PROCESSING OF SOLID WASTE FOR MATERIAL RECOVERY

GEORGE M. SAVAGE AND LUIS F. DIAZ
Cal Recovery Systems, Inc.
Richmond, California

ABSTRACT

Various equipment and processing technologies are available for processing mixed and source-separated solid waste feedstocks for the recovery of secondary materials. The selection of the appropriate equipment and the incorporation of the equipment into a viable processing system is a function of the characteristics of the feedstock and the specifications for the recovered products, among other considerations. The state of the art of available waste processing equipment, as well as the design of systems to process mixed municipal waste, yard waste, commingled recyclables, and segregated recyclables, is discussed.

INTRODUCTION

The design of material recovery facilities (MRFs), or intermediate processing centers (IPCs), and refuse-derived fuel (RDF) plants is contingent on several key fundamental considerations. The key considerations are throughput capacity, composition of the feedstocks, product specifications, and available equipment. Throughput capacity affects, among other things, the sizing of equipment, the tipping floor, and product storage areas. The composition of the feedstocks (in the broadest, simplest form, whether the recyclable categories are commingled, segregated, or remain mixed with municipal solid waste) and the product specifications influence the separation and processing configurations that are employed. Subsequent to identification of the processing configurations and processing throughput specification, selection of equipment is required.

The mechanical processes employed in handling municipal solid waste (MSW), or fractions therefrom, and in extracting and conditioning its various reusable components are influenced by a number of considerations:

(a) The type of waste-to-energy system, if any, under consideration.

(b) The area available and dedicated to landfill, which may determine the allowable quantity and type of system residue

(c) The capital and operating costs associated with material handling of MSW, along with extracting and conditioning the reusable components.

(d) The requirement for redundancy in the event that one or more pieces of equipment experiences planned or unplanned downtime and the effect upon overall plant availability.

FUNDAMENTAL DESIGN CRITERIA

The foundation of the process design is an accurate knowledge of the character of the solid waste feedstock and the specifications for the recovered products. Both requirements should be the subject of detailed analyses. The breadth of potentially recyclable secondary materials, at this writing, requires an equally broad characterization of the components of the waste stream. An example illustration of the detail required for waste characterization is shown in Table 1. The characterization should be conducted seasonally to provide an accurate feedstock composition.

The specifications for the recovered products should be acquired from potential users or markets. Written confirmation of specifications should be required early in the planning of a resource recovery project inasmuch as the product specifications are key determinants of equipment selection.

Specifications vary from location to location and furthermore from user to user within a given secondary material category (such as aluminum cans). The situation is illustrated in Tables 2-1 through 2-4 for a variety of recyclable categories.

The designer must be aware of the types and quantities of waste feedstocks as well as their composition. For example, post-consumer waste can be source-separated or collected as mixed waste. Either or both types of waste can serve as the feedstock to a material processing facility. Furthermore, the different types of waste typically are collected and deposited at the facility by vehicles of different design. Consequently, the facility design must accommodate the type of feedstock and the method of delivery. A typical material balance for a facility to process mixed waste as well as source separated recyclables is shown in Table 3.

MECHANICAL PROCESSING EQUIPMENT

The extraction of recyclable components from MSW is usually accomplished through the utilization of one or more of the following processes:

(a) size-reduction
(b) air classification
(c) screening
(d) magnetic separation
(e) aluminum and glass separation
(f) densification

Ancillary equipment used in material recovery facilities includes:

(a) conveyors
(b) storage and retrieval bins
(c) cyclone separators
(d) explosion and fire control systems
(e) dust control system
(f) electrical equipment and controls

