SORTING PLASTIC BOTTLES FOR RECYCLING

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This manual could not have been completed without the consent and assistance of the MRF owners/operators who willingly participated in the project. To maintain the confidentiality of the MRFs, individuals cannot be specifically credited, however it is hoped that the results of the project will be of benefit to them.

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1. ABOUT THIS GUIDE

In 1996, there were 363 Materials Recovery Facilities (MRFs) processing commingled containers and paper for recycling in the United States.[1] MRF operators have little control over the prices received for the materials they recover. Therefore, it is important to minimize handling costs under all market conditions. This is especially the case for high volume plastic containers.

The American Plastics Council (APC) published "How To Collect Plastic For Recycling" (Collection Manual) in May 1995. The Collection Manual was intended to provide reliable data and information to anyone seeking to improve collection efficiencies to reduce collection costs.

It was recognized at the time of publication of the Collection Manual that there was a similar need to provide reliable information to the growing number of MRFs separating and processing collected plastic containers in a commingled container stream.

This Guide is intended to fill this gap. The decision that a guide rather than a manual would be more appropriate to address the handling of plastic after collection is based on the following:

- References are currently available for those interested in the design of MRFs (see, for example, *Material Recovery Design Manual*, CalRecovery and PEER Consultants, 1993).
- A majority of MRFs are privately owned and the owners/operators consider their design or operations to be proprietary. As such, the participating MRFs are not identified to protect the confidentiality promised to the owners/operators.

Within these constraints, it is hoped that existing MRF operators, and potential new MRF owners and design engineers, can use the information presented in this Guide to improve the efficiency of sorting and recovering plastic containers collected from the residential and commercial recyclables streams.

MRFS INCLUDED IN THE STUDY

Seven MRFs accepting a wide variety of plastic containers and representative of the major MRF owners and operators in the United States were selected for this project.

Table 1.1 identifies the packaging containers recovered and the daily throughput of the container line at each of the participating MRFs.

[1] Government Advisory Associates, "The Materials Recycling and Processing Industry in the United States: 1995-96 Yearbook, Atlas, and Directory."

CANADIAN STUDY

Concurrent with the APC study, a parallel study of six Canadian MRFs was undertaken by Environment and Plastics Institute of Canada (EPIC). The APC utilized a computer model developed by EPIC (see page 28) to help analyze costs and operations of the United States MRFs and collaborated with EPIC consultants on the analysis of the United States MRFs. This collaboration with EPIC contributes to a larger database on which to base observations and recommendations.

ORGANIZATION OF THE GUIDE

This Guide is organized in a manner corresponding to the flow of material through a MRF, beginning with the impact of *collection* programs, policies, and methodologies on MRF efficiency, followed by

- data on the *composition* of commingled plastic and other recyclable containers entering the MRF;
- a discussion of the impact of *contaminant removal* versus material separation on MRF design and operation;
- observations on *material receiving and storage*;
- information, data, and observations concerning the *manual sorting* of plastics from other recyclables and contaminants, and the sorting of plastic by resin type;
- a discussion of *automated sorting*;
- observations concerning the *densification* of sorted materials;
- presentation of the EPIC *computer model* as one method for organizing MRF data; and
- a presentation of *allocated costs*, by container type.

TABLE 1.1: Average Daily Throughput and Materials Recovered By Participating MRFs in the United States

MRF Number		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Avg Daily Throughput (t/day)*		70	120	83	55	42	36	72
PET		X	X	X	X	X	X	X
HDPE	Natural	X	X	X	X	X	X	X
	Pigmented	X	X	X	X	X	X	X
PVC					X	X		
3-7 Bottles		X				X	X	
PS	Foam				X	X		
	Trays				X			
Film					X	X		
Glass	Clear	X		X	X	X	X	X
	Amber	X	X	X	X	X	X	X
	Green	X	X	X	X	X	X	X
	Mixed Cullet		X			X	X	X
Cans	Steel	X	X	X	X	X	X	X
	Aluminum	X	X	X	X	X	X	X
Poly-coated paperboard containers		X						

*Mixed bottles & cans only

2. HOW DATA WERE OBTAINED FOR THIS GUIDE

The input to a MRF is heterogeneous, varying with the seasons, on a day-to-day basis, and even by the hour. Sorter efficiency and the output of the MRF also vary, depending on the quality of the incoming material, sorter productivity on any given day, and the operating condition of equipment used for moving and separating materials.

As a result, development of definitive data on the operating characteristics of a MRF requires a significant sampling effort over an extended period of time. Such an effort was outside the scope of this project and, in most cases, would have been too disruptive to MRF operations to be acceptable to the MRF owners/operators.

Data collection at each MRF ranged from a minimum of two to a maximum of four days at each MRF. First, detailed information on operating parameters and costs for the commingled container line were collected from the MRF manager for input into the EPIC model. Then, one to three full days of sampling of incoming and outgoing material was undertaken, together with video taping of sorting lines. Finally, the model and data collection results were reviewed with the MRF manager.

Given the admittedly short time spent at each MRF and the sampling procedures used, data presented in this Guide should be viewed as a "snapshot" of each MRF.

SAMPLING OF INCOMING MATERIAL

Sampling of incoming commingled container material varied depending on the specific constraints at each MRF. At MRF 1, grab samples were taken at the top of the initial incline feed conveyor every 30 minutes during the day. In this case, the 40-pound grab samples represented material that had been tipped on the floor, pushed into a storage pile, pushed from the storage pile into a pit, and dragged out of the pit and up a steep incline conveyor.

At MRFs 2 and 4, full bucket loads were taken at random from various locations in the storage pile using a front-end loader. These samples represented material that had been tipped on the floor, then mixed with additional material and pushed into a pile.

Samples collected at MRFs 5 and 6 consisted of full (10 to 15 cubic yard) truckloads of commingled bottles and cans. At MRF 7, where material is delivered in plastic bags, the sample consisted of 30 plastic bags of commingled containers pulled at random from trucks entering the facility throughout the day.

No sampling of incoming material was conducted at MRF 3.

OUTGOING MATERIAL

Sampling of outgoing processed plastic was conducted at five of the seven MRFs. Sampling consisted of either (1) sorting of bales of material selected at random (MRFs 1 and 7) or (2) sorting of skid steer loader bucketloads of loose plastic stored prior to baling.

MEASUREMENT OF SORTING RATES

Videotaping of manual sorting was carried out at all of the participating MRFs. The video recording was then used to count the number of throws, by material type, for each sorter on the plastic or "lights" line, and to allocate sorting time among materials and residue.

3. THE IMPACT OF COLLECTION PROGRAMS ON PROCESSING EFFICIENCY

ESTIMATING INCOMING QUANTITIES

The quantity and type of plastic bottles delivered to the MRF can be estimated using household generation and capture rate data.

Estimates of household generation, participation, and capture rates for recyclable plastic bottles are presented in Table 3.1. These estimates, based on nationwide field analyses, can be used by MRF developers and design engineers to help identify the building size and equipment best suited to maximize efficiency. It should be noted that while there is significant variation between bottle-bill and non-bottle-bill states in the amount of PET set out for recycling, the variation among states with or without a bottle bill is not significant enough to provide a range of values. However, based on limited data, residents in urban areas appear to produce fewer plastic bottles per household than suburban areas. Capture rates vary widely depending on program maturity and commitment to recycling education.

