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Data Summary of Municipal Solid Waste Management Alternatives

Volume VII: Appendix E—Material Recovery/Material Recycling Technologies

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SRI International
Menlo Park, California

NREL Technical Monitors: Bimleshwar Gupta
Philip Shepherd

National Renewable Energy Laboratory
(formerly the Solar Energy Research Institute)
1617 Cole Boulevard
Golden, Colorado 80401-3393
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Report Organization

This report, *Data Summary of Municipal Solid Waste Management Alternatives*, comprises 12 separately bound volumes. Volume I contains the report text. Volume II contains supporting exhibits. Volumes III through X are appendices, each addressing a specific MSW management technology. Volumes XI and XII contain project bibliographies. The document control page at the back of this volume contains contacts for obtaining copies of the other volumes.

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MATERIAL RECOVERY/RECYCLING TECHNOLOGIES

E.1 INTRODUCTION/OVERVIEW

In its 1989 report, The Solid Waste Dilemma: An Agenda for Action (295), the U.S. EPA advocated the concept of integrated solid waste management, setting forth a hierarchy of solutions to the burgeoning solid waste disposal crisis in the nation, namely: 1) source reduction and reuse; 2) materials recycling and composting; 3) waste combustion with energy recovery; and 4) landfill disposal.

At that time, the U.S. EPA also proposed a national source reduction and recycling goal of 25 percent by 1992. While a national goal was never established through regulatory action, by 1990, 28 states and the District of Columbia had mandated ambitious recycling and waste management programs (776). The recycling goals established by these states are outlined in Table E-1. In addition to the ultimate goals listed in the table, many states have set interim goals as well. As noted, only a few states have separate targets for source reduction or composting.

The enthusiasm for and commitment to recycling is based on several intuitive benefits (295, 772, 774):

- o Conservation of landfill capacity
- o Conservation of non-renewable natural resources and energy sources
- o Minimization of the perceived potential environmental impacts of MSW combustion and landfilling
- o Minimization of disposal costs, both directly and through material resale credits

In this discussion, "recycling" refers to materials recovered from the waste stream. It excludes scrap materials that are recovered and reused during industrial manufacturing processes and "prompt industrial scrap," i.e., scrap generated in a production process that can be returned to the basic production facility for reuse (e.g., scrap ferrous and nonferrous metals) (723).

Materials recycling is an integral part of several solid waste management options. For example, in the preparation of refuse-derived fuel (RDF), described in Appendix B, ferrous metals are typically removed from the waste stream both before and after shredding. Similarly, composting facilities, covered in Appendix G, often include processes for recovering inert recyclable materials such as ferrous and nonferrous metals, glass, plastics, and paper. While these two technologies have as their primary objectives the production of RDF and compost, respectively, the demonstrated recovery of recyclables emphasizes the inherent compatibility of recycling with these MSW management strategies.

TABLE E-1. STATES' RECYCLING GOALS (776)

California	50%	by	2000	
Connecticut	25%	by	1991	
Delaware	30	by	1994	(1)
Dist. of Columbia	45%	by	1994	
Florida	30%	by	1994	
Georgia	25%	by	1996	(2)
Illinois	25%	by	2000	(3)
Indiana	50%	by	2001	
Iowa	50%	by	2000	
Louisiana	25%	by	1992	
Maine	50%	by	1994	
Maryland	20%	by	1994	(4)
Massachusetts	56%	by	2000	(5)
Michigan	50%	by	2005	
Minnesota	25%	by	1993	
Mississippi	25%	by	1996	
Missouri	35%	by	2000	
New Hampshire	40%	by	2000	
New Jersey	25%	by	1992	
New Mexico	50%	by	2000	
New York	50%	by	1997	(6)
North Carolina	25%	by	1993	
Ohio	25%	by	1994	
Pennsylvania	25%	by	1997	
Rhode Island	maximum possible			(7)
Vermont	40%	by	2000	
Virginia	25%	by	1995	
Washington	50%	by	1995	
West Virginia	30%	by	2000	

(1) The goal combines a 10 percent recycling target with a 20 percent composting target.