TABLE 1 EXAMPLE OF WASTE COMPOSITION BREAKDOWN REQUIRED FOR THE DESIGN OF MATERIAL RECOVERY PROJECTS

Component	Average Composition Wt.		%
Organics			80.8
Paper			
OCC/Kraft-Recyclable	14.9		
OCC/Kraft-Contaminated	6.2		
Newsprint	2.8		
High Grade	12.5		
Magazines	0.6		
Mixed Paper	9.1		
Other Paper	10.1		
		56.2	
Plastic			
Film	6.0		
HDPE	1.6		
PET	0.4		
Polystyrene Foam	0.5		
Other Plastic	0.5		
		9.0	
Yard Waste			
Firewood	0.0		
Other Plant Matter	0.0		
		0.0	
Wood	8.3	8.3	
Food	3.0	3.0	
Textiles	0.5	0.5	
Other Organics	3.8	3.8	
Inorganics			15.1
Metals			
Steel Food Cans	1.0		
Other Ferrous	7.9		
Aluminum Cans	0.5		
Other Aluminum	0.1		
Other Metals	0.1		
		9.6	
Glass			
Redeemable Glass	4.8		
Wine and Liquor	0.5		
Other Container Glass	0.0		
Other Glass	0.0		
		5.3	
Soil	0.0	0.0	
Other Organics	0.2	0.2	
Special Wastes			4.1
Appliances	0.5	0.5	
Chemicals	2.5	2.5	
Reusable	1.1	1.1	
TOTAL	100.0	100.0	100.0

Table 4 lists most major unit processing equipment categories that have been incorporated in the mechanical processing facilities implemented to date.

Brief descriptions of solid waste processing equipment are given in the subsequent text. Substantially greater discussion of processing equipment and its operation and performance can be found in Refs. [1–5].

Size Reduction/Shredders

Size reduction is an essential step in most centralized mixed waste processing operations. The reduction in

TABLE 2-1 EXAMPLES OF SPECIFICATIONS FOR PLASTICS

Material	Specifications
HDPE	Baled (bale size is flexible); ≤ 1% contamination
	Granulated; ≤ 3/8" (.95 cm) size
HDPE	Baled; 700-800 lb (318-363 kg)/bale (caps removed)
	Granulated (caps removed)
LDPE	Allow 3% contamination level; aluminum caps and labels acceptable
LDPE	Baled (prefer maximum density)
PET	Baled; 3' x 4' x 5' (.9 m x 1.2 m x 1.5 m) and 10 lb (160 kg/m^3)/cu ft; paper labels, caps, base cup acceptable: Clear bottles; Green bottles; Mixed ≤ 15% green; Mixed ≤ 25% green; Mixed ≤ 35% green
Mixed (HDPE and PET)	Baled must contain at least 25% by weight HDPE. Ratio of PET must be at least 75% clear and maximum of 25% green

TABLE 2-2 EXAMPLES OF SPECIFICATIONS FOR GLASS

Material	Specifications
Glass - Clear, Brown, Green	Whole or ≥ 1/4" (6 mm); three color sorted; bottle rings, bottle caps, and labels acceptable; no pane glass
Glass - Clear, Brown, Green	Whole or ≥ 1/4" (6 mm); three color sorted; bottle rings and labels acceptable; 50% caps removed; no pane glass

TABLE 2-3 EXAMPLES OF SPECIFICATIONS FOR METALS

Material	Specifications
Aluminum cans	Densified; density-flexible; size about 12" x 12" x 12" (.3 m x .3 m x .3 m)
	Loose/flattened
Aluminum cans	Densified bale; 64" x 44" x 52" (1.6 m x 1.1 m x 1.3 m); ≤ 3% contamination (moisture, dirt, plastic, metal)
	Densified biscuits; 8" x 10" x 13.25" (.20 m x .25 m x .34 m); ≤ 3% contamination (moisture, dirt, plastic, metal)
Tin-plated steel cans	Baled; maximum density of 40 lb/ft^3 (640 kg/m^3), 42" x 44" x 52" (1.06 m x 1.1 m x 1.32 m); ≤ 3% contamination
Tin-plated steel cans	Baled; maximum density of 30 lb/ft^3 (480 kg/m^3); label removed; one end removed or opened; ≤5% aluminum by weight

TABLE 2-4 EXAMPLES OF SPECIFICATIONS FOR PAPER

Material	Specifications
Corrugated	Mill size bales; ≥ 60" (1.5 m) length and density ≥ 600 lb (270 kg)/bale; ≤ 10% moisture content; 0% metals and plastic; ≤ 3% non-corrugated paper
	Loose; ≤ 10% moisture; 0% metals and plastic; ≤ 3% non-corrugated paper
Newsprint	Baled, all non-newsprint items (such as inserts) removed

size enhances ease of handling, and renders the dimensions of bulky items compatible with those of the processing equipment. Size reduction brings about a degree of uniformity (a requirement of most mechanical sorting systems) in terms of the maximum particle size of the diverse components of the incoming waste stream.