MATERIAL DENSITIES

The average density of commingled plastic bottles delivered to the MRFs was 30 lbs/yd³, and ranged from 20 lbs/yd³ for natural HDPE to 42 lbs/yd³ for pigmented HDPE.

TABLE 3.1: Estimating Incoming Quantities of Plastic Bottles

Plastic Bottle Material	Density (lbs/yd³)	Weekly Generation [1] Bottle-Bill (lbs/hh)	Weekly Generation [1] Non-Bottle-Bill (lbs/hh)	Capture Rate [2] (Range/%)
HDPE (Natural)	20	0.24	0.24	60-90
HDPE (Pigmented)	42	0.12	0.12	30-60
PET (Soda)	32	0.02	0.25	50-80
PET (Custom)	32	0.09	0.09	30-60
PVC	32	0.01	0.01	20-50
PP	35	0.01	0.01	20-50
All Other	35	0.03	0.03	20-50
Total	**30**	**0.52**	**0.75**	**NA**

[1] Generation is defined as the total amount of bottles set out for recycling and set out for disposal.
[2] Capture Rate is defined as the total amount of the recyclable material set out for recycling by a household *participating* in the recycling program divided by the total amount of the recyclable material generated by the *participating* household.

The mix of plastic bottles, and therefore the density of the mix, will vary depending on the location of the MRF. Densities reported in the Collection Manual for commingled plastic bottles ranged from 27 to 37 lbs/yd^3. The following factors may affect density:

- Beverage container deposit legislation will significantly reduce the quantity of PET in the recycling stream. The resulting density of the remaining plastic bottles will therefore be less due to the greater percent of lightweight HDPE natural milk and water bottles.
- Use of powdered detergents (sold in boxes or bags) as opposed to liquid detergents will affect the quantity of heavier HDPE pigmented detergent bottles.
- The preference for purchase of milk in natural HDPE containers (the lightest plastic bottles) as opposed to polycoated paperboard containers may have an impact on densities of the mixed plastic containers.
- Consumption of large amounts of bottled water in HDPE gallon jugs in certain areas will reduce average densities.
- The significant increase in single-serve PET containers is (due to their higher weight-to-volume ratios) increasing the average density of the mix of PET bottles delivered to the MRF.

COMPOSITION OF RECYCLABLES DELIVERED TO THE MRF

The composition of material delivered to the MRF has a significant impact on processing efficiency. Contaminants entering MRFs 5, 6, and 7 represented between 3.7 percent and 6.7 percent of the incoming material. This seemingly small amount of incoming contamination was responsible for between 31 and 67 percent of sorting labor at these three MRFs.

Table 3.2 illustrates measured contaminant levels in recyclables delivered in the collection vehicles to MRFs 5, 6, and 7. Measurement of manual sorting time devoted to removal of contaminants, as opposed to sorting of recyclables, was made from the videotapes of sorters at these same three participating MRFs, as well as at three of the other participating MRFs. These findings indicate the critical importance of educating customers and collectors of the importance of minimizing contamination.

Acceptance of even small amounts of recyclables in plastic bags will significantly reduce equipment and manual sorting efficiency unless all of the film is removed with a film removal system at the front end.

Two of the seven participating U. S. MRFs accepted commingled containers from some communities using plastic bags for storage of the material. In both cases, it was reported that material from these communities represented less than 20

TABLE 3.2: Average Composition of Incoming Recyclable Container Material

Material	As Delivered by the Collection Truck MRF 5 (%)	MRF 6 (%)	MRF 7 (%)
All Plastic Bottles	**16.1**	**16.4**	**16.0**
PET	5.1	6.2	6.6
HDPE (Natural)	7.2	5.4	5.9
HDPE (Pigmented)	3.2	4.5	3.2
PVC	0.1	0.1	0.1
4-7 Bottles	0.4	0.2	0.2
Glass Bottles	**53.7**	**59.6**	**59.2**
Broken Glass (<2 inches)	**4.8**	**0.0**	**1.0**
Steel Cans	**12.4**	**8.0**	**10.4**
Aluminum Cans	**6.2**	**9.2**	**9.7**
Polycoated Containers	**0.0**	**0.5**	**N/A**
All Residue and Rejects	**6.7**	**6.3**	**3.7**
Rigid Plastic Containers	0.4	1.3	0.6
Other Rigid Plastic	0.8	1.4	0.4
Plastic Film	4.2	0.0	1.5
Other Residue	1.3	3.6	1.2
Total	**100.0**	**100.0**	**100.0**
Sample Size (Pounds)	949	3,770	2,149

percent of the total material delivered to the MRF. Even at these low levels, the impact on MRF efficiency was significant.

In each case, efforts to remove this film at various points along the container line required two full-time equivalent sorters. In addition, film remaining after an initial attempt to remove the film manually

- reduced the efficiency of the ferrous magnet by allowing steel cans wrapped in plastic film to pass by the ferrous magnet;
- clogged disk screens, increasing contamination to the sorting conveyors; and
- reduced sorter productivity by requiring sorters to sort through film.

If film cannot be eliminated during collection, consideration should be given to installation of a bag breaker, with subsequent film removal either manually or by vacuum.

One of the participating MRFs accepts the majority of commingled material in bags. An auger type bag breaker is installed at this MRF in a pit on the tipping floor, feeding the incline feed conveyor. Observations at this MRF, combined with discussions with the MRF manager, indicate that the bag breaker works well and has had few mechanical problems. Glass breakage, as measured by the annual output of aggregate (residue) versus cullet, is similar to the average for the other six MRFs. More importantly, the bag breaker presents a metered flow of material to the incline feed conveyor, reducing slugs of material observed at other participating MRFs.

The bag breaker does not remove the film; it simply rips open the bags. Therefore, one full-time laborer is responsible for manually removing film after the material has left the bag breaker. Videotaping of the sorting lines indicates that some film is passing the film removal sorting station, reducing sorting efficiency. At the time of the analysis of this MRF, a vacuum removal system was being installed to aid the sorter in the removal of film. The MRF operator was hopeful that this system would improve removal of film.

Increased public education is necessary to better inform participating households which plastic containers are acceptable in the recycling program.

Exclusive of broken glass, nonbottle rigid plastic containers and non-container plastic represented the largest single contaminant, by weight, of residential recyclables entering the participating MRFs.

Nonbottle, rigid plastic containers (e.g., yogurt and deli containers) and noncontainer plastic (e.g., plastic bags, plastic toys) ranged from a low of 33 percent to a high of 83 percent of all commingled container contaminants.

Programs targeting only PET and HDPE bottles receive as many or more untargeted plastic bottles and rigid plastic containers as those programs that accept all plastic bottles.

Three of the participating MRFs serve collection programs that promote delivery of all plastic bottles. The other participating MRFs serve programs that promote the delivery of only PET and HDPE.