(2) 25 percent of 1992 per capita waste generation.

(3) This goal only applies to countries with populations greater than 100,000.

(4) Twenty percent recycling is the optimum goal. Countries with populations under 150,000 must recycle at least 5% of their waste.

(5) The goal calls for a 46 percent recycling rate and a 10% reduction in 1990 per capita waste generation rate by 2000.

(6) The goal combines a 10 percent source reduction target and a 40% recycling target.

(7) Municipalities must achieve a least 15% recycling by 1993.

Facilities that have as their primary function the processing and marketing of recyclables, received as either commingled or source separated, are typically referred to as materials recovery facilities (MRFs). MRFs can be operated in conjunction with drop-off centers, where community residents voluntarily deposit recyclables, and/or buy-back centers, where the public receives payment for pre-sorted, pre-separated materials (769).

The designation "MRF" has also been extended to encompass the recovery of recyclables from mixed municipal solid waste (723). In order to avoid confusion in terminology, a mixed waste MRF is defined here as a materials recovery facility whose primary function is to separate marketable recyclables from mixed municipal solid waste. This definition of a MRF excludes recycling as a part of RDF production and composting, but includes front-end processing systems for mass burn plants. These MRFs or front-end processing systems (as they are more commonly called) serve not only to recover recyclables, but also to minimize the introduction of glass or aluminum that can foul the combustor, and household batteries that can lead to air emissions problems.

This appendix discusses several technology options with regard to separating recyclables at the source of generation, the methods available for collecting and transporting these materials to a MRF, the market requirements for post-consumer recycled materials, and the process unit operations. Mixed waste MRFs associated with mass burn plants are also presented.

E.1.1 Complexity of Recycling Decision-Making

Materials recycling alternatives involve a variety of technologies, each having technical, economic, and institutional impacts. Any recycling application involves decisions on technologies for:

- Collection
- Materials separation and processing
- Repackaging
- Resale
- Reprocessing and reuse as a consumer or industrial product
- Disposal of rejects from separation, processing and reprocessing

These decisions are highly influenced by such factors as waste quantities and composition, and secondary (i.e., resale) market availability, as well as a variety of subtle institutional factors. Of the non-technical factors, the level of citizen and industry participation, along with existing administrative structures and traditions, are key determinants in the selection, initial success, and progress of a recycling program. (774)

A variety of factors must be considered in the conceptual design of a recycling program and its MRF (723, 295, 773):

- Quantity and composition of the waste stream in the service area. MSW feedstock characteristics affect the economic and technical feasibility of materials recovery strategies and technologies including equipment selection and facility sizing. For example, if bottle bill legislation exists, the quantity of aluminum beverage containers that will end up in a MRF will be much less than if no such legislation were in effect.

- Types and quantities of materials targeted for recovery. These factors determine the extent of generator participation and the processing steps required at a MRF. Modest program objectives possibly can be accomplished by a combination of selective targeting of recyclables and less capital intensive processing. Depending on the waste composition and other factors, an ambitious program may require more pervasive involvement of waste generators and higher degrees of processing to maximize materials separation and recovery.

- Quality of recyclable materials required by end-users. Higher degrees of recovered material quality, especially from the standpoint of contamination, may dictate generator set-out protocols, collection methods, and processing alternatives. The absolute quantity of recyclable materials processed for resale also may affect marketability. Large producers can seek volume uses and collaborate more on quality specifications; small recyclers typically must conform to the market norms.

- Degree of generator involvement desired and participation attainable. Determining the expected deliveries to the MRF, regardless of the form (source separated or mixed waste) is essential to the sizing of the collection fleet and the MRF. In addition, the reliability of material flows affect the processing efficiency, market commitments, and financing arrangements. Deliveries to a MRF processing source-separated materials are a function of the waste generation rate, generator participation, and generator separation efficiency (if applicable).

- o <u>Degree of technical risk to be assumed</u>. More ambitious recycling goals can be met through various approaches to collection and processing Selection of more capital-intensive, automated approaches must balance the promise of higher recovery rates, enhanced material quality, and unit cost against the risks of system reliability and technological obsolescence.