Size-reduction equipment used in solid waste processing includes hammermills, shear shredders, flail mills, and crushers. Descriptions of solid waste size-reduction equipment and their operating characteristics are provided in a number of Refs. [1–4, 6–8].

In the course of size reduction, shredder elements are subject to frequent rebuilding and replacement due to the tough and abrasive nature of the materials normally found in solid waste. Components of the size-reduction device that are subjected to the extensive and intensive wear and tear are the hammers (or cutters) and the grate bars, if any. This is to be expected because these components come into direct and continuous contact with the throughput wastes.

TABLE 3 INPUT MATERIAL BALANCE FOR A MATERIAL PROCESSING FACILITY (TONS[a] PER YEAR)

	Mixed Solid Waste			Source-Separated Recyclables		
Component	Front Loader	Roll-off	Total	Resi-dential	Com-mercial	Total
Newsprint	513	491	1,004	1,295	30	1,325
Corrugated	2,552	2,044	4,596	156	1,037	1,193
High Grade	2,027	777	2,804		13	13
Other Paper	1,026	1,186	2,212			
TOTAL PAPER	6,118	4,498	10,616	1,451	1,080	2,531
HDPE	117	66	183	134		134
PET	23	15	38	22		22
Films	385	278	663			
Other Plastics	326	645	971			
TOTAL PLASTICS	851	1,004	1,855	156	0	156
YARD WASTE	280	44	324			
FOOD WASTE	921	300	1,221			
WOOD WASTE	1,095	542	1,637			
OTHER ORGANICS	769	308	1,077			
FERROUS	396	154	550	223		223
Aluminum Beverage	82	29	111	45	1	46
Other Aluminum	46	15	61		1	1
TOTAL ALUMINUM	128	44	172	45	2	47
BI-METAL BEVERAGE	93	37	130	45	1	46
Container Glass	326	147	473	580	102	682
Other Glass	47	29	76			
TOTAL GLASS	373	176	549	580	102	682
OTHER INORGANICS	629	220	849	33	49	82
TOTAL:	11,653	7,327	18,980	2,533	1,234	3,767

a) 1 Mg = 1.1 tons

TABLE 4 MECHANICAL EQUIPMENT USED IN MATERIAL PROCESSING FACILITIES

1. Size Reduction/Shredding
   a. Hammermills - vertical and horizontal shaft
   b. Shear shredder
   c. Rotary, guillotine and scissors-type shears
   d. Grinders - roller, disc-mill, ball mill
   e. Flail mill
   f. Wet pulper
   g. Knife mill
2. Air Classifiers
   a. Vertical
   b. Vibrating inclined
   c. Horizontal
   d. Inclined rotating drum
   e. Density separators (stoners, etc.)
   f. Air knife
3. Screens
   a. Trommel
   b. Vibrating
   c. Disc
4. Magnetic Separators
   a. Belt-type
   b. Drum-type
   c. Head pulley
5. Glass and Aluminum Separators
   a. Heavy media separation
   b. Eddy current separation
   c. Froth flotation units
   d. Optical sorting
   e. Hand sorting
6. Densifiers
   a. Pelletizers
   b. Briquetters
   c. Cubers
   d. Extruders
   e. Compactors
   f. Balers
      (1) Rectangular prism shapes
      (2) Flat cylindrical shapes
   g. Can flatteners
   h. Stationary compactor
7. Handling Equipment
   a. Front-end loaders
   b. Grapples
   c. Conveyors
   d. Forklifts

Coarse or primary size reduction, usually to a minimum particle size of about 4 in. (10 cm), is a feature of many mixed waste processing facilities. Secondary size reduction is introduced whenever a particle size significantly smaller than 4 in. (10 cm) is specified, as, for example, in the production of some forms of RDF, of waste wood fuel, and of glass cullet. In addition to RDF preparation, other applications in which size reduction may be involved are the recovery and processing of ferrous, aluminum, and glass scrap to meet user specifications.