Table 3.3 illustrates that:

• While programs targeting all plastic bottles received more #3-#7 bottles, on average, they received fewer non-bottle rigid containers than the PET and HDPE only programs; and

• PET and HDPE bottles constituted, on average, 91 percent of all plastic containers collected in both all plastic bottle and PET/HDPE only programs.

Therefore, targeting all plastic bottles accomplishes two objectives: first increasing overall capture of HDPE and PET bottles and secondly reducing non-bottle contamination.

TABLE 3.3: Comparison of Plastic Bottle Streams from *All* Plastic Bottle and PET/HDPE *Only* Collection Programs (as percent of total plastic)*

Material	"All Bottle Programs"			PET and HDPE Only		
	MRF 1 (%)	MRF 4 (%)	MRF 5 (%)	MRF 2 (%)	MRF 6 (%)	MRF 7 (%)
HDPE	77.1	45.3	60.5	53.6	51.6	53.1
PET	13.3	48.0	29.5	42.7	32.5	38.8
Total PET and HDPE Bottles	**90.4**	**93.3**	**90.0**	**96.3**	**84.1**	**91.9**
PVC	1.2	2.9	0.7	0.5	0.6	0.6
4-7 Bottles	1.3	3.2	2.3	0.7	1.0	0.9
Total Bottles	**92.9**	**99.4**	**93.0**	**97.5**	**85.7**	**93.4**
Non-bottle Rigid Containers	**7.1**	**0.6**	**7.0**	**2.4**	**14.3**	**6.6**
All Plastic Containers	**100**	**100**	**100**	**100**	**100**	**100**

* Data were not collected by resin type at MRF 3

4. MATERIAL RECEIVING AND STORAGE

ELIMINATION OF MATERIAL STORAGE BACKLOGS

Minimizing incoming material storage time improves processing efficiency.

A comparison of MRF 6, which processed all material delivered each day, with the other six MRFs, which maintained a backlog of materials ranging from one day of delivery to as much as one week of deliveries, revealed that:

- The quality of the material for processing appeared to be higher because of the lack of contact with other materials and with contaminants. Specifically, there appeared to be less imbedded glass in the plastics, and there was less liquid contamination on the outside of the plastic containers.
- Traffic flow on the tipping floor was smoother and less constrained, reducing waiting times for the collection trucks, thereby improving collection efficiency.
- A smaller skid steer loader could be used to push material onto the pit conveyor because there was no need to manage large piles of material.
- The MRF was generally much cleaner, providing the workers with an environment more like a manufacturing plant than a waste handling facility.
- Most importantly, the amount of glass leaving MRF 6 as aggregate, as opposed to cullet, was approximately one-half of the average for the other participating MRFs (see Table 7.1), due to less breakage from storage "management."

It should be noted here that some of the benefits of processing all material delivered each day may be negated by deliveries of 100 cubic-yard trailer loads of commingled material. These loads may arrive at the MRF with large amounts of broken glass.

The percent of broken glass increases as the length of time the material is stored on the tipping floor increases.

MRFs 1 and 4 maintained the largest backlog of material for processing. The amount of aggregate (<2 inches) as a percent of total glass marketed annually at these two MRFs averaged 62 percent compared to 51 percent for the remaining MRFs.

5. IMPROVING MANUAL SORTING EFFICIENCY

The greatest potential for reducing the cost of processing plastic is likely to come from improvements on the sorting line. This section reviews ways to improve manual sorting efficiency. Section 6 provides a review of automated sorting equipment that can potentially replace manual sorting labor.

FACTORS IMPACTING SORTING EFFICIENCY

Videotaping of container flow and manual sorting of plastic containers was carried out at each participating MRF. The videotapes were then utilized to determine manual sorting rates. Manual sorting rates were compared among MRFs and with sorting rates for the Canadian MRFs to develop maximum sustainable sorting rates by plastic bottle type and to identify factors that affect sorting rates. These factors include:

- Degree of contamination of the material presented to the sorter
- Sequence of material sorting
- Burden depth and consistency
- Density of material presented to the sorter
- Sorting belt speed
- Environmental conditions for sorting
- Sorter training and experience

CONTAMINATION OF MATERIAL PRESENTED TO THE SORTER

Removal of contaminants during curbside collection and prior to sorting at the MRF can reduce labor requirements and increase sorting productivity.

Table 5.1 illustrates that an average of 37 percent of observed sorter activity (ranging from 18 to 67 percent) was devoted to removal of contaminants that, on average, represent only 3.7 percent of the incoming material stream (see Table 3.2) and 11.2 percent of MRF output. The discrepancy between contaminant levels measured entering three of the participating MRFs and residue rates reported by all seven participating MRFs is a function of labels and bottle caps falling off containers as they travel through the MRF, as well as missed containers that end up in the residue.

SEQUENCE OF MATERIAL SORTING

The first sorter(s) should be assigned to the highest volume material, typically HDPE natural.

Assigning sorters based on the highest volume material ensures that the amount of time spent searching

TABLE 5.1: Allocation of Labor for Material Sorting and Contaminant Removal

	Labor Allocation				
	Contaminant Removal		Material Sorting		Total
MRF #	# of Sorters	% of Total	# of Sorters	% of Total	# of Sorters
1	1.75	19	7.25	81	9.0
2	5.5	42	7.5	58	13.0
3	3.0	18	14.0	82	17.0
4	6.8	40	10.2	60	17.0
5	2.8	31	6.2	69	9.0
6	4.0	67	2.0	23	6.0
7	3.5	40	5.5	60	9.0
Average		37		63	

through other materials to find the assigned material is minimized.

Forced air separation of plastic from glass containers is preferable to mechanical separation.

Observations at the participating MRFs utilizing air classification systems indicate that properly designed air classifiers can separate plastic from glass with limited cross-over of glass to the light line (or plastic to the heavy line), irrespective of the size of the plastic or glass bottles.

By comparison, participating MRFs utilizing equipment designed to separate bottles based on size and/or weight indicate that these are not acceptable separation criteria. This is especially the case given the significant increase in smaller volume, single-serve plastic bottles now on the market and included in the incoming material.

In all cases, the primary criteria for selection of mechanical separation equipment should be to choose equipment that performs under the widest range of conditions. This will help ensure that equipment does not become inefficient or obsolete due to future changes in bottle types or size.

BURDEN DEPTH AND CONSISTENCY

Sorter productivity is directly related to the presentation of a consistent depth and flow of material to the sorter.

Videotape observations indicate that sorters were most efficient when presented with a consistent flow of material approximately one or two bottles deep (approximately 4 inches) at the beginning of the sort line.

Initial incline feed conveyor angles of less than 40 degrees improve sorting efficiency by reducing alternating slugs of heavy and light material presented to the sorters.

