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Sorting plastic bottles for recycling

By Ted Siegler and Ron Perkins

Optimum operational procedures and equipment requirements at MRFs for efficient materials sorting are detailed.

The continuing trend toward commingled recycling collection places greater emphasis on efficient sorting and processing at materials recovery facilities (MRFs). MRF operators have little control over the fluctuating prices paid for the materials they recover. Therefore, improving the economics of recycling requires that processing costs be minimized under all market conditions.

Between 1994 and 1997, the American Plastics Council (Washington) sponsored research at seven MRFs in the U.S. in an effort to improve the efficiency of handling plastic containers. Similar research was carried out concurrently by the Environment and Plastics Institute of Canada (Mississauga, Ontario) at six Canadian MRFs (see "New Resource-savings Guide for Plastics Reprocessing" in the October 1997 issue).

The U.S. study was carried out by DSM Environmental Services, Inc. (Ascutney, Vermont), with assistance from R.W. Beck (Orlando, Florida) and Proctor & Redfern Ltd. (Toronto). The complete results are available from APC in the guide *Sorting Plastic Bottles for Recycling*. Important findings are summarized here.

How data were obtained

MRFs accepting a wide variety of plastic containers, and representative of the major MRF owners and operators, were selected for this project (see Table 1). The names and locations of the MRFs are not disclosed because confidentiality agreements were signed with each MRF operator to improve the amount and quality of data to be collected, analyzed and reported.

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 MRF output also vary, depending on the quality of 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 significant sampling effort over an extended period of time. Such an effort was outside the scope of this project.

Data collection at each MRF ranged from two to four days. First, detailed information on operating parameters and costs for the commingled container line was collected from the MRF manager. Then, sampling of incoming and outgoing material was undertaken, together with video taping of sorting lines to analyze sorting rates by material. Analysis of the information gathered at each MRF allowed for the development of the following findings for each stage associated with the processing of commingled containers.

Effect of collection on processing efficiency

Estimating incoming quantities and density. Estimates of household generation, participation and capture rates for recyclable

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containers as well as the density of the collected containers are presented in Table 2. These estimates can be used to help identify building and equipment size best suited to maximize efficiency.

Types of contaminants. Except for broken glass, the largest categories of contaminants, by weight, of residential recyclable containers entering the participating MRFs are non-bottle rigid plastic containers (e.g., yogurt tubs and deli containers) and non-container plastic (e.g., flower pots, plastic toys), as shown in Table 3. Increased public education is necessary to better inform participating households to distinguish between plastic bottles and other plastic containers.

Impact of film plastic. 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 at the front end.

Even low levels of film (less the 20 percent of incoming material delivered in plastic bags) required two full-time-equivalent sorters to remove this film at two of the participating MRFs. In addition, the film that remained after attempts to remove it:

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

Therefore, 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.

Acceptance of all plastic bottles versus PET and HDPE only. Two of the participating MRFs serve programs that promote collection of all plastic bottles, while four of the participating MRFs serve programs that promote the collection of only PET and HDPE bottles. Table 4 illustrates that deliveries of bottle plastic other than HDPE and PET are essentially the same between the two programs that promote all bottles and those that promote only HDPE and PET bottles. Therefore, whether targeted or not, #3- #7 plastic bottles will be found in the commingled stream.

Table 1 Average daily throughput and materials recovered, by participating U.S. materials recovery facility (MRF)

MRF number	Average daily throughput of mixed bottles and cans, in tons/day	Material recovered: PET	HDPE natural	HDPE pigmented	PVC	#3- #7 bottles	PS foam	PS trays	Film	Clear glass	Amber glass	Green glass	Mixed cullet	Steel cans	Aluminum cans	Polycoated
1	70	X	X	X		X				X	X	X		X	X	X
2	120	X	X	X							X	X	X	X	X	
3	83	X	X	X						X	X	X		X	X	
4	55	X	X	X	X		X	X	X	X	X	X		X	X	
5	42	X	X	X	X	X	X		X	X	X	X	X	X	X	
6	36	X	X	X		X				X	X	X	X	X	X	
7	72	X	X	X						X	X	X	X	X	X	

Source: DSM Environmental Services, Inc., 1999.

Table 2 Estimates of incoming quantities of plastic bottles

Material	Density (lbs/yd³)	Weekly generation (1): Bottle bill (lbs/hh)	Weekly generation (1): Non-bottle bill (lbs/hh)	Capture rate (2) range (%)
Plastic bottles (total)	**30**	**0.52**	**0.75**	**N.A.**
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

hh = Household. N.A. = Not available.
(1) "Generation" is the total amount of bottles set out for recycling and set out for disposal.
(2) "Capture rate" is the total amount of recyclable material set out for recycling by a participating household, divided by the total amount of recyclable material generated by the participating household.
Source: DSM Environmental Services, Inc., 1999.

