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SPECIAL REPORT

The Cost To Recycle At a Materials Recovery Facility

It costs on average $50.30 to process a ton of recyclables at a materials recovery facility (MRF), before revenues from sales of the recyclables are counted. Given current markets, sales of most recycled materials to end users do not cover costs.

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NSWMA

With the growth of recycling in the U.S. over the past five to seven years, numerous materials recovery facilities (MRFs, pronounced "murfs") have been sited to process residential recyclables. These facilities, which are now found in all regions of the country, separate commingled recyclables (bottles and cans) and prepare them and several grades of paper for subsequent shipment to end-user markets. The number of MRFs has increased dramatically in recent years, from fewer than a dozen in the mid-1980s to more than 170 operating facilities and many more in various stages of planning. More than half of the operating facilities came on-line after 1990.

Because the growth in MRFs has been so rapid, little information exists on the costs of these facilities. The National Solid Wastes Management Association commissioned a study of MRFs for two purposes:

- to determine the average cost per ton to process residential recyclables at MRFs, along with the range of low and high costs; and
- to determine the costs per ton to process each individual recyclable material.

The study relies on data provided directly by 10 MRFs operating in several regions of the U.S. The data include capital costs, monthly operations costs, monthly weight records of materials received and processed, staffing information, space utilization estimates, and other relevant data.

ABOUT THIS STUDY

The National Solid Wastes Management Association commissioned Roy F. Weston Inc. to obtain detailed processing cost data from materials recovery facilities (MRFs). Target facilities processed 100–300 tons per day of recyclables (the average MRF processes 130–140 tpd) and had three consecutive months of cost data. Candidate facilities were selected from directories compiled by *Waste Age* magazine and Government Advisory Associates, New York City. Ten facilities supplied all of the cost data requested in a 68-page questionnaire. Weston visited each facility to confirm data and fill in gaps. Confidentiality was guaranteed.

Four of the 10 MRFs were located in the Northeast, three were in Florida, one was in the Midwest, and two were on the West Coast, a geographical pattern consistent with the universe of existing U.S. MRFs. Four facilities were partially or completely publicly owned. All were privately operated. Five of the 10 were sited at or near a solid waste landfill; the rest were in urban industrial districts. The facilities received, sorted and processed recyclables in a wide variety of ways, including different combinations of automated and hand-sorting systems.

Average costs to process a ton of recyclables at each MRF were determined by dividing total operations costs (including the amortized cost of capital, labor, supplies, maintenance and other costs) for the three months studied by the total tons processed during that period.

To determine average costs for individual recyclables, costs were assigned in a number of ways:

- directly for equipment or labor that was devoted exclusively to one material (for example, a baler used only for newspaper);
- on a pro-rated basis by material weight (for equipment such as conveyors and rolling stock, for example);
- on a time usage basis for equipment dedicated to different materials at different times (for example, a baler used 50 percent for newspaper and 50 percent for PET); and
- on a volume basis for buildings and land, since space requirements are the main consideration in sizing a facility.

The study looked only at processing costs and did not take into account recycling collection costs, revenues from the sale of recyclables, taxes, profit/loss calculations, or avoided costs of disposal.

Background on MRFs

A materials recovery facility usually accepts all or some portion of the municipal waste stream, and sorts and processes it into marketable commodities for remanufacturing. Most MRFs specialize in processing commingled residential recyclables, although the primary function of certain MRFs is to process recyclable waste paper from commercial generators. Recently, some MRFs that used to process only residential, commingled material have begun to accept limited quantities of recyclables from commercial sources. MRFs receive non-residential loads for several reasons:

- to increase total revenues;
- to use equipment and personnel to capacity (and thus lower operating costs); and
- to acquire new municipal contracts or to expand their private-sector customer base.

MRFs enhance residential recycling programs in several ways. If recyclables are sent to a MRF, rather than directly to an end user, the collection program can be simplified, requiring less sorting and processing by the generator or the collector. This simplification, in turn, can increase participation rates and decrease collection costs. A MRF also allows for accumulation of recyclables, which can increase leverage in the marketplace, since most end-user markets favor larger lot shipments. But perhaps the greatest benefit is that a MRF improves the marketability of the materials by processing them into a form more acceptable to markets. Often, materials collected from residents are not in the form desired by markets and may contain some contamination. Thus, without additional processing, either the material is unmarketable, or the price is low because the buyer has to clean up the material..