A common problem observed at a number of participating MRFs was that the angle of the cleated conveyor feeding the sorting line was too steep. Heavy containers, such as glass bottles and steel cans, tended to fill the space between the cleats, while the plastic containers rode on top of

Table 5.2: Composition of Commingled Containers Discharged From the Initial Incline Feed Conveyor at MRF 1

Material	Range (% by weight) High Glass	Range (% by weight) High Plastic	Average
All Plastic Bottles	4.8	21.7	8.2
Rigid Plastic Containers	0.1	1.0	0.8
Plastic Film	0.2	0.3	0.2
Glass Bottles	9.8	38.7	37.1
Broken Glass (<2 inches)	75.7	2.0	33.9
Steel Cans	8.5	27.2	16.1
Aluminum Cans	0.7	6.3	2.5
Polycoated Containers	0.1	0.1	0.1
Residue	0.1	2.7	1.1
Total (may not = 100 due to rounding)	**100.0**	**100.0**	**100.0**

the heavy material. This results in the tumbling of lighter material down the conveyor and alternate peaking of heavy material (glass and steel cans) and then of plastic and aluminum cans on the sorting conveyors. Table 5.2 illustrates the range of composition of material discharged to the sorting conveyor at MRF 1, with slugs of material composed of virtually all glass and cans (94 percent), followed by slugs of material with high concentrations of plastic bottles and aluminum cans (29 percent).

This peaking negatively affects sorter utilization, with sorters overworked when a peak of material is presented, and then underutilized when the peak shifts to the other line. Peaking can also lead to increased bypass of materials, or to wasted effort by the sorters pulling material back to them.

Compaction of recyclables during collection may improve efficiency by reducing peaking of heavy and light materials. This will result in less peaking and higher daily sorting rates.

One of the participating MRFs with a steep incline conveyor agreed to conduct a test run of flattened plastic bottles. The flattened plastic bottles significantly reduced tumbling of material on the incline conveyor. The flattened plastic also alleviated the alternate peaking of materials on the heavy and lights lines, with no observable increase in the error rate of the air classifier and no change in manual sorting rates.[2] Therefore, the sorters were able to maintain consistently high sorting rates with a consistent flow of material presented to them, increasing daily sorting rates.

DENSITY OF MATERIAL PRESENTED TO THE SORTER ON THE LIGHTS LINE

The average density of material presented to the first sorter on the lights line (consisting primarily of

[2]Note that the tests were run on a dry day. Tests of the efficiency of the air classifier to separate wet plastic from glass remain to be run.

aluminum cans and plastic) was measured at 28.5 lbs/yd³.

Samples were taken at MRFs 1 and 4 (see Table 5.3) to measure the actual density of commingled material presented to the first sorter on the lights line. This material is primarily a mix of aluminum and commingled plastic bottles. However, it also contains whatever contaminants have made it to the sorting line.

SORTING BELT SPEED

Slowing the speed of the sorting conveyor may increase sorter productivity without negatively impacting daily throughput.

The EPIC study of Canadian MRFs used the processing model to calculate the sorting conveyor speed sufficient to move the required daily throughput past the sorters on a given day or shift. This calculated speed was then compared with the reported or measured speed recorded at the participating MRFs during the study. For five of the six participating Canadian MRFs, belt speeds were reduced to measure the change in sorter productivity. As illustrated by Table 5.4, reducing belt speeds at the Canadian MRFs by an average of 32 percent increased sorter productivity by an average of 17 percent. This was because the slower speed increased burden depth, and therefore the amount of material presented to the sorter, while allowing the sorter to pick the material off the belt rather than requiring that he or she also pull

TABLE 5.3: Measured Density of Material Presented to First Sorter on Plastic Sort Line [1]

Sample	MRF 1 (lbs/yd³)	MRF 4 (lbs/yd³)
1	30	78 [2]
2	24	27
3	23	28
4	33	33
Average	28	41
Average, Exclusive of Sample 1, MRF #4	28	29

[1] Samples consist of all material taken off a 10-foot length of sort belt, which was sorted, weighed, and converted to a density measurement based on the depth of the material burden and the width of the belt.

[2] Sample 1 at MRF 4 was an anomaly, with 5.2 pounds of broken glass.

TABLE 5.4: Impact of Reduced Belt Speed on Sorter Productivity

Canadian MRF	Reduced Belt Speed (ft/min)	Belt Speed Reduction	Estimated Productivity Increase
MRF 1	90	33%	20%
MRF 2	45	40%	20%
MRF 3	45	20%	10%
MRF 4	60	33%	15%
MRF 5	30	33%	20%

Source: Environment and Plastics Institute of Canada the material back up the belt to finish sorting it.

ENVIRONMENTAL CONDITIONS FOR SORTING

There was general agreement among MRF managers that the quality of the work environment affected sorter productivity.

Although videotape measurements of sorting rates did not appear to correlate the work environment with sorter productivity, there was general agreement among the MRF managers that adequate lighting, heat and ventilation, and attention to cleaning the sorting area improved sorter productivity.

Sorters should be throwing forward into a bunker, as opposed to pulling the material back off the belt.

The highest observed sorting rates corresponded with pushing or throwing material forward as opposed to pulling material back off the belt.

SORTER TRAINING AND EXPERIENCE

Full-time, properly trained staff had higher sorting rates.

Videotape measurements of sorting rates clearly showed higher sorting rates for full-time, trained, and experienced sorters.

Assigning too many tasks to an individual sorter reduced sorting speed.

Whenever possible, sorters should be assigned to a specific material to minimize the number of sorting decisions required as the material is presented to them.

Sorters should be trained to sort with both hands.

Sorters should be presented with sufficient flow of material so that they are consistently using both hands to sort material.

MANUAL SORTING RATES

Table 5.5 presents the range of manual sorting rates measured at participating MRFs. The high observed sustainable rates reflect the highest sorting

TABLE 5.5: Range of Sustainable Manual Sorting Rates, Measured at U. S. and Canadian MRFs

	Observed Sustainable Sorting Rates		
Material	**Low (lbs/hr)**	**High (lbs/hr)**	**Mean (lbs/hr)**
HDPE (Natural)	440	925	680
HDPE (Pigmented)	495	925	710
PET	220	880	550
Rigid Containers	130	260	195
Plastic Film	55	110	80
Container Residue	220	660	440

rates observed that could be maintained over the sorting day. The measured sustainable rates can be used by other MRFs to compare their sorting rates against the high observed sustainable rates. Where their rates fall in the lower range of measured sustainable rates, the factors discussed above can be assessed to improve sorter productivity.

It should be noted that the high sustainable sorting rates are based on *positive sorting of targeted material only*, with no sorting of contaminants interspersed within the material. If sorters are required to positively sort contaminants as well as a targeted material, then hourly sorting rates for sorting the targeted material will be correspondingly reduced.

Sustainable sorting rates also depend on a steady flow of the targeted material to the sorter. Often, the first sorter on the line is assigned to sort HDPE natural, with the next sorter sorting HDPE pigmented or PET. Especially in states with beverage container deposit legislation, the quantity of PET bottles may not be great enough to ensure a steady flow of this material to the sorter, thus reducing the sorting rate.

SORTER ERROR RATES

Manual sorters are capable of sorting to low levels of contamination, even at high sustainable sorting rates. On average, total contaminant levels were less than 3 percent and ranged from a high of 5.3 percent to a low of 0.3 percent.