Material receiving and storage

Elimination of material storage backlogs is a key to improving MRF efficiency. A comparison of MRF 6, which processed all material delivered each day, with the other six MRFs, which maintained a backlog of material deliveries ranging from one day to as much as one week, revealed that:

- The quality of the material for processing appeared to be higher due to the lack of contact with other materials and with contaminants. Specifically, imbedded glass appeared to be less in the plastics, and liquid contamination was less 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 important, the amount of glass leaving MRF 6 as aggregate, as opposed to bottle cullet, was approximately one-half of the average for the other participating MRFs (see Table 6), due to less breakage from storage "management." In most cases, the percent of broken glass increased as the length of time the material stored on the floor increased.

It should be noted here that collection and transport also have a significant impact on material quality and glass breakage. MRFs that accept significant quantities of material from large transfer trailers will have more contaminated material and higher glass breakage than MRFs accepting primarily curbside-collected material delivered in the collection vehicle. This finding is irrespective of storage time on the tipping floor.

Improving manual sorting efficiency

The greatest potential for reducing the cost of processing plastic is likely to come from improvements on the sorting line. These improvements can come through increases in manual sorting efficiency or, in some cases, investment in automated sorting equipment.

Manual sorting rates. Video taping of the container flow and manual sorting of plastic containers was utilized to determine manual sorting rates. To minimize potential behavioral change by sorters associated with video taping, the video camera was set up and allowed to run throughout the day without an attendant. Table 5 presents the range of manual sorting rates measured at participating MRFs. The high rates reflect the highest sorting rates observed that could be sustained over the sorting day. The measured sustainable rates can be used to assess sorter productivity. Where rates at a particular MRF fall below or in the lower range of measured sustainable rates, the factors discussed below can be assessed to improve sorter productivity.

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

Contamination of material presented to the sorter. An average of 37 percent of observed sorter activity (ranging from 19 to 67 percent among the different MRFs) was devoted to removal of contaminants which, on average, represent only 3.7 percent of the incoming material stream. Thus, continued public education aimed at reducing contamination is a key to improving MRF efficiency.

Selecting proper mechanical separation equipment. Mechanical separation equipment often precedes manual sorting. Efficient manual sorting requires that mechanical separation function properly.

Observations at those participating MRFs utilizing air classification systems indicate that properly designed air classifiers can separate plastic from glass with limited crossover, either 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.

The primary criterion for selection of mechanical separation equipment should be performance 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. Video tape observations indicate that sorters were most efficient when presented with a consistent flow of plastic containers approximately one or two bottles deep (approximately four inches) at the beginning of the sort line.

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. This results in tumbling of lighter material down the conveyor and alternate peaking of heavy material (glass bottles and steel cans) and then of the lighter-weight plastic containers and aluminum cans on the sorting conveyors.

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

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. These error rates result in an acceptable range of contaminants for most plastic reclaimers.

Automated sorting

Because labor represents the largest single cost category at most MRFs, interest continues in automated sorting systems.

Two primary types of automated plastic bottle sorting systems exist. Single-line systems require that the plastic containers be separated from non-plastic containers and then be conveyed in a single line past detectors set up to identify plastic containers according to their physical and/or chemical properties.

Once the container has been identified, the system's 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.

Binary systems sort bottles of a single resin type from the remaining mass of plastic containers in a mixed plastic stream that has not been singulated. The ability to feed non-singulated containers significantly reduces space requirements, allowing for potential

Table 3 Average composition of incoming recyclable container material (in percent) (1)

Material	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 (2)	**0.0**	**0.5**	**—**
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 (lbs)	949	3,770	2,149

Note: Totals may not sum due to rounding.
(1) Based on sampling of truck deliveries as opposed to tipping floor composition collected at MRFs 1-4.
(2) MRF 7 does not accept polycoated containers.
Source: DSM Environmental Services, Inc., 1999.

Table 4 Comparison of the delivery of PVC bottles, #4- #7 bottles, and other rigid plastic packaging, as a percent of all plastic bottles (1)

	All-bottle programs		HDPE and PET only			
Material	MRF 1 (2)	MRF 4	MRF 2	MRF 5	MRF 6	MRF 7
All plastic bottles	**95**	**99**	**98**	**93**	**86**	**93**
HDPE	82	45	54	60	52	53
PET	11	48	43	29	32	39
PVC	1	3	1	1	1	1
#4 - #7	1	3	1	2	1	1
Rigid plastic containers	**5**	**1**	**2**	**7**	**14**	**7**
Total plastic	100	100	100	100	100	100

(1) Wide variation in the percent of PET and HDPE is due to the impact of container deposit laws.
(2) Disaggregation of plastic bottles based on previous sorting data from this MRF.
Source: DSM Environmental Services, Inc., 1999.

installations in existing MRFs with limited space. The disadvantage of a binary system is that it can achieve only one sort, instead of multiple sorting. Multiple sorting requires 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.