Air Classification

Air classification finds its use in waste processing principally as a means of separating materials of different densities from processed solid waste streams. Lighter refuse components ("light fraction") are suspended in the air stream, while heavier ones ("heavy fraction") settle out of the stream.

In the air classification of shredded mixed waste, paper and plastic tend to be concentrated in the light fraction while metals and glass constitute the principal components of the heavy fraction. The quality of the magnetically recovered ferrous fraction, as discussed subsequently, can be substantially improved by removal of residual paper and plastic in an air classifier, or synonymously an air knife.

Air classification, in the form of an air knife, can be used to clean up the mixed nonferrous material generated by eddy current processing. The objectives of the cleanup are: *(a)* to remove the organic matter (largely textiles) that has accompanied the metals, principally through entrainment with the aluminum and other nonferrous material; and *(b)* to separate light aluminum from heavier aluminum castings, copper, bronze, etc.

Variables other than density also affect the process of material separation through air classification. Consequently, fine glass particles, by virtue of their high drag-to-weight ratio, may appear in the light fraction and flat, unshredded milk cartons may appear in the heavy fraction.

Air classifiers may be one of a number of designs that are listed in Table 4 (with the vertical type being most common) and require appurtenant dust collection, blower, separation, and conveying equipment.

Screening

Screens can be used in solid waste processing to achieve an efficient separation of refuse particles on the basis of differences in physical size in any two dimensions. Although several types of screens are manufactured, only three have been used for sizing particular fractions of processed and unprocessed municipal solid waste. The three types are the vibratory flat bed screen, the disk screen, and the trommel screen. The trommel screen is the most common and has been proven to be quite effective and efficient due to the mixing action inherent in the screen's design and operation.

When used to process raw mixed waste, the trommel screen: *(a)* removes a large percentage of inorganic materials such as stones and metals; *(b)* opens and tears containers and bags of waste; and *(c)* breaks and removes such friable materials as glass containers. When installed downstream of a shredder, a trommel screen is effective in segregating combustible materials from predominately noncombustible materials.

Disk screens are used to process size-reduced mixed wastes, primarily in RDF applications where they are effective in segregating combustible wastes from predominately noncombustible wastes. Disk screens have also seen use in wood waste processing wherein their function is one of product sizing.

Magnetic Separators

Magnetic separation is a relatively simple process used to recover the ferrous metal fraction from MSW or from commingled materials containing nonferrous recyclables.

Magnets may be either of the permanent or the electromagnetic type. They come in one or more of three configurations, namely, the drum, the magnetic head pulley, and the overhead magnetic belt. They may be assembled and suspended in line, crossbelt, or mounted as head pulleys in the material transfer conveyor. The magnetic head pulley-conveyor consists of a magnetic head pulley mounted in a conveyor. In its operation, the material to be sorted is passed over the pulley in such a manner that the nonferrous material will fall by gravity vertically onto the next conveying device while the ferrous is attracted by the head pulley and deflected to a separate area.

In the suspended-form configuration, the electromagnetic assembly usually is mounted stationary inside an outer rotating drum. The drum magnetic assembly can be installed for either overfeed or underfeed. The magnetic belt, in its simplest form, consists of single magnets mounted between two pulleys that support the conveyor belt mechanism.

The efficiency of magnetic metal recovery from shredded mixed waste, in terms of weight of magnetic metal recovered per unit weight of magnetic metal in the infeed stream, typically is about 80%. The efficiency of ferrous metals recovery from the heavy fraction of shredded mixed waste (i.e., separated through air classification) is generally on the order of 85–90%. Greater removal efficiencies can be achieved through the use of sequential magnetic separation processes and by careful design of the preparatory size-reduction process.

Ferrous scrap recovered from MSW by a magnetic separator placed directly downstream of primary size-reduction equipment is generally inferior in quality to that removed by a separator located farther downstream where more of the flexible particles (paper, plastic film, textiles) have been removed. The reason for the difference in quality is that paper, plastic, rags, and other contaminants that otherwise might cling to or be entrapped by the ferrous scrap or be carried over with the metal, are removed by screening and air classification. It is difficult, if not impossible, to market a ferrous fraction in which there is significant entrainment of paper, rags, plastic, etc.