It is important to know the level of contaminants remaining in the sorted plastic after manual sorting for compliance with market specifications and comparison with measured error rates for automated sorting. Therefore, at five of the seven participating U. S. MRFs, samples of the sorted plastic were re-sorted. The weight of contaminants and the weight of plastic containers of the wrong resin type were recorded. The results are presented in Table 5.6. Note that for MRFs 1 and 7, full bales of each material were selected at random, opened, and re-sorted. For the other three MRFs, samples of the sorted material were taken prior to baling.

The average measured contaminant level of 3 percent is too high to allow for granulation and sale to most end users.

Recently there has been discussion concerning the feasibility of adding value to recovered plastic at MRFs by grinding, with sale to end users. The measured contaminant levels remaining after manual sorting at the MRFs observed in this study would not meet minimum specifications for sale of flake or pellets to most reclaimers or end users. Therefore, an evaluation of the feasibility of granulating plastic at a MRF for sale to an end user should include secondary sorting to further reduce contaminant levels.

TABLE 5.6: Composition of Outgoing Plastic Bottle Bales

	MRF 1 (%)	MRF 2 (%)	MRF 4 (%)	MRF 5 (%)	MRF 7 (%)
HDPE Natural Bales					
HDPE Natural Bottles	**98.0**	**97.0**	**99.6**	**98.1**	
Contaminants	**2.1**	**3.9**	**0.4**	**1.9**	
HDPE Bottles (Pigmented)	0.5	0.1			
Other Plastic Bottles	0.1	0.0	0.3		
Loose Caps	0.3				
Rigid Plastic Containers	0.5				
Film Plastic			0.1		
Glass	0.7	3.8			
HDPE Pigmented Bales					
HDPE Bottles (Pigmented)	**99.2**	**98.1**	**99.7**	**92.8**	**94.5**
Contaminants	**0.9**	**1.9**	**0.3**	**7.3**	**5.5**
HDPE Bottles (Natural)	0.0	0.2	0.2	1.0	
Other Plastic Bottles	0.5	0.9	0.1	0.2	0.8
Rigid Plastic Containers		0.4			
Film Plastic		0.1		5.0	2.6
Paper	0.2			0.6	0.1
Glass	0.1				
Aluminum Cans	0.1	0.2		0.1	
Other Residue		0.1		0.4	2.0
PET Bottle Bales					
PET Bottles	**97.6**	**95.1**	**98.9**	**99.3**	**91.1**
Contaminants	**2.4**	**4.9**	**1.1**	**0.7**	**8.9**
HDPE Bottles	0.4	0.6		0.0	0.8
PVC Bottles	1.1	0.6	0.8	0.3	1.1
Other Plastic Bottles	0.0	0.2	0.3	0.3	1.2
Rigid Plastic Containers		0.2			
Aluminum Cans	0.0	0.1			
Glass		3.2			
Other Residue	0.9			0.1	5.8

[1] MRF 7 markets a mixed natural and pigmented bale.

6. AUTOMATED SORTING

Labor represents the largest single cost category at the commingled container MRFs, averaging 44 percent of annual per ton costs (see Section 9; Table 9.2) at the participating MRFs. For this reason, there is continued interest in automated sorting systems.

Currently, two manufacturers in the United States produce automated systems for sorting whole plastic bottles: National Recovery Technologies, Inc. (NRT), Nashville, Tennessee, and Magnetic Separation Systems, Inc. (MSS), Nashville, Tennessee.

Both MSS and NRT have operating systems at MRFs and Plastics Recovery Facilities (PRFs) in the United States. Because of the interest in automated sorting, this study included one MRF utilizing an automated sorting system for sorting of plastic bottles. In addition, the APC has been actively involved with the development of the Garten Services PRF in Salem, Oregon. Both the participating MRF and the PRF use MSS single line automated sorting systems capable of sorting 1200 to 1500 pounds per hour of singulated plastic containers. However, this should not imply APC's endorsement of an MSS system compared to an NRT system.

One other participating MRF was interested in adding an automated sorting system. The EPIC model was used to evaluate the cost effectiveness of adding a binary bottle sorting system at this MRF. Both NRT and MSS supply binary bottle sorting systems.

DESCRIPTION OF SINGLE LINE AUTOMATED SORTING SYSTEMS

Plastic containers must first be separated mechanically or manually from glass and cans. The plastic containers must then be singulated prior to passing by the resin detectors. At the participating MRF, singulation is accomplished using a sloped conveyor that forces all bottles to one side of the conveyor. They are discharged to a narrow conveyor that is wide enough to hold only one bottle. The bottles that fall off the narrow conveyor are conveyed back to the sloped conveyor.

The PRF uses a series of 90-degree turns and diverters to accomplish singulation.

After singulation, the plastic containers pass through an array of up to four detectors (depending on the number of separations desired) at a rate of up to three containers per second. The PRF, which utilizes all four detectors, was separating plastic bottles at the time of this study as follows:

- An infrared light high density array recognizes clear, translucent and opaque containers.
- A machine vision color sensor, programmed to ignore labels, identifies the color of pigmented containers.
- An X-ray transmission unit identifies PVC plastic by sensing the chlorine atom.
- A near infrared spectrum detector identifies resin type and reconfirms data from the other detectors.

Once the container has been identified, the system computer tracks the item as it travels down the conveyor until it reaches the ejection point along the conveyor belt. The computer then triggers a concentrated air jet to blow the container into the designated storage cage or onto an incline conveyor feeding a storage cage.

Each storage cage holds the equivalent of 1 to 1.5 bales of sorted material. The storage cages are emptied onto the baler feed conveyor. The separated plastic containers are then manually inspected and any remaining contaminants, or plastic containers of the wrong resin type, are removed prior to the baler.

DESCRIPTION OF A BINARY SYSTEM

A binary system sorts a single resin type of bottles from the remaining mass of plastic bottles or containers in a mixed plastic stream that has not been singulated. The primary benefits of the binary system are (1) that the plastic containers do not need to be singulated prior to sorting and (2) throughput is significantly greater than for a singulated system (e.g., 3000 pounds per hour compared to 1500 pounds per hour). The ability to feed nonsingulated containers significantly reduces the space requirements, allowing for potential installations in existing MRFs with limited space. The disadvantage of a binary system is that it can only achieve one sort, instead of multiple sorts.

Typical binary sorts that can be achieved include:

- PET from pigmented and natural HDPE
- Pigmented PET from clear PET
- Natural HDPE and clear PET from pigmented HDPE
- Natural HDPE from pigmented HDPE
- PVC from PET

Because only one sort can be accomplished at a time, multiple sorts require back-to-back binary systems, with each system sorting one type of plastic and the remaining plastic containers discharged to a second (or third) binary system sorting a second (or third) plastic type.

PERFORMANCE OF AN AUTOMATED MSS SINGLE LINE SYSTEM AT A MRF

An automated sorting system can be efficiently integrated into a commingled MRF environment.

Based on three full days of sampling over three seasons at the participating MRF, and one full year of operating history, it is clear that an MSS system can operate in the MRF environment at costs that are competitive with manual sorting.

The quality of the plastic stream presented to the automated equipment is critical to the efficient operation of an automated system within a MRF environment.