The technical complexity of MRFs varies widely. Some MRFs contain little more than a tipping floor, where wastes are dumped for sorting, and a baler, and use manual labor to do most of the sorting. At the other extreme, some MRFs are highly automated with a network of conveyers and mechanical sorting and processing equipment. Regardless of the degree of automation, all MRFs must employ manual labor to some extent for certain sorting or quality control functions. In other words, no completely automated MRF exists yet, and most facilities should rightly be classified as "semi-automated."

Status of Materials Recovery Facilities

Estimates vary, but according to the *1992–3 Materials Recovery and Recycling Yearbook* (Government Advisory Associates, New York City), 172 MRFs operate in the United States, processing 18,644 tons of recyclables per day for an average of 132 tons per day per MRF. Another 50 MRFs are expected to come on line in 1992 and 1993. The planned facilities will add a total of 10,608 tons per day of capacity. Facilities now in planning, design or construction stages have an average processing capacity of 212 tons per day. The general trend is toward larger MRFs.

Initially, most MRFs were developed in the Northeast. By 1991, only 41 percent were in the Northeast, while the rest were spread throughout the U.S.

According to the GAA Yearbook, approximately 65 percent of operating MRFs are highly manual ("low technology"), while 35 percent use more mechanical equipment ("high technology") for sorting and processing. These definitions are subjective, and most facilities actually employ a combination of mechanical and manual separation stages. Most MRFs operate one eight-hour shift per day, five days per week, 245 to 260 days per year.

One other trend in MRF development is a tendency toward private ownership and operation. Currently, the private sector owns approximately 73 percent of all MRFs and operates 82 percent. This percentage is increasing each year. Municipalities and local governments prefer private sector involvement for several reasons:

- Increasingly, private sector firms have the experience to design, build and operate an effective and reliable MRF.
- The private-sector firm represents a single source of responsibility/liability in case the MRF does not perform up to specifications. Many MRF designers will offer performance guarantees, which financially or otherwise ensure the regular and effective operation of their systems.
- Most major MRF operators can offer a "turnkey" package, wherein they will design, construct and operate the MRF for a fixed contract period. This reduces the amount of administration and contract management the public body must provide.
- Some private-sector firms are the only source of access to a proprietary technology; if the municipality wants that particular system, it must purchase it through the designer.

Materials Processed at MRFs

The primary mission of most MRFs is to process recyclables collected through residential curbside collection programs. MRFs also often receive residential materials from drop-off programs. The containers for these drop-off programs may be located at the MRF itself or at remote locations. Additionally, recyclables may be received from buyback centers, which pay residents for the materials they bring in. The buyback center may be located at the MRF or at some other location.

The major paper item processed at MRFs was historically and continues to be newspaper, although many now also receive one or several of the following: corrugated boxes (also called old corrugated containers or OCC), used telephone books, magazines and mixed waste paper (advertising mail, etc.). Because of changing technology in the newspaper end-user markets, much greater quantities of magazines are expected to be accepted at MRFs in future years. Mixed waste paper collection is more common on the West Coast because of this region's proximity to Far Eastern paper markets.

Non-paper, commingled recyclables accepted at MRFs normally consist of:

- aluminum and bimetal beverage containers (often called used beverage containers or UBC);
- tin-plated steel food cans;
- glass food and beverage containers (which normally occur in clear, green, and brown colors); and
- certain types of plastic bottles and containers. The most commonly received plastics (due to a higher market demand for them) are polyethylene terephthalate (PET) soda pop and water bottles and high-density polyethylene (HDPE) bottles, such as those used for milk, laundry detergent, and shampoo. Some facilities may also accept and process containers made from polyvinyl chloride (PVC), polystyrene (PS), or polypropylene (PP). Plastic bags are not usually accepted at MRFs unless the collection system(s) in the service area uses bags instead of rigid containers for material set-out.

Materials handled at MRFs also include non-recyclable items, commonly termed "rejects" and "process residues." Reject materials are those mistakenly set out or dropped off by the residents and not captured or removed by the collectors. On the other hand, process residues are materials that lose their marketability after traveling through the processing system, such as small particles of glass that are too difficult to effectively separate by color. Since much of a MRF's residue stream is mixed-color broken glass, facilities can improve their financial performance by recovering and marketing this material rather than paying for its disposal. MRFs in regions with high disposal fees will also often strive to recover and market the more unusual types of paper and plastics they receive. The distinction between process residues and rejects blurs at many MRFs because these materials are combined in the same refuse container for disposal at a landfill or incineration facility. Rejects are ideally removed at the tipping floor before the materials enter the processing system, but this is sometimes not possible.