Glass and Aluminum Separators

A number of technologically complex processes have been utilized or proposed for both aluminum and glass separation. For aluminum, eddy current separation, which causes aluminum to be ejected from the processed waste stream due to electromagnetic flux, is commercially feasible as of this writing. For glass, both froth flotation and optical electronic sorting have been used. Both aluminum and glass recovery processes are costly and complex.

Densifiers

Balers and stationary compactors have been effectively used as a means to minimize transportation costs for recovered products. Because of the relatively limited processing capability of commercial densifiers and the need to process input material to an exceedingly fine particle size, briquetters, pelletizers, and cubers appear impractical for all but small-scale densified RDF operations (less than 150 tons per day (135 Mg) of MSW).

MECHANICAL PROCESSING SYSTEMS

Mechanical processing systems can be broadly divided into material recovery facilities and refuse-derived fuel recovery facilities. Alternatively, both material and RDF recovery can be integrated into one facility. The selection of equipment and the design of a mechanical processing system should include the considerations discussed in the previous sections. The characteristics of the incoming waste stream and end product specifications substantially influence the system design.

Material recovery facilities are generally designed to handle the following types of feedstock materials:

(a) Presorted individual recyclable components.

(b) Presorted commingled waste components.

(c) Unsorted mixed special waste having a dominant recyclable material (such as corrugated).

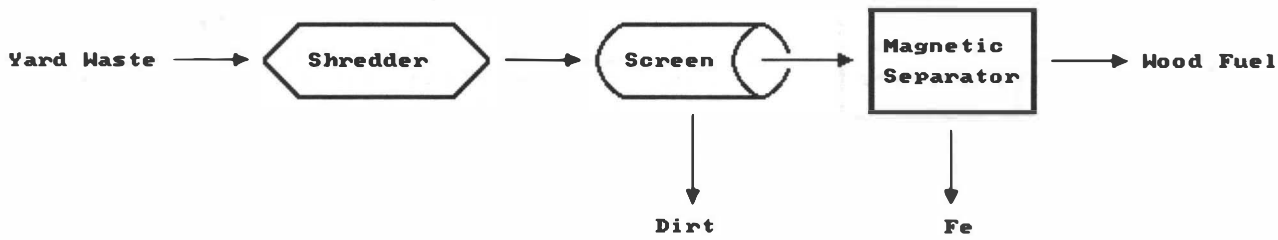

FIG. 1 WOOD AND YARD WASTE PROCESSING

Examples of each of these feedstocks are described below:

*(a)*Individual components such as:

(1) paper
(2) aluminum cans
(3) glass bottles
(4) yard waste

(b) Commingled components such as:

(1) paper and plastic
(2) glass and metal containers
(3) steel and aluminum containers

(c) Mixed special waste such as:

(1) Commercial mixed waste (predominantly corrugated).

RDF recovery facilities process mixed municipal solid waste.

A few examples of mechanical processing operations are described below:

Example I — Wood and Yard Waste

Wood and yard waste (with potential dirt and ferrous contamination) delivered to the MRF is processed in the following steps, as shown in Fig. 1:

(a) Shredder—For size reduction so that the material can be more readily handled and meet the maximum particle size specification.

(b) Screen—To remove dirt and other inorganic matter from the fuel stream

(c) Magnetic separation—To separate ferrous contamination from the fuel stream.

Example II — Commingled Beverage Cans Processing

Source separated, commingled aluminum, and tin cans delivered to the MRF are processed in the following steps, as illustrated in Fig. 2:

(a) Magnetic Separation—To extract the ferrous material from the aluminum cans.

(b) Can Flattener (tin)—To flatten the tin cans for minimum volume.

(c) Can Flattener (aluminum)—To flatten the aluminum cans for minimum volume.

Example III — Commercial Mixed Waste Processing

Commercial mixed waste, predominately corrugated, delivered to the MRF is processed in the following steps, as illustrated in Fig. 3:

(a) Trommel Screen—Which separates the waste stream by particle size. A proper screen design will assure that virtually all of the glass will accompany the small fraction, while most of the corrugated will accompany the large fraction.

(b) Magnetic Separator—Both the oversize and undersize fractions from the screen are subjected to magnetic separation where the ferrous fraction is extracted.