An automated system must be presented with a clean, plastic-only stream to efficiently sort by resin type. At the participating MRF, the majority of manual sorting on the commingled line was devoted to contaminant removal prior to the MSS line.

For this reason, the automated sorting system must be combined with upfront contaminant removal equipment and sorters. The use of air classification and/or eddy current systems to remove paper, labels, aluminum, etc. can be critical to achieving optimum automatic sorting efficiency. It may be most efficient to contract with the automated system supplier to design and install this initial sorting and contaminant removal system to ensure that it is fully compatible with the automated sorting system.

Cost-effective operation of an automated sorting system requires that the system be fully utilized as many hours as possible per day.

The participating MRF operates 16 to 18 hours per day. Capital costs for an automated system are high (see "Automated System Costs"), especially when necessary upfront contaminant removal, perforation, and surge capacity are included. Therefore, in addition to keeping the automated system operating as many hours as possible per day, it is important to make sure that the automated system is supplied with a constant stream of plastic bottles (between 900 and 1500 pounds/hour) throughout the MRF operating day, irrespective of manual sorter breaks and baler down time. In most cases, this will require surge capacity, both in front of and at the discharges from the system.

Maintenance of the automated system requires computer and electrical system knowledge and maintenance skills.

Mechanical skills necessary for maintenance of most MRF equipment may not be sufficient to maintain an automated system adequately. In most cases, it will be necessary to have one or more maintenance staff members knowledgeable in computer and electrical systems. Lack of maintenance will result in higher error rates and increased manual sorting for quality control, negating the expected labor savings.

PVC removal at the participating MRF is designed to maximize removal of PVC from PET, not to produce a pure PVC stream. As a consequence, the PVC stream typically includes significant quantities of bottles made from other resins.

Table 6.1 illustrates the composition of the PVC stream leaving the MSS line at the participating MRF. Between 71 and 89 percent of the material sampled over a two-day period was not PVC.

Seventeen percent of the annual throughput of the automated sorting line at the participating MRF was mixed bottles that had either not

TABLE 6.1: Composition of MSS Sort of PVC

Material	Summer (%)	Fall (%)
PVC	**28.5**	**10.6**
Total Contaminants	**71.5**	**89.4**
PET	7.3	0.7
HDPE (Natural)	17.9	5.4
HDPE (Pigmented)	40.5	81.7
PP	0.0	0.0
PS	0.0	0.0
Other Plastic Bottles	0.5	0.0
Rigid Plastic Containers	1.9	1.7
Aluminum Cans	0.8	0.0
Steel Cans	2.5	0.0
Residue	0.0	0.0
Total	**100.0**	**100.0**

TABLE 6.2: Composition of Mixed Bottles Missed by MSS Sort

Material	Spring (%)	Summer (%)	Fall (%)
PET	38.6	43.9	26.6
HDPE (Natural)	34.7	69.4	34.1
HDPE (Pigmented)	16.3	9.3	34.9
PVC	1.0	0.0	0.0
LDPE	0.4	0.0	0.0
PP	0.3	0.2	0.0
PS		0.6	0.0
Other Plastic Bottles	0.6	0.4	1.3
Rigid Plastic Containers	6.4	5.8	2.8
Aluminum Cans	0.1	0.2	0.3
Steel Cans	1.5	0.2	0.0
Glass	0.1	0.0	0.0
Total	**100.0**	**100.0**	**100.0**

been identified or not been ejected by the air stream.

Observations at the MRF and discussions with the equipment manufacturer indicate that a majority of the plastic containers missed by the sorting system were missed because the containers were not adequately flattened prior to entering the MSS system. As a consequence, the air jet would hit some bottles at an angle and the bottles would bounce off the side of the discharge chute and back onto the conveyor. The bottles that remain on the conveyor never get sorted and must be sold as a mixed resin bale at a lower price than single resin bales. Table 6.2 presents the composition of this mixed bottle stream measured at the participating MRF.

Contaminants measured at the participating MRF after automated sorting of PET, HDPE natural, and HDPE pigmented ranged from a low

TABLE 6.3: Composition of Outgoing Bottle Bales Sorted by an MSS System Integrated Into a MRF

Material	Spring (%)	Summer (%)	Fall (%)
HDPE (Natural)	**94.6**	**91.3**	**90.9**
Total Contaminants	**5.4**	**8.7**	**9.1**
PET	1.5	3.3	3.5
HDPE (Pigmented)	1.5	2.0	3.1
PVC	0.3	0.0	0.0
PP	0.4	1.6	1.3
PS	0.0	0.0	0.0
Other Plastic Bottles	1.8	1.6	1.1
Miscellaneous Residue	0.0	0.1	0.2
HDPE (Pigmented)	**87.4**	**94.7**	**93.0**
Total Contaminants	**12.6**	**5.3**	**7.0**
PET	3.3	1.2	2.5
HDPE (Natural)	5.4	3.3	0.5
PVC	0.3	0.0	0.0
LDPE	0.0	0.0	0.0
PP	0.1	0.4	1.4
PS	0.0	0.0	0.0
Other Bottles	0.4	0.1	0.4
Rigid Plastic Containers	1.7	0.0	1.4
Aluminum	0.2	0.2	0.2
Steel	0.5	0.1	0.0
Polycoated Containers	0.1	0.0	0.0
Residue	0.6	0.0	0.7
PET	**92.0**	**93.0**	**93.1**
Total Contaminants	**8.0**	**7.0**	**6.9**
Brown PET	0.5	0.0	0.9
HDPE (Natural)	4.8	4.4	4.0
HDPE (Pigmented)	1.3	1.1	1.3
PVC	0.3	0.0	0.0
PP	0.2	1.4	0.6
PS	0.0	0.0	0.0
Other Plastic Bottles	0.2	0.0	0.1
Rigid Plastic Containers	0.6	0.0	0.0
Aluminum Cans	0.0	0.0	0.0
Steel Cans	0.0	0.0	0.0
Residue	0.0	0.0	0.0

Total may not add due to rounding.

of 5.3 percent to a high of 12.6 percent.

Table 6.3 presents the sorting results, over three different seasons, of material sorted by the MSS single line system at the participating MRF. A small amount of quality control labor (3 person-hours per 8-hour shift) stationed on the baler feed conveyor was sufficient to further reduce contaminants to levels that were acceptable to plastic reclaimers.

PERFORMANCE OF AN MSS SINGLE LINE SYSTEM AT THE GARTEN SERVICES PRF

The Garten Services PRF provides an alternative to sorting mixed plastic at a MRF. Garten Services receives mixed plastic bales which are then sorted using an MSS single line system and manual quality control sorters to produce single-resin bales for sale to reclaimers.

The mixed bales are first broken apart using a bale breaker consisting of a series of counter-rotating blades that separate the baled plastic into individual bottles and containers. The separated plastic containers enter the sorting conveyor and travel past a single manual sorter/inspector who is responsible for pulling off contaminants (primarily film and paper). The plastic containers then pass over a two-stage screen. In the first stage, small pieces of plastic, dirt, gravel, and caps are removed. The second stage separates small bottles and containers (<8 ounces), which are baled and shipped commingled to a processor for reclamation.