Processing Systems and Equipment

Most MRFs have separate processing lines for paper and commingled container streams. Most paper processing systems are similar in design, relying on hand-sorting of the different grades, which are then baled. Commingled processing systems all achieve more or less the same function, but the equipment and configuration of the system varies widely from facility to facility.

MRF equipment can be classified into two categories: sorting equipment and processing equipment (Table 1). Sorting devices assist in the separation of the commingled recyclables, while processing equipment bales, crushes, granulates, screens or otherwise prepares the separated materials for shipment to markets. The types of processing equipment found in a MRF are, in part, a function of the delivery specifications of the MRF's markets and the distance from the MRF to its markets. For example, many end users prefer to receive material in loose condition so that they may more easily inspect it for reject materials that might act as contaminants in their remanufacturing operation. A MRF located close to a paper processing/shipment facility may ship its newspaper in loose form, whereas a MRF using a distant or overseas market will bale it to reduce transportation costs. A MRF may install more extensive processing equipment and thus have higher processing costs, but this may simultaneously allow it to secure markets that offer a higher price and consistent demand for the material. An example would be a MRF that installs a glass beneficiation system on the back end of its glass sorting line. Such a system accepts color-sorted or mixed glass, crushes it to a uniform particle size, and removes non-glass items via screening machines, air classifiers, and magnetic separators. A complete system normally represents a capital investment of several hundred thousand dollars.

One of the most critical (and usually most costly) pieces of equipment a MRF will contain is a baler. Most MRFs that process residential recyclables typically have one or two balers to process all separated recyclables (if two, one for paper materials and one for plastics and metals). But some designers choose to install a baler to process each type of plastic and metal, resulting in five or six balers inside the facility. This is obviously more costly, but it can increase the operational efficiency of the entire system because the balers do not have to be stopped and cleaned out after baling each type of material.

A process known as negative sorting is being used at more and more MRFs. In negative sorting, one material (usually the most abundant in the waste stream being processed) is allowed to remain on the sorting belt and travels off the end onto a conveyor or into a storage bunker or container. Only the less abundant materials are removed from the sorting belt. By not handling the most abundant

TABLE 1. MRF PROCESSING EQUIPMENT

Type of Equipment	Description	Purpose
Infeed Conveyors	Z-shaped moving conveyor belts, which usually start below floor level and elevate materials to a certain height above floor level. Usually of steel, apron-pan construction; may also be either chain-driven rubber belts or rubber slider belts.	Move mixed paper and non-paper material from tipping floor into process area, and deposit it onto sorting conveyors or into sorting equipment. Also used to feed sorted materials into the baler(s).
Sorting Conveyors	Horizontal moving rubber belts, of either slider or trough-pulley design. Usually mounted on elevated platforms, below which are storage bins, bunkers, or transfer conveyors.	Hand-sorters stand on one or both sides of the belt and pull specific materials, which are then dropped/tossed into storage bins or bunkers. Negatively-sorted materials are allowed to remain on the belt.
Transfer Conveyors	Moving rubber belts, of slider or trough-pulley design.	Transport loose, separated materials from the sorting area to processing equipment and processed materials from processing equipment to storage bunkers or trailers.
Baling Presses or "Balers"	Machines that compress loose material into dense rectangular blocks or "bales." Typical bale dimensions are 2.5 ft. × 4 ft. × 5 ft. long. The bale is formed by a moving pressure plate, mounted on a hydraulic cylinder or "ram," which packs the material together inside a closed chamber.	Densify recyclables for ease of handling and for more cost-effective shipping.
Magnetic Separator	Typically an electromagnet housed in a moving conveyor belt. The device is mounted above a conveyor carrying commingled recyclables. Ferrous metals, e.g., tin cans, are attracted by the magnet and shoveled onto a transfer conveyor by the moving belt.	Automatically remove ferrous metals from the commingled materials stream.
Eddy-current Separator	Consists of a short belt conveyor that surrounds the eddy current mechanism. The mechanism contains a rotor with rare earth magnets of alternating polarity. As the rotor spins, it creates a magnetic field, which induces eddy currents in non-ferrous metals passing over it. These currents in turn establish a repulsive magnetic force that hurls the metals off the belt at different trajectories than non-metallics. A splitter plate divides the two flows.	Automatically remove aluminum and non-ferrous metals from the commingled materials stream.
"Air Classifier" or "Air Knife"	Normally consists of a blower or suction fan and accompanying tubes and chutes. The air jet created by the blower or fan captures or diverts the lighter materials in the stream from the heavier ones.	Divide the commingled stream into "lights" (aluminum and plastics) and "heavies" (glass). Also may be used to extract paper labels during glass beneficiation processes (described on page 4).
Inclined Sorting Table	A proprietary device that consists of an inclined moving conveyor and a "curtain" of dangling chains that travels along the surface of the conveyor.	Used to separate the commingled stream into lights and heavies.
Trommel Screen	A cylindrical drum with holes of specific size that rotates about its central axis. "Undersize" material (material smaller in diameter than the holes) falls through the holes and is thus separated from "oversize" material.	Most often used to size-classify and remove caps from crushed glass after it is sorted. Also may be used to separate lights from heavies, although this application usually results in unacceptably high glass breakage.
Vibrating or Oscillating Screen	Flat plates, punched with holes, that are mechanically vibrated in one or two dimensions. A similar design is the "finger" screen, which instead of pierced plates employs parallel bars for the screening surface. Undersize materials fall through the holes or between the bars, while oversize material slides across the screening surface.	Separate mixed broken glass from the commingled stream. Also sometimes used to size-classify lights for easier sorting or eddy current separation.
Glass Crusher	Consists of a crushing chamber, with rotating hammers or drums. Many models are sold with attached transfer conveyors and magnetic head pulleys for removal of caps.	Increase density of sorted glass by breaking it into small pieces.
Can Flattener	Consists of one or two rotating drums or wheels mounted inside a crushing chamber. Most models come equipped with an attached blower and blow-tube, which shoot the crushed cans directly into a waiting trailer.	Densify aluminum and/or steel cans for more cost-effective shipping.
Can Densifier	Similar in principle to a baler, but produces small, dense blocks called "briquettes." The briquettes are bundled together with steel strapping prior to shipment.	Densify aluminum and/or steel cans for more cost-effective shipping.
Granulator	Machines which use rotating propeller-like blades to chop plastic bottles into small chips.	Densify plastic for more cost-effective shipping, and to prepare it for remanufacturing.
Plastic Bottle Perforator	A rotating drum upon which spikes are mounted. The spikes pierce the bottles in multiple locations, thus decreasing their resilience.	Make plastic bottles easier to bale. Especially effective on bottles whose caps have been screwed back on.