(c) Manual Sorting—For the oversize fraction, manual sorting is used to separate the corrugated, newsprint, and plastic components. Depending upon the quantity, particularly of corrugated and newsprint, the end products may be baled. The material remaining after manual sorting may be suitable as RDF if it is combustible, or it becomes a process residue. For the undersize fraction to meet market specifications, sorting may also be used to remove other recyclables with the glass going through a crusher.

MIXED RESIDENTIAL WASTE PROCESSING

As an illustration of process system design, several of the aforementioned pieces of equipment can be integrated into a system that recovers ferrous materials, aluminum cans, glass containers, corrugated, plastics, as well as other product forms from a mixed residential solid waste stream. The system design is shown in Fig. 4. The recovery of secondary materials is accomplished

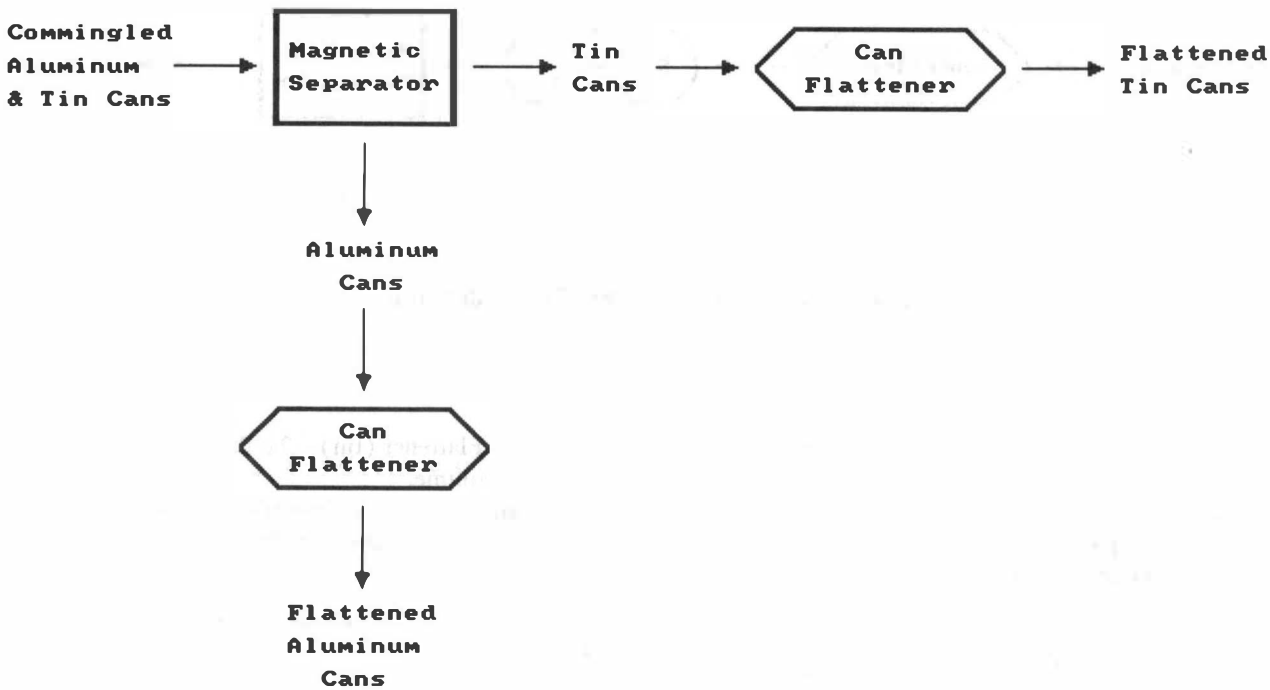

FIG. 2 COMMINGLED BEVERAGE CANS PROCESSING

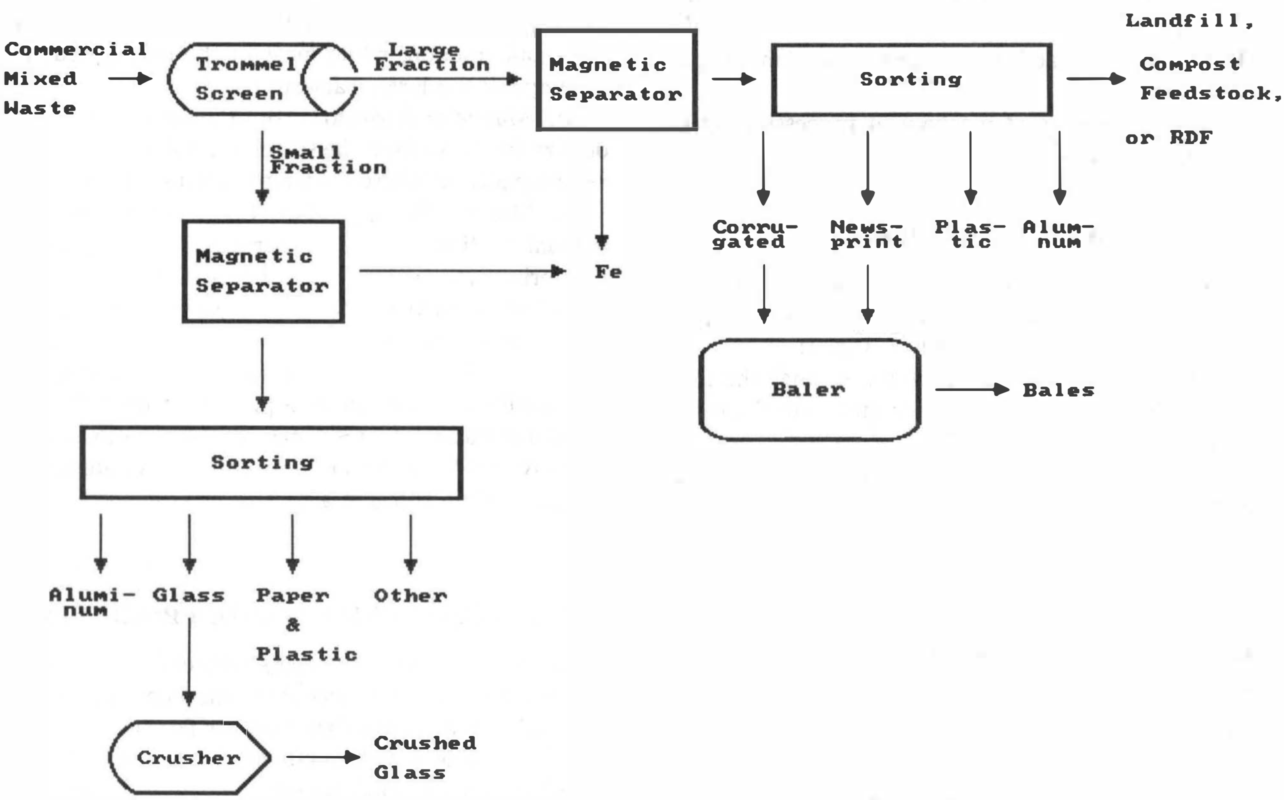

FIG. 3 COMMERCIAL MIXED WASTE PROCESSING

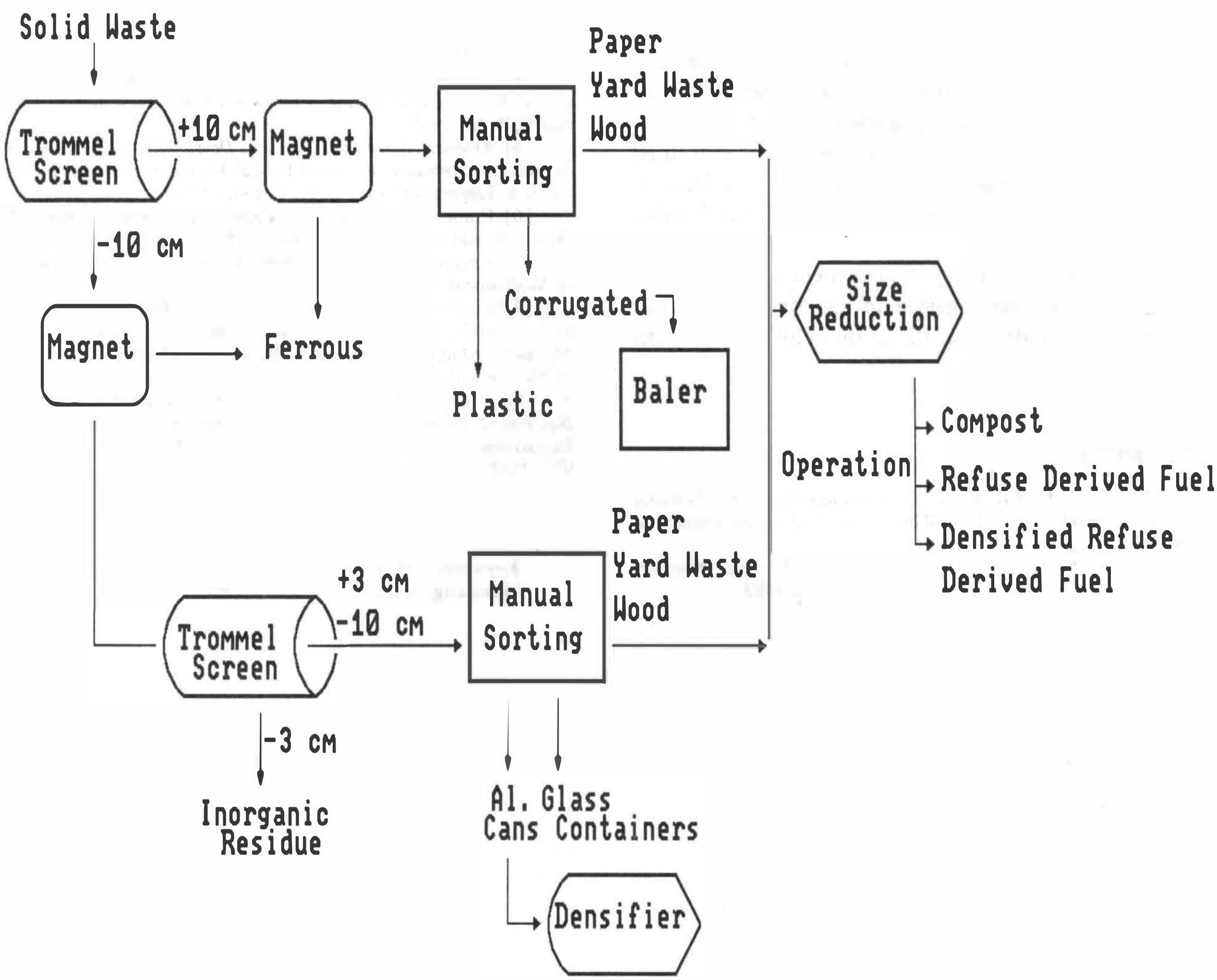