Larger plastic containers pass over the screen and onto the singulating conveyors, which use three 90-degree turns and a series of baffles located on either side of a smaller conveyor to force the plastic containers into a singulated stream. A gap filler senses openings on the singulated stream conveyor and drops plastic bottles onto these areas to create a more even flow to the MSS sorting line.

The MSS system uses four detectors to sort the plastic into as many as seven categories. The categories can be varied based on market conditions. At the time of the MRF study, the Garten Services PRF was sorting into the following categories:

- PVC
- HDPE Blue and White
- HDPE Red, Orange, and Yellow
- HDPE Colored
- PET
- HDPE Natural
- PP

After the appropriate scanner has identified the plastic resin, the bottle is tracked on the sorting conveyor until it reaches the appropriate ejection point where a concentrated air jet blows the container onto an incline feed conveyor feeding the storage bin. Conveyors at the bottom front and back of the these bins are used to empty the bins and deliver the sorted plastic to quality control sorting lines. Sorters positively sort out any remaining contaminants and plastic containers of the wrong resin type. The negatively sorted plastic is fed to a horizontal baler, with the baled plastic sent to reclamation facilities.

During the last fiscal year for which data are available, Garten Services sold approximately 3.6 million pounds of plastic and disposed of an additional 252,000 pounds of residue (6.5 percent residue rate). Table 6.4 illustrates the composition of the output of the Garten Services PRF.

AUTOMATED SYSTEM COSTS

Capital costs for a complete binary system including a feed conveyor, perforator/flattener (to enhance

TABLE 6.4: Composition of the Annual Output, Garten Services PRF

Material	Percentage
HDPE - Natural	46.2
HDPE - Pigmented	20.7
HDPE - Blue/White	*12.7*
HDPE - Red/Orange/Yellow	*3.7*
HDPE - Mixed	*4.3*
PET	23.3
PP	2.6
PVC	1.8
Rigids	5.4
Total	**100.0**

Source: Garten Services

performance), and two modules to allow for three sorts is approximately $200,000, exclusive of engineering, compressed air, electrical, support structures, and storage cages.

Capital costs for a complete single line system, including feed and singulating conveyors, are approximately $250,000, exclusive of compressed air, electrical, support structures, and storage cages.

LABOR REQUIREMENTS

Each of the MSS systems evaluated as part of this project required at least one quality control sorter in front of the automated system and one quality control sorter prior to baling of the material.

SUMMARY OF AUTOMATED SORTING SYSTEM FINDINGS

- An automated sorting system can be efficiently integrated into a commingled MRF environment.
- Contaminants and nonplastic containers must be removed upfront of the automated system.
- When air-classification and/or eddy current systems are used to assure delivery of a pure plastics stream, automatic sorters work at peak efficiency.
- The automated system must be fully utilized throughout the operating day, given its high capital cost.
- Maintenance of an automated system requires computer and electrical skills.
- There will still be a need for manual sorters for quality control of the plastic sorted by the automatic system.

7. MATERIAL DENSIFICATION AND MRF OUTPUT

Baling of sorted plastic bottles is a significant cost and processing issue at MRFs. However, because there are many good references available to MRF owners/operators concerning baler design and operation,[3] this Guide does not attempt to duplicate this information. Instead, only observations that affect MRF efficiency are presented.

Where automated feed horizontal balers are used, the ability to feed the plastic to the baler, not baler cycle time, is the limiting factor in the production of a bale of plastic bottles.

Typically, the ability to convey a sufficient number of plastic bottles to the baler using a common conveyor is the limiting factor. This is especially the case if quality control is occurring on the baler feed conveyor, or if a perforator is used to increase bale density.

Perforation can increase plastic bale density by 20 percent, reducing trucking costs for plastic.

Use of a perforator/flattener to flatten plastic bottles prior to baling can increase a tractor trailer load of baled plastic from 30,000 to between 36,000 and 40,000 pounds. Transportation of full truck loads significantly reduces transportation costs, improving revenues received per pound of plastic material.

However, perforators can slow down baling time requiring that surge capacity be installed between the perforator and the baler to maximize baler efficiency.

COMPOSITION OF ANNUAL MRF CONTAINER LINE OUTPUT

Data were obtained from all of the participating MRFs on the annual output of material, by type. As illustrated by Table 7.1, plastic bottles comprised 8.4 to 16.0 percent of total container tonnage processed.

Glass aggregate, material not returned for use in glass containers, on average represented 32.4 percent of total output from the container line at the participating MRFs, and ranged from 17 percent to 45 percent.

As previously discussed in this Guide, management of the incoming material to reduce storage time can significantly reduce glass breakage. MRF 6, which has a policy of cleaning the tipping floor at the end of each day, has a glass aggregate output of less than one-half the average for the participating MRFs. The large range in glass aggregate indicates that this is an area with significant potential for improvement at some MRFs.

[3]See, for example *Recycling Today*, "Baler Guide," February 1997.

TABLE 7.1: Annual Output From the Container Line, by Material, by Participating U.S. MRF

Material	MRF 1 (%)	MRF 2 (%)	MRF 3 (%)	MRF 4 (%)	MRF 5 (%)	MRF 6 (%)	MRF 7 (%)
Aluminum Cans	1.6	3.8	3.9	3.5	4.2	6.3	3.6
Aluminum Foil	0.5		0.1				
Steel Cans	20.5	14.3	9.6	10.4	9.6	10.6	11.3
Scrap Metal	0.8					1.7	
Plastic Bottles	9.8	10.0	10.9	8.4	10.0	16.0	11.6
PET	1.8	4.0	4.3	3.4	3.6	3.6	4.0
HDPE (natural)	4.6	3.1		2.7	4.5	5.5	
HDPE (pigmented)	2.2	2.9		2.2	1.6	2.3	
HDPE (mixed)			6.6				7.6
PVC				0.1			
3-7 Bottles	1.2				0.3	4.6	
Other Plastic	**0.0**	**0.0**	**0.0**	**0.4**	**5.0**	**0.0**	**0.3**
Film				0.1	4.9		0.3
PS				0.2			
PS Foam				0.1	0.1		
Glass	**59.6**	**66.3**	**67.8**	**62.5**	**51.0**	**52.3**	**61.9**
Cullet	24.8	21.5	47.3	21.9	14.5	35.4	27.5
Aggregate	34.8	44.8	20.5	40.6	36.5	16.9	34.4
Polycoated Containers	**0.9**						
Residue	6.2	5.4	7.8	14.8	20.0	13.3	11.2
Total (Percent)	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Total Tons Produced	**18,245**	**26,760**	**21,643**	**13,274**	**10,878**	**9,318**	**21,191**

8. COMPUTER MODELING OF MRF OPERATIONS AND COSTS

One valuable way to assess options to improve processing efficiency is to organize processing and cost data in a computer spreadsheet, or "model." Some of the larger MRF operators have developed their own models, which are not publicly available. Other models have been developed to analyze a specific MRF or processing issue, but are not readily available for use by other MRF operators. Additional models are currently being developed.[4]

EPIC and the Ontario Ministry of Environment and Energy (OMEE) contracted with Proctor & Redfern Limited to develop a computer model that could be used by EPIC and by MRF operators to examine the resource and equipment requirements and the cost impacts of processing recyclable materials in a MRF.