material, fewer sorters are required on the processing line. In the opposite process (positive sorting), all recyclables are pulled off the sorting belt by hand and deposited onto conveyors or into storage bunkers. Since sorting labor is usually one of the largest operating costs for a MRF, negative sorting often results in a much more cost-effective facility.

Personnel Requirement

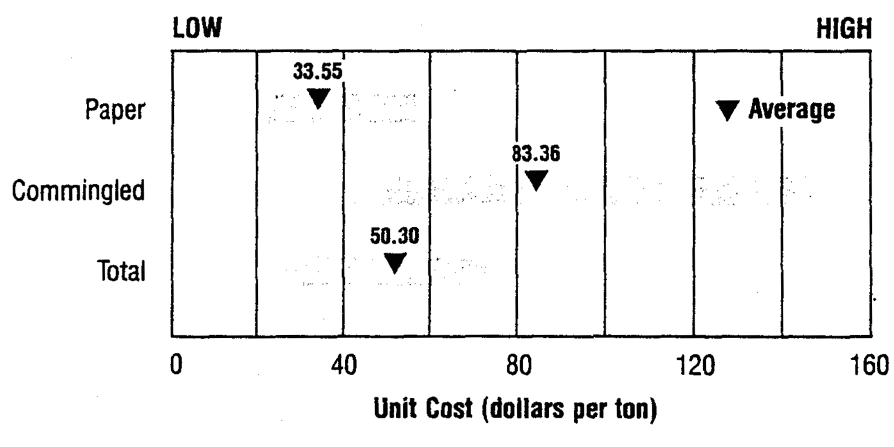
The number and classifications of jobs at MRFs can vary considerably. The total number of employees will depend largely on the throughput tonnage per shift and the degree of automation of the plant. However, there are certain positions (for example, plant manager, vehicle operator, maintenance technician) that must be filled for any MRF.