FIG. 4 INTEGRATION OF UNIT PROCESSES

in the left-hand area of the process flow. The separation is effected by taking advantage of the size of the materials as they are discarded in the waste stream and of the ferromagnetism of some of the waste materials. The size separations are accomplished using two trommel screens as shown, while ferrous materials are extracted using two magnetic separators. Manual sorting subsequently is used to recover a portion of the corrugated and plastic materials, aluminum cans, and glass containers. After removal of the above secondary materials, the resultant large-size waste fraction (that is, greater than about 4 in. (10 cm) is comprised primarily of paper, yard waste, wood, and other organic materials, As shown in the right-hand area of the process flow in Fig. 4, these materials can be further processed in other operations.

CONCLUSION

The unit processes described and discussed here require arrangement by system designers in a sequence that is conducive to the recovery of usable end products. The objective can be accomplished only if the processes and the equipment involved in the processes are well understood. Additionally, the designer must fully grasp the characteristics of the waste feedstock and the end product characteristics required by the users.

Other ancillary design considerations must be realized. For example, in the case of source separated feedstocks, it must be recognized that there will be some contamination of the recyclables with materials other than those specified. Some form of manual sorting at the waste processing facility is usually provided to handle this eventuality. As a second example, mechanical processing equipment may extract material other than that which was planned. Consequently, extraneous material may become entrapped or entrained with the desired separated material and may have to be manually removed in order to secure a marketable product.

The selection and sizing of equipment and the design of a material processing system can only be accomplished properly after consideration of all the pertinent criteria.

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Keywords: Materials Recovery; Recycling; Screening; Shredding; Trommel