. Low-interest loan provisions were enacted in California and Wisconsin, bringing the total number of states with such provisions to 11. As of 1990, 10 states have grant provisions with Virginia and Wisconsin being the most recent additions. In total, 19 states provide some type of financial incentive for market development (Glenn and Riggle, 1991).

Another way in which states can encourage market development is to establish procurement guidelines for the purchase of products made with some fraction of recycled feedstock. By the end of 1990, 34 states had procurement legislation enacted and another 3 had executive orders passed.

A dilemma shared by many states following enactment of recycling legislation is finding the funding to support budgets for the various programs. In states that depend on general tax revenues, the current recession has made implementation difficult. Fifteen states have some form of disposal tax or

TABLE C-1

State Recycling Goals

State	Recycling goal[a]	Mandate	Deadline
Alabama	NS	Yes	1991
California	NS	Yes	2000
Connecticut	25%		1991
District of Columbia	45%	Yes	1994
Florida	30%[b]	Yes	1995
Georgia	NS	Yes	1996
Illinois	25%	Yes	2000
Indiana	50%[b]	Yes	2000
Iowa	50%	Yes	2000
Louisiana	NS	Yes	1992
Maine	50%	No	1994
Maryland	15-20%	Yes	1994
Massachusetts	25%	Yes	2000
Michigan	20-30%	No	2005
Minnesota	25-35%	Yes	1993
Mississippi	NS	Yes	1996
Missouri	NS	Yes	1998
New Hampshire	NS	Yes	2000
New Jersey	25%	Yes	1990
New Mexico	NS	Yes	2000
New York	40-42%	No	2000
North Carolina	NS	Yes	1993
Ohio	25%	Yes	1994

TABLE C-1 (continued)			
State	Recycling goal[a]	Mandate	Deadline
Pennsylvania	25%	Yes	1997
Rhode Island	15%	Yes	1993
Vermont	NS	No	2000
Virginia	25%	Yes	1995
Washington	NS	Yes	1995

[a]Includes yard waste composting (except for New Jersey).
[b]Includes source reduction.
NS = Not specified.

Source: Glenn and Riggle, 1991.

collection fee in place to fund programs. New Mexico enacted a 0.12 percent tax on business gross receipts in 1990 to fund its recycling program.

MUNICIPAL INVOLVEMENT

The success of state recycling programs requires that municipalities take an active role in researching, planning, and implementing programs that meet their specific community and regional needs. Municipalities in turn look to state agencies for information and funding and to recycling organizations for information and support.

The increase in municipal recycling programs nationwide is reflected in the growth of state recycling organizations, which have experienced more than a 50 percent increase in membership in the last 3 years (Apotheker, 1992). These organizations comprise individuals, businesses, nonprofit groups, and governments. Their efforts concentrate on disseminating information on recycling issues to their membership and the public. The newly formed Southern States Recycling Coalition, which represents individuals from 16 states and Puerto Rico, has established objectives that include seeking to develop, stimulate, and stabilize markets for recyclables and to promote effective recycling methods (Ramay, 1992).

To better characterize local programs, the Municipal Waste Management Association, an affiliate of the U.S. Conference of Mayors, conducted a survey of the 163 cities applying for the Heinz National Recycling Awards Program (U.S. Conference of Mayors, 1991). Although all 163 cities have recycling programs, more than 80 percent responded that landfilling and energy recovery through combustion were still their predominant methods of solid waste disposal. Sixty-nine percent of the cities landfilled more than 50 percent of their MSW, whereas 2 percent of the cities reported combusting for energy recovery more than 50 percent of their MSW. Of the 163 cities, 104 reported marked increases in the cost of traditional MSW disposal methods. The survey noted the correlation between increased disposal costs and an increase in the number of recycling programs; more than 65 percent of the responding cities started their programs within the last 3 years.

The survey also gathered information on the types of recycling programs implemented and the key recycling issues facing cities in the next 5 years. For residential customers, 87 percent of the cities operate curbside collection systems, 68 percent operate drop-off facilities, and 27 percent operate buy-back centers. Many cities offer more than one type of program and offer services to multifamily dwellings. The key issues facing cities, in descending order of importance follow:

- Market development and stability for recyclables
- Cost and funding of programs
- Development of waste reduction
- Public education
- Establishing local ordinances and requirements
- Enforcement of recycling ordinances
- Purchasing recycled products
- Increased public participation
- Improved technology

APPENDIX D

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