- o <u>Degree of marketing risk to be assumed</u>. Decision-making on program design assumes that the targeted recyclable materials can be reused in some beneficial manner, thereby avoiding their disposal and optimizing their resale value. Failure to accomplish these objectives results in incurring disposal costs and/or costly materials processing. For example, a decision to commingle paper with glass in collection or processing might sufficiently contaminate the paper so as to adversely affect its marketability. Or, for example, an investment in plastic granulator equipment might reduce transportation costs, but might reduce the value to certain end-users who would be unable to ascertain the level of contaminants in the material.

- o <u>Collection alternatives available</u>. Unlike most other solid waste management alternatives, materials recycling can greatly affect waste collection methods and costs. In general, greater source separation requires different approaches to collection that directly affect productivity and costs. It is essential that the incremental costs and potential environmental impacts of these different collection technologies be considered in program analysis. Also, certain collection-related limitations must be considered, including population density issues, traffic congestion, noise, safety, fleet maintenance needs, and parking needs.

- o <u>Compatibility with other components of the local solid waste management system</u>. While the U.S. EPA hierarchy (295) favors recycling over combustion and landfilling, it also contemplates that all four waste management options complement one another to safely and efficiently manage MSW. Recycling "is <u>not</u> meant to be rigidly applied when local unique waste and demographic characteristics make source reduction and recycling infeasible" (295).

- o <u>Overall program cost</u>. The overall cost of alternative programs must be assessed; this includes collection, processing, resale, and public education.

- Public education strategies. The implementation of a recycling program requires an initial program to educate all involved parties on acceptable practices and the need to implement them. It is likely that the education program will need to be continued to sustain or to improve recycling performance. As a companion to education, new ordinances and compliance policies must be implemented.

E.1.2 Current Status of Recycling in the U.S.

An estimated 13 percent of the MSW generated in the United States was recovered from the national waste stream for recycling in 1988 (774). This number represents contributions from commercial, industrial, and household sources, spanning materials recovery/recycling facilities and curbside collection programs as well as bottle redemption, drop-off, and buy-back centers. Recycling in this context refers to the materials recovered from the waste stream as opposed to the lessor amount actually made into new products. Table E-2 indicates how the entire solid waste stream has been, and will likely continue to be managed for the period 1980-2000 (774, 776).

Table E-3 itemizes materials recovered from MSW in 1988 and the percentage that each recovered waste fraction represents of that generated (774). Of the approximate 180 million tons of materials recycled, almost one-fifth is paper and paperboard products. This quantity represents about 26 percent of paper products generated as waste. Although representing smaller absolute fractions of the overall waste stream by weight, glass and metals are materials prominently recycled with 12 and 15 percent of virgin material recovered, respectively. Based on projections for recycling by respective industries manufacturing the major commodity components of MSW, the goal of 25 percent recycling by the mid-1990s may be achievable (777).

For the residentially-generated component of MSW, one significant trend is the emergence of greater mandatory or voluntary source separation of recyclable materials. These so-called "curbside programs" require the participation of residents to separate recyclable materials into one or more fractions for collection. Biocycle magazine reported (778) that, in 1989, 1,042 curbside programs existed in 35 states (Table E-4). There has been considerable growth since that time with the implementation of ambitious programs in New York, Florida, California, Ohio, and other states.

TABLE E-2. HOW U.S. WASTE IS MANAGED (776)

	1980		1986		1988		1995		2000	
	tons (1)	%	tons (1)	%	tons (1)	%	tons (1)	%	tons (1)	%
Recycling (2)	14.5	10	18.3	11	23.5	13	48.3	24	54.4	25
Waste-to-Energy	2.7	2	9.6	6	24.5	14	45.0	23	55.0	26
Incineration (3)	11.0	7	3.0	2	1.0	2	0.5	0.3	0.1	<.1
Landfill	121.4	81	136.5	82	130.5	73	106.0	53	106.5	49
	149.6	100	167.4	100	179.5	100	199.8	100	216	100

(1) All tons in millions of TPY.
(2) Recycling used in this context refers to materials recovered from the waste stream as opposed to the lesser amount made into new products.
(3) Incineration without energy recovery.