After development and testing of the model, EPIC utilized the model to analyze plastic container sorting and processing costs and efficiency at six Canadian MRFs in 1996. The APC agreed with EPIC to utilize the same processing model for the parallel U. S. study. The intent was to use a common tool so that data would be organized in a uniform manner allowing for comparison of the results and combination of information.

[4]See, for example, MRF Software Model, Analytical Research and Economic Strategies, Inc., Bethesda, Maryland.

The model is in a spreadsheet format based on Microsoft Excel software. It is, of necessity, a large spreadsheet, in order to adequately incorporate all of the processing and cost parameters of a commingled MRF. It has been utilized in this project for the container line of the MRF only, although it can be applied to paper processing lines as well.

MRF operators may find that the model is a useful planning and management tool for organizing data on their MRF, especially for assessing necessary belt speeds and comparing sorter productivity against other MRFs. The model can also be used as a tool to assess contemplated changes in processing equipment, labor inputs, or materials accepted at a MRF.

The model can be downloaded from APC's website at *www.plasticsresource.com/recycle* or a disk containing the model can be mailed to you by calling APC (800-2-HELP-90).

The appendix to this Guide, "EPIC MRF Model for Assessing MRF Operations and Costs," is a general user guide for the model. A detailed line-by-line description of the model is available from EPIC, 5925 Airport Road, Suite 500, Mississauga, Ontario, M3C3K3.

It should be noted that the model is the property of EPIC and the Ontario Ministry of Environment and Energy. Model assumptions and formulas are locked and cannot be accessed by the user. Therefore, it must be used with caution because the assumptions and related formulas may not be consistent with the relevant ones for any given MRF. However, despite this limitation, the model remains a useful tool for organizing data on an operating MRF, especially for those MRF operators who have not developed their own spreadsheet models or who do not have access to company models.

9. ALLOCATION OF COSTS AMONG MATERIALS

Ultimately, improvements in processing efficiency must be measured in improvements to the bottom line, through reduced costs and increased revenues. Detailed information on costs are proprietary and therefore beyond the scope of this Guide. In addition, many costs are unique to each MRF. For example, labor and utility rates vary from region to region, and land, building, and equipment costs are often affected by the arrangements between the public sector using the MRF and the private MRF operator/owner.

For these reasons, data on costs at the participating MRFs are presented as ranges only, not as specific costs for each MRF. The range of costs can be used by MRF operators as a rough indication of other MRF costs.

More importantly, the EPIC model can be used to organize costs for a specific MRF. Changes to improve efficiency can then be evaluated to estimate the potential cost and revenue impacts on the specific MRF.

To fully understand where cost savings might be, it is useful to allocate MRF capital and operating costs among the various materials processed at the MRF. These allocated costs can then be used to assess ways to improve efficiency on a material-by-material basis.

There are many ways to allocate costs, and no single methodology is universally accepted. Therefore, it is important to specify the assumptions that are made as part of the allocation process.

The EPIC model divides costs into the following five categories:

- Buildings and Land Capital Cost
- Equipment Capital Cost
- Labor
- Building/Equipment Operation and Maintenance
- Administrative

The model allows the user to allocate costs among materials within each category on the basis of weight, volume, or units of recyclable material recovered. The user can also assign all or a portion of the costs of specific equipment or individual sorters to a specific material, irrespective of weight, volume, or units.

It should be noted here that the model is only useful for examining costs in a single year, with capital costs either amortized at specified interest rates and terms or depreciated at a specified rate. The model is not set up to perform more sophisticated investment analysis, such as net present value or internal rate of return calculations. Finally, the model is structured to present average costs as opposed to marginal costs, although marginal costs can be estimated from the difference in average costs under two sets of conditions.

Table 9.1 presents the range in per ton costs, by material, for the participating MRFs for which sufficient cost information was provided to perform the allocation. Costs have been allocated as follows.

BUILDINGS AND LAND CAPITAL COST

Most buildings and land costs depend on area (e.g., square feet, acres). Therefore, buildings and land capital costs have been allocated by the volume of each recyclable material managed at the facility on an annual basis.

EQUIPMENT CAPITAL COST

Equipment specific to a given material (e.g., eddy current, magnet) has been allocated to the specific material. However, it should be noted that each piece of equipment is really separating a certain material from other materials and from residue.

Although it has not been done for this Guide, it could be argued, for example, that allocation of an eddy current separator should not be 100 percent for aluminum. Instead, some of this cost should be allocated to residue and to other materials passing over the eddy current separator.

Some equipment is, however, specifically used for residue removal (e.g., grisly screens, rotary trommels) and can be allocated to residue and glass aggregate.

Other equipment (e.g., conveyors) is sized both for volume and weight. For purposes of this Guide, weight has been used to allocate these capital costs.

Rolling stock (e.g., skid steer and front-end loaders) have been allocated evenly among the materials, including residue.

Baler capital costs have been allocated based on the volume of each material that is baled, as a surrogate for the time spent baling each material.

Table 9.1: Estimated Processing Costs, by Material

Material	Low ($/ton)	High ($/ton)	Mean ($/ton)
Aluminum	96	266	166
Ferrous	60	97	74
Plastic Bottles	95	557	269
Glass	33	74	53
Residue	44	165	85
Paper Residue *			59
Container Residue *			296
Rejects *			137

* Data are only available from one of two participating MRFs for these three material streams.

LABOR

Sorting labor has been allocated based on videotape observations of the material sorted, including residue.

Rolling stock labor has been allocated evenly among materials.

Maintenance labor is more difficult to allocate. However, given the impact of broken glass on equipment, especially conveyor maintenance, maintenance labor has been allocated based on weight of materials.

BUILDING/EQUIPMENT MAINTENANCE AND OPERATIONS

Building and equipment maintenance and operation have been allocated by weight.

ADMINISTRATIVE

Administrative costs have been allocated evenly among materials, by dividing total administrative costs by the number of materials managed at the MRF.

IMPACT OF RESIDUES

As illustrated in Table 9.1, residue removal has significant impacts on labor and equipment costs at all MRFs. For this reason, residue is treated as a material, and costs allocated to residue similar to other materials.

ALLOCATION OF COST BY COST CATEGORY

It is also useful to allocate costs among the EPIC cost categories to highlight areas with the greatest potential for efficiency improvements.

As illustrated by Table 9.2, labor, averaging 42 percent of overall cost, is the largest single cost category. Therefore, improving sorter productivity should be of utmost importance to all MRF operators.

Table 9.2: Allocation of Costs by Cost Category (percent of total annual costs)

	Low	High	Mean
Buildings/Land Capital [1]	7	19	13
Equipment Capital [2]	9	17	13
O & M	12	42	22
Labor	28	52	44
Administration	5	20	12

[1] Amortized over 15 years.
[2] Amortized over 7 years.