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

Capital costs for a complete binary system, including a feed conveyor, perforator/flattener to enhance performance and two modules to allow for three sorts, is approximately $200,000, exclusive of engineering, compressed air, electrical, support structures and storage cages.

Performance of a single-line automated system at a MRF. One of the participating MRFs uses a single-line system. Based on sampling over three seasons and one full year of operating history, it is clear that the system can operate in the MRF environment at costs that are competitive with manual sorting if the following conditions can be met.

- Space must be sufficient for the singulating and feed conveyors and the automated system.
- The automated system must be presented with a clean, plastics-only stream. At the participating MRF, the majority of all manual sorting on the commingled container line was devoted to contaminant removal prior to the automated line.
- Cost-effective operation requires that the automated system be fully utilized as many hours per day as possible. The participating MRF operated approximately 18 hours per day.
- Surge capacity, both in front of and at the discharges from the system, is necessary so that the automated system can be operated irrespective of manual sorter breaks and baler downtime.
- It is necessary to have one or more maintenance staff 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.
- Finally, in comparison to manual sorter error rates, contaminants measured at the participating MRF after automated sorting of PET, HDPE natural and HDPE pigmented ranged from a low of 5.3 percent to a high of 12.6 percent. Quality control labor (three person-hours per eight-hour shift at the participating MRF), stationed on the baler feed conveyor, is needed to further reduce contaminant levels to levels comparable with manual sorting.

Material densification

Many good references are available to MRF owners/operators concerning baler design and operation (several operational hints are offered in "Increase Baler Productivity and Improve Worker Safety" in this issue). Therefore, limited time was spent on this issue during this project. Yet, key observations were made:

- 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.
- Use of a perforator/flattener to flatten PET plastic bottles prior to baling is helpful in obtaining legal trailer load limit weights.

Table 5 Manual sustainable sorting rates, by plastic type at U.S. and Canadian MRFs (lbs/hr)

	Observed sustainable sorting rates		
Material	Low	High	Mean
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

Source: DSM Environmental Services, Inc., 1999.

Table 6 Annual output from the container line, by material, by participating U.S. MRF (in percent)

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 plastic	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

Note: Totals may not sum due to rounding.
Source: DSM Environmental Services, Inc., 1999.

MRF output

Data were obtained from all of the participating MRFs on the annual output of material, by type. As illustrated in Table 6, plastic bottles composed from 8.4 to 16.0 percent of total output from the container line.

Glass aggregate — material not returned for use in glass containers — accounted for an average 32.4 percent of total output from the container line from the participating MRFs, ranging from 17 to 45 percent. This represents between 30 and 72 percent of the total quantity of glass received at the participating MRFs. The large range in glass aggregate output indicates that this is an area with significant potential for improvement at some MRFs. As previously discussed, management of the incoming material to reduce storage time can significantly reduce glass breakage, and increase material revenue.

Allocation of costs

Ultimately, improvements in processing efficiency must be measured in improvements to the bottom line, through reduced costs and/or increased revenues. The EPIC computer model was used to evaluate costs at the participating MRFs.

Among materials. To identify potential areas for cost savings, it is useful to allocate capital and operating costs among the various materials processed at the MRF. These allocated costs then can be used to assess ways to improve efficiency on a material-by-material basis. Table 7 presents the wide range in per-ton costs, by material, for the participating MRFs for which sufficient information was provided to perform the allocation.

By cost category. It also is useful to allocate costs among the cost categories to highlight areas with the greatest potential for efficiency improvements. Table 8 presents this allocation.

Summary

The continued trend toward greater quantities and a greater variety of plastic containers, coupled with the inevitable fluctuations in plastic recycling markets, will require that MRF operators continue to assess all aspects of MRF operations to minimize costs and maximize revenues.

The results of research at seven MRFs on improving plastic processing suggest several areas with significant potential for reducing plastic bottle processing costs:

- Reduce contamination entering the MRF through consistent and clear education of recycling participants.
- Minimize material storage time on the tipping floor.
- Increase manual sorting rates by presenting sorters with a clean, consistent burden depth of containers.
- As the technology evolves, replace manual sorting with automated sorting.
- Improve baler efficiency and bale weight through installation of perforator and surge capacity.

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Table 7 **Allocation of MRF capital and operating costs among annual throughput of materials (dollars per ton)**

Material	Low	High	Mean
Aluminum	$ 96	$ 266	$ 166
Ferrous	60	97	74
Plastics	95	557	269
Glass	33	74	53
Residue	44	165	85

Source: DSM Environmental Services, Inc., 1999.

To obtain copies of *Sorting Plastics Bottles for Recycling* and the MRF Model by EPIC, contact the American Plastics Council at (202) 974-5400; 296-7154 (fax).

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