TABLE E-3. MATERIALS RECOVERED IN THE U.S., 1988 (774)

	Amount Generated (1)	Amount Recovered (1)	% of Material Generated
Paper and Paperboard	71.8	18.4	25.6
Glass	12.5	1.5	12.0
Metals	15.3	2.2	14.4
Plastics	14.4	0.2	1.4
Rubber and Leather	4.6	0.1	2.2
Textiles	3.9	0	0.0
Wood	6.5	0	0.0
Food Waste	13.2	0	0.0
Yard Waste	31.6	0.5	1.6
Other	5.8	0.7	12.1
Total	179.6	23.6	13.1

(1) In millions of tons.

TABLE E-4. CURBSIDE RECYCLING PROGRAMS (778)

	Curbside Recycling Programs:					
State	*Number*	*Population Served*	*Multi-Material*	*Single Item*	*Mandatory*	*Voluntary*
AL	3	N/A	2	1	0	3
AK	0	—	—	—	—	—
AZ	1	N/A	1	0	0	1
AR	2	10,000	2	0	0	2
CA	62	3,300,000	62	0	0	62
CO	2	N/A	2	0	0	2
CT	24	N/A	18	6	12	12
DE	0	—	—	—	—	—
DC	0	—	—	—	—	—
FL	8	N/A	7	1	0	8
GA	UNK	N/A	—	—	—	—
HI	0	—	—	—	—	—
ID	0	—	—	—	—	—
IL	25+	N/A	25+	—	0	25+
IN	9	N/A	9	0	0	9
IA	1	15,000	1	0	0	1
KS	0	—	—	—	—	—
KY	0	—	—	—	—	—
LA	3	100,000	3	0	0	3
ME	2	25,000	2	0	1	1
MD	5	N/A	5	0	0	5
MA	7	N/A	4	3	N/A	N/A
MI	5+	N/A	N/A	N/A	0	5+
MN	93	N/A	87	6	6	87
MS	0	—	—	—	—	—
MO	8	N/A	7	1	0	8
MT	0	—	—	—	—	—
NE	2	N/A	N/A	N/A	0	2
NV	0	—	—	—	—	—
NH	2	30,000	2	0	0	2
NJ	439	N/A	439	0	439	0
NM	0	—	—	—	—	—
NY	UNK	—	—	—	—	—
NC	3	15,000	2	1	0	3
ND	0	—	—	—	—	—
OH	13	175,000	11	2	0	13
OK	1	—	1	—	—	1
OR	106	2,600,000	106	0	0	106
PA	141	1,300,000	75[a]	N/A	55	86
RI	8	300,000	8	0	8	0
SC	2	N/A	2	0	0	2
SD	0	—	—	—	—	—
TN	0	—	—	—	—	—
TX	2	100,000+	2	0	0	2
UT	0	—	—	—	—	—
VT	1	10,000+	1	0	0	1
VA	4	N/A	3	1	1	3
WA	4	500,000+	4	0	0	4
WV	2	N/A	2	0	0	2
WI	50+	N/A	37	13+	7	43
WY	0	—	—	—	—	—
TOTAL	1042	8,480,000	932	35	529	504

[a]*Programs with three or more materials.*

E.2 TECHNOLOGY DESCRIPTION

Figure E-1 depicts several technology options for the separation and collection of recyclables that feed a MRF. The characteristics of the MRF feed stream are directly related to the processes utilized in the MRF. For example, highly separated materials (streams A, B, and C) will require minimal processing. The following sections discuss the complete source separation, collection, and processing components of a materials recovery program. Case studies are provided to illustrate the recycling options, as appropriate.

E.2.1 Generation of Recyclables

Recyclables can be either source separated by residents and commercial businesses or they can be mixed with the non-recyclable MSW. Source separation refers to the segregation of recyclable components from the non-recyclable portion of MSW through the use of one or more plastic bins or bags. (Plastic containers are waterproof unlike paper bags and corrugated boxes.) The specific materials to be recycled and the degree of source separation required are defined by the recycling program. Materials are selected based on the availability and reliability of markets.