Findings

The study found the following:

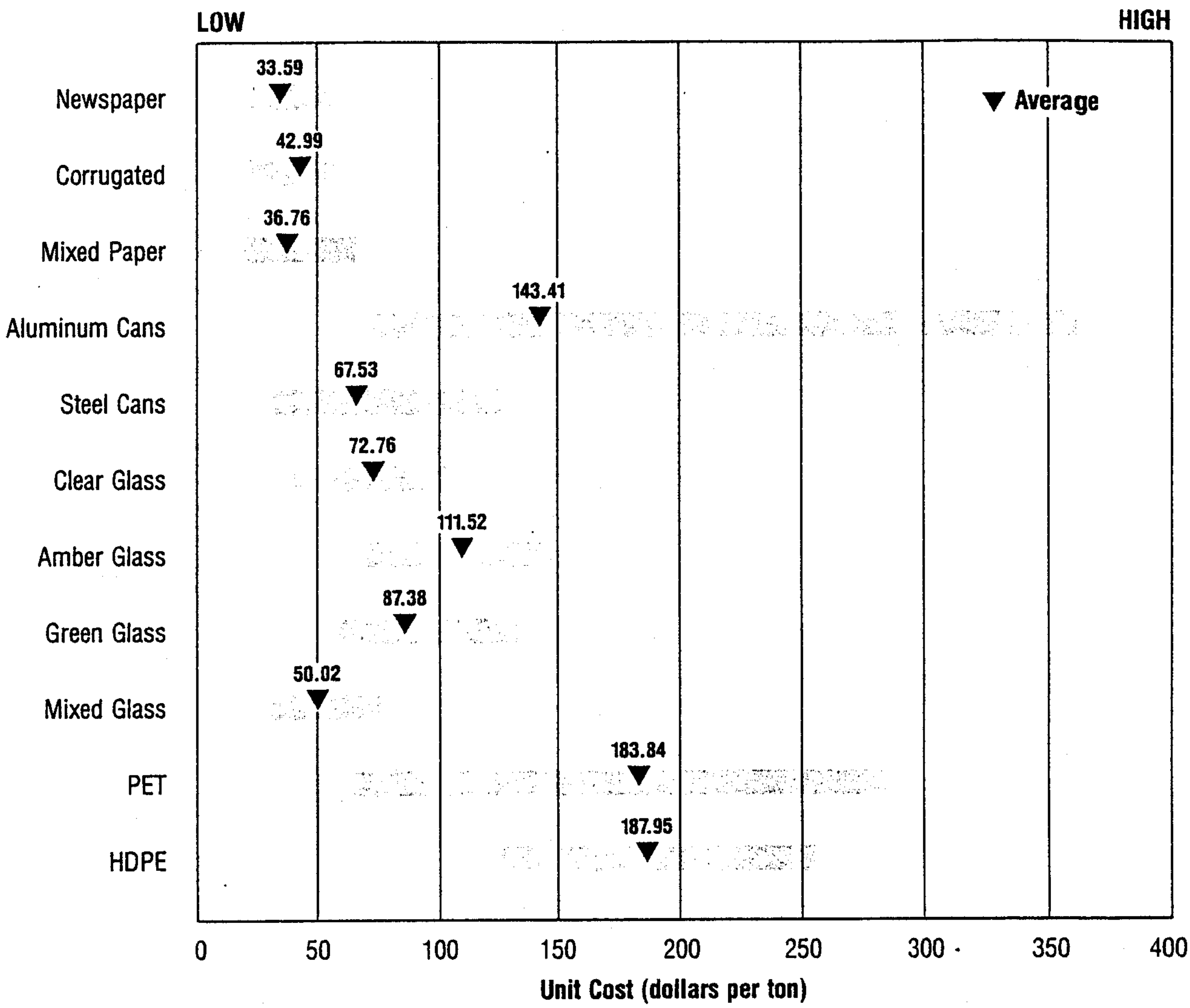
- The average cost to process recyclables at a MRF, before revenues from the sale of the recyclables are considered, is $50.30 per ton, with a range of costs from $28.11 to $72.06 per ton (Figure 1). The median cost (half the facilities are higher, half lower) is $48.54 per ton.
- Paper costs $33.55 per ton on average to process, considerably less than commingled recyclables, which cost $83.36 per ton on average.
- Commingled bottles and cans have a much greater range of processing costs, from $40.76 to $146.29 per ton (a difference of $106), than paper, which ranges from $20.43 to $55.93 per ton (a difference of $36).
- Newspaper is the least expensive recyclable to process, averaging $33.59 per ton (Figure 2). Mixed paper ($36.76 per ton) and corrugated boxes ($42.99 per ton) also have relatively low processing costs.
- Plastic is the most expensive of the typical recyclables to process, averaging $183.84 per ton for polyethylene terephthalate (PET) and $187.95 for high density polyethylene (HDPE).
- The costs of processing clear and mixed glass are generally lower than the costs of processing amber and green glass. For most MRFs, this is because clear and mixed glass are more abundant in the waste stream and typically are being removed through negative sorting (see definition, bottom of page 4) or mechanical means.
- Aluminum cans have the greatest range of costs, from $72.88 to $362.59 per ton (a difference of $290 per ton). Newspaper has the narrowest range of costs, from $19.94 to $55.33 per ton (a difference of about $35).
- For most of the recyclables—and for aluminum cans, green glass and all commingled recyclables in particular—one MRF with unusually high processing costs skews the average. Eliminating the high and low MRF processing costs for aluminum cans lowers the average processing cost from $143.41 to $124.83 per ton. An unusually high processing cost may be caused by low tonnages (due, for example, to the characteristics of the local waste stream) or to above-average labor costs.
- The average throughput, or tonnage processed, at the study MRFs is 162 tons per day. Paper accounts for approximately two-thirds of the throughput. Residue constitutes 4.5 percent. Commingled bottles and cans make up the rest.
- Worker productivity is greatest for paper, averaging 7.42 tons per employee per day (Figure 3). Metals account for the second-highest productivity, at 5.96 tons per employee per day,

FIGURE 1. MRF PROCESSING COSTS



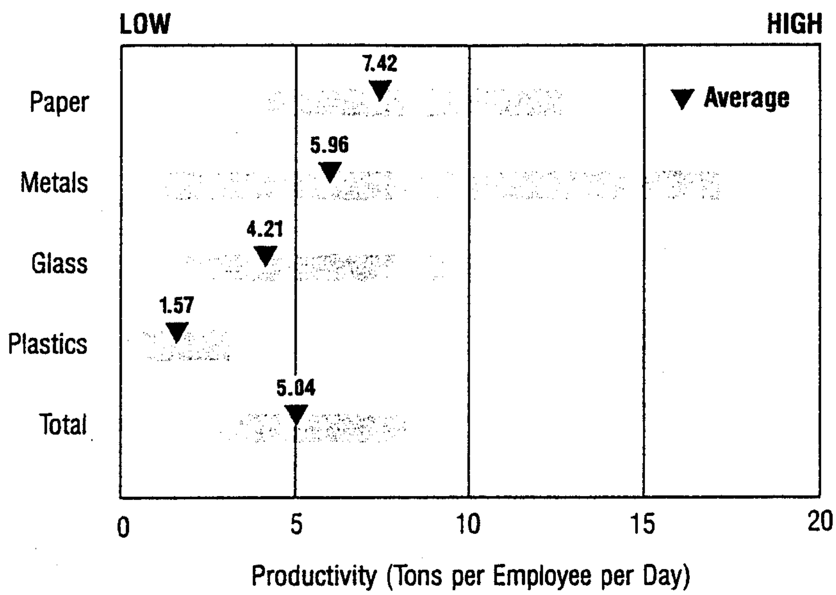
Material	Range	Average
Paper (all grades)	20.43– 55.93	33.55
Commingled Containers	40.76–146.29	83.36
Total Recyclables	28.11– 72.06	50.30

FIGURE 2. RECYCLABLES PROCESSING COSTS



Material	Range	Average
Newspaper	19.94– 55.33	33.59
Corrugated (OCC)	20.29– 56.26	42.99
Mixed Paper	16.82– 65.59	36.76
Aluminum Cans	72.88–362.59	143.41
Steel Cans	30.22–125.64	67.53
Clear Glass	37.17–105.62	72.76
Amber Glass	69.70–148.92	111.52
Green Glass	57.56–134.21	87.38
Mixed-Color Glass	28.51– 76.24	50.02
PET Plastic	64.43–295.35	183.84
HDPE Plastic	121.58–256.15	187.95

FIGURE 3. MRF EMPLOYEE PRODUCTIVITIES



Material	Range	Average
Paper (all grades)	4.29–12.85	7.42
Metals	1.19–17.25	5.96
Glass	1.59– 9.97	4.21
Plastics	0.59– 3.16	1.57
All Materials	2.65– 8.31	5.04

followed by glass (4.21 tons) and plastics (1.57 tons). The MRF average is 5.04 tons per employee per day..

What Contributes to MRF Costs

MRF costs are affected by many variables (Figure 4), making it difficult to predict how to minimize costs in all cases. While larger facilities operating at or near design capacity and making efficient use of labor tend to have lower costs, this is not always true.

Labor is the highest-cost component, accounting for 33.4 percent of overall processing costs on average (ranging from 27.1 to 43.3 percent). MRF operators are sensitive to this cost element and often successfully seek ways to substitute equipment for labor. Equipment costs, however, create thresholds below which the equipment may not be economical to own and operate.