The separation method selected will have a direct influence on the effectiveness of the recycling program. Generally speaking, the less residents have to do to comply with the recycling program requirements, the more likely they are to participate (265). In addition to the degree of material separation, the degree of household preparation of the materials affects both the perceived inconvenience of participation and the market value of the recyclables (264). The rinsing of all containers, removal of metal caps from glass containers, and the removal of labels from metal cans all positively affect the market value of the products. Such requirements may also make recycling too inconvenient for certain residents, perhaps resulting in a significant decrease in participation. Thus, the trade-offs between participation and market value must be considered.

A public attitude survey conducted in New York's Oneida and Herkimer counties found that the perceived inconvenience of recycling increases with the number of separation and preparation steps requested (339). The survey also confirmed that most residents were unwilling to make more than two separations from their mixed waste. Research has shown that the participation rate doubles when recycling containers are provided to residents, but the participation rate does not necessarily increase with the number of individual containers provided (334).

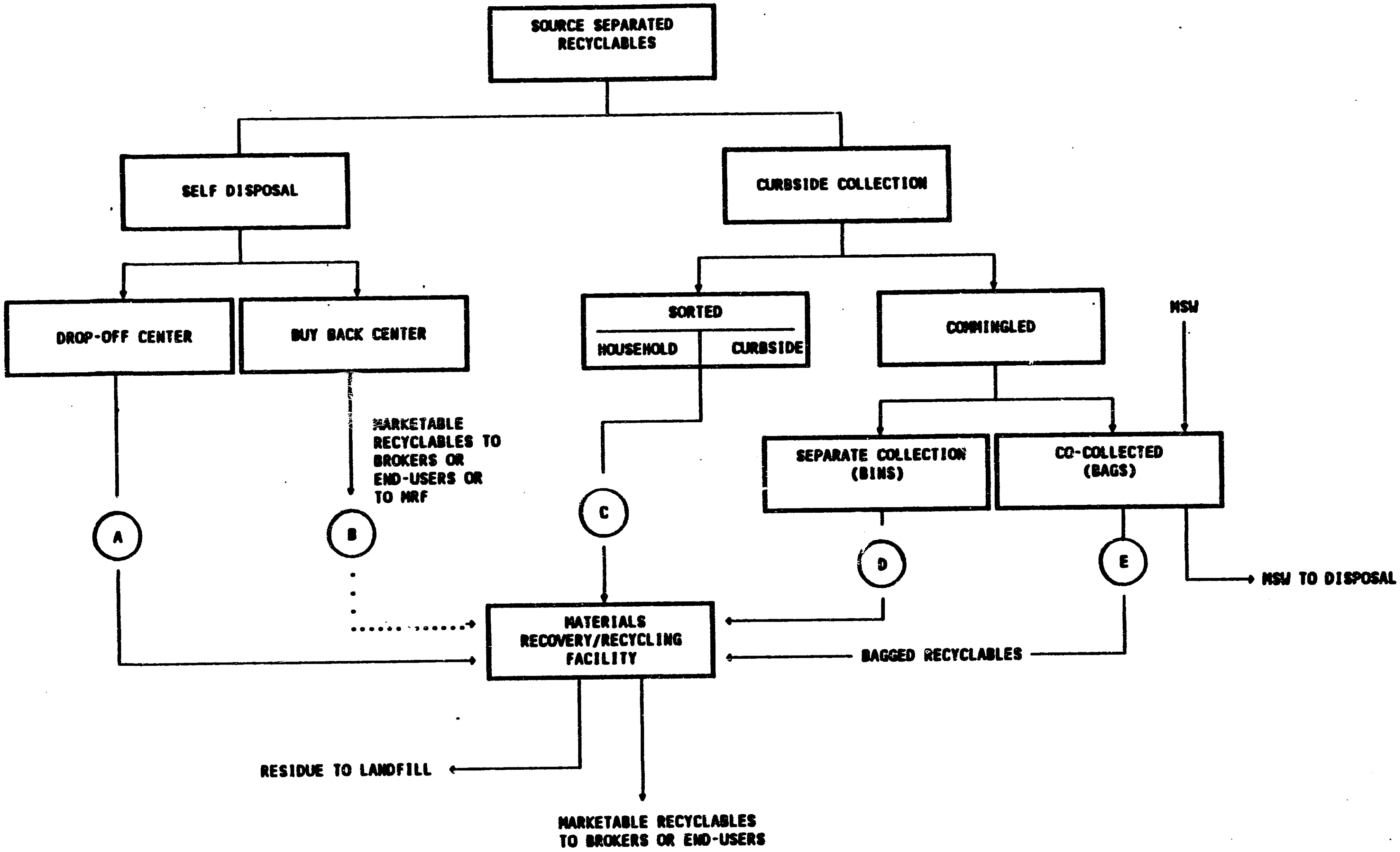

Figure E-1. Options for Recovering Source-Separated Recylables

Obviously, the most convenient source separation recycling scheme from the residents' perspective is where all the recyclables are mixed (commingled) in one container for pick up at the source (curbside), leaving any further material separation up to either the collection crew or to a MRF. A commingled recyclable requirement is generally believed to maximize public participation (265).

An alternative to source separation is to leave the recyclables intermixed with the MSW and remove them, for example, in a front end process prior to a mass burn system. This option requires a substantial amount of processing at the MRF to recover the recyclables. The generator participation rate is not a concern with this method, since the sole responsibility for material recovery is on the mixed waste MRF itself.

E.2.2 Collection of Recyclables

Recyclables can be either delivered to a drop-off center or buy-back center, or collected from the point of generation, at curbside. Again, the method used will influence the effectiveness of the recycling program.

E.2.2.1 Curbside Collection

Collection can accommodate many degrees of source-separated materials. When the generator separates recyclables into discrete product-specific containers at curbside, collection crews can simply load each material into its own compartment on a specially designed collection vehicle. In programs where the generator commingles all recyclables into one bin with newspapers separately bagged, the collection crew typically sorts the recyclables at curbside. Alternatively, the commingled recyclables can be transported to a MRF where separation will take place.