Eddy current separators, for example, can lead to lower processing costs for aluminum cans, but a facility needs a minimum throughput of aluminum cans to justify the capital cost. Automated sorting of plastic leads to increased efficiency, but changing materials specifications and technologies could jeopardize the efficiency and investment in such equipment.

Negative sorting (see description, page 4) is gaining as a cost-effective labor practice in MRFs.

Building rental or amortization represents an average of 16.7 percent of MRF costs (ranging from 7.5 to 34.4 percent). Locating a MRF on land used for other solid waste management activities will lower costs slightly and minimize NIMBY siting opposition.

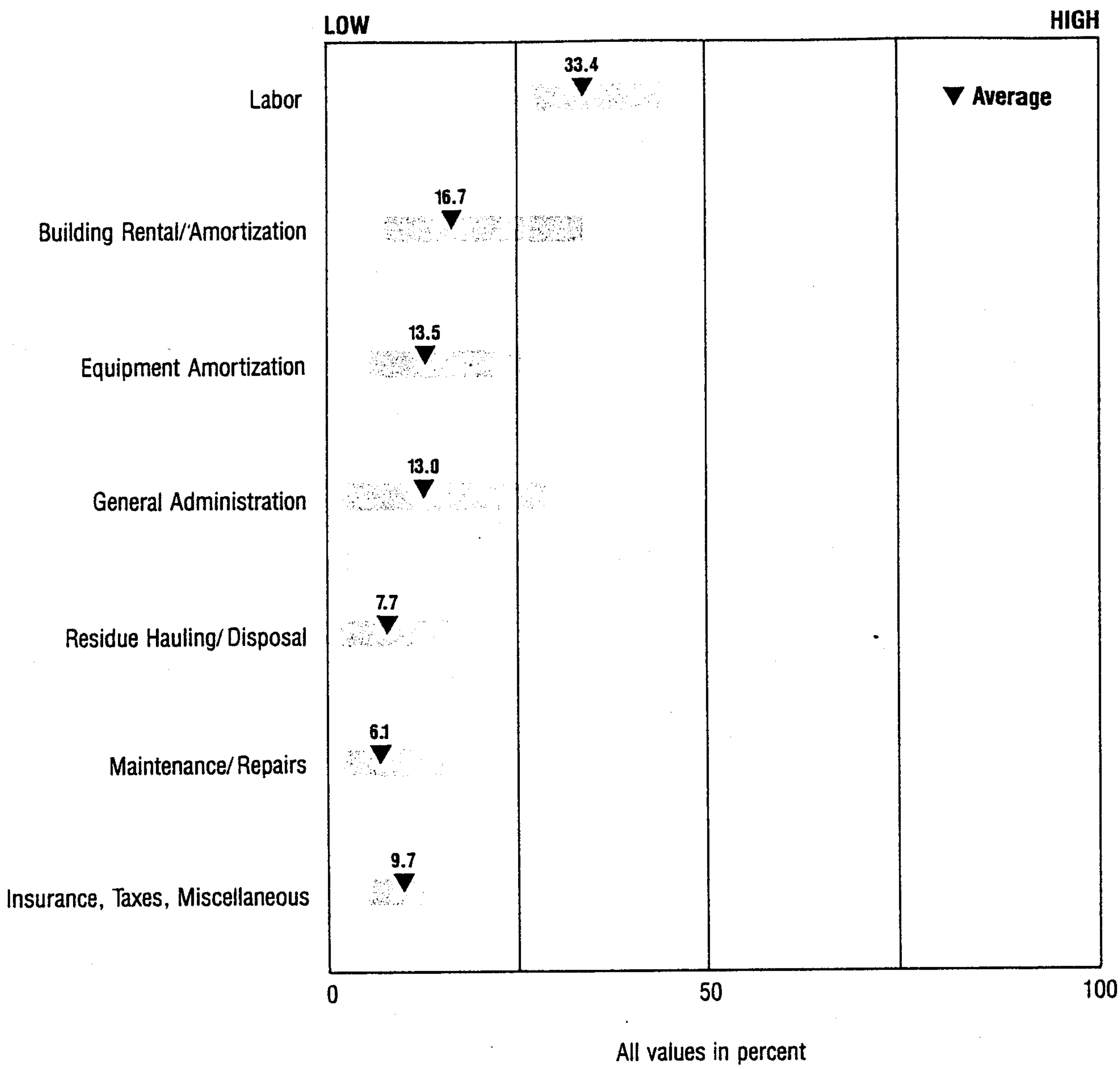
Equipment amortization costs are the next most expensive part of MRFs, accounting for 6 to 25.2 percent of costs and 13.5 percent on average. Sales and general administrative costs range from 2.1 to 28.8 percent.

Residue hauling and disposal costs (*i.e.*, carting away and disposing of material such as mixed, broken glass from the MRF) range from 1.5 to 16.6 percent of total costs and average 7.7 percent. Residue costs can be kept down if markets such as aggregate are found for mixed glass. Aggregate markets are low-value, but they offer some additional cash flow and obviate disposal costs. Improved collection and processing also can lead to lower residue levels.

Costs outweigh revenues

At current prices offered by end users for most recycled materials, average costs exceed revenues. While the average processing cost is $50.30 per ton, the average value of a ton of recyclables is approximately $30, although a MRF delivering steady quantities of quality materials will receive more than that. Table 2 shows ranges of prices paid

FIGURE 4. MRF COST COMPONENTS



Component	Range	Average
Labor	27.1–43.3	33.4
Building Rental/Amortization	7.5–34.4	16.7
Equipment Amortization	6.0–25.2	13.5
General Administration	2.1–28.2	13.0
Residue Hauling/Disposal	1.5–16.6	7.7
Maintenance/Repairs	2.0–14.8	6.1
Insurance, Taxes, Miscellaneous	5.2–12.4	9.7

TABLE 2. REGIONAL PRICES FOR SELECTED RECYCLABLES

As shown in the Markets Page of *Recycling Times*, July 14, 1992 (published by NSWMA).

All prices are per ton, end-market prices. These prices are intended as general guides and are not intended to make a market or as a firm quote for recyclables. *Because commodity prices fluctuate, the reader is advised to consult current pricing information before drawing any conclusions about prices for recyclables.*

The MRFs participating in the cost study are located in these four market regions.

Old Newspaper:		Old Corrugated:	
Northeast:	$10–25	Northeast:	$15–25
East Central:	0–15	East Central:	20–25
South:	0–25	South:	35–40
West:	12–20	West:	40–50
Clear (flint) Glass:		Amber (brown) Glass:	
Northeast:	$26–30	Northeast:	$15–26
East Central:	40–50	East Central:	22–25
South:	50	South:	50
West:	40	West:	20
Green Glass:		Steel Cans:	
Northeast:	$0–15	Northeast:	$65
East Central:	0–15	East Central:	30–60
South:	10–20	South:	40–60
West:	10	West:	40–60
PET:		HDPE Natural:	
Northeast:	$120–140	Northeast:	$100–200
East Central:	120–200	East Central:	80–120
South:	80–100	South:	120–160
West:	120–160	West:	0–100
HDPE Mixed Color:		Aluminum Cans:	
Northeast:	$80	Northeast:	$780–800
East Central:	120–140	East Central:	700–780
South:	80	South:	780–800
West:	60	West:	780–840

Mixed glass and mixed paper are not tracked by *Recycling Times*. Mixed glass is generally used as an aggregate or a filler and has a value of $0–5 per ton. Mixed paper generally has a low to zero value.

regionally for recycled materials according to the Markets Page of *Recycling Times* dated July 14, 1992.

Markets alone do not fully explain the economics of recycling, however. Other costs are involved in figuring what makes economic sense. Avoided disposal fees, for example, help justify recycling economically despite low market prices.

Generally, only facilities at the low end of the cost scale may be able to process recyclables profitably.

Theoretically, a good way to lower costs is to alter the mix of materials processed at the MRF. Since the cost of paper is relatively low (it is processed more productively than other materials, at an average of 7.42 tons per employee per day), it would seem that increasing the throughput of paper would lead to lower overall processing costs.

Not all types of waste paper are cost-effective to process at this point, however. Mixed paper represents the largest amount of unrecycled paper, and boosting paper throughput probably would require taking in more mixed paper than any other kind. With the high cost of upgrading mixed paper to revenue-rich paper grades and the negative value of mixed paper in most markets, it does not make economic sense to add this material to a recycling program without strong local markets for the end product.

Betting on the Market

The MRF study shows that it costs money to process residential recyclables. Based on these costs and current revenues from markets, few materials can be profitably processed. Therefore, tipping fees are necessary to support MRFs financially.

Markets must also be further developed so that materials can be economically recycled. Requiring the collection of recyclables without adequate manufacturing demand for the collected materials has weakened markets and raised costs to recycle. If markets continue to remain weak and user specifications for recycled materials continue to tighten, processing costs for recycled materials may rise.

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