Combinations of these approaches also are possible. For example, residential waste generators could be required to separate glass generically, and the collection crew would sort glass into its clear, green, and brown fractions.

The specific type of curbside collection program selected will be a function of the community's demographics, the availability and reliability of processing facilities, the type of collection vehicles used, and community values (258). If the materials are to be directly marketed instead of being processed in a MRF, they must be either separated into individual components by the generators or by the collection crew. If the materials are to be processed in a MRF, the complexity of the MRF (i.e., its capability for material separation) will determine whether the incoming materials can be commingled.

The day and frequency of collection also can affect the participation rate and the total tonnage recycled. Weekly, bi-monthly, and monthly collection frequencies may be valid choices. The most convenient arrangement is for recyclables to be collected on the same day as the mixed MSW. Bi-weekly collection may be less costly than weekly collection, but it can reduce program participation due to confusion and a loss of the perceived "mandatory impact", since the mixed trash would most likely be picked up whether or not the household participated in the recycling program (325). The collection frequency will also influence the size of the collection container required.

The use of dedicated recycling containers has the following advantages (334):

- They make sorting and storing recyclables in the home convenient and their presence is a constant reminder of the need to recycle.

- The presence of containers at curbside on collection day raises awareness of recycling, and may create a "peer pressure" that encourages non-participants to recycle.

- Dedicated recycling containers are easily distinguishable contributing to the efficiency of the collection process. The efficiency of collection can also be increased if residents put out full containers.

- Constructed of plastic, they can resist the degradation that befalls paper containers which can result in scattering of recyclables and increased collection time.

An alternative to the conventional curbside collection bin method is known as the "blue bag" co-collection system. Under this method, recyclables are placed in a specially colored plastic bag (typically blue) and placed at the curb with the remainder of the trash. The bags are collected in the same vehicle that hauls the trash, eliminating the need for separate collection by specialized vehicles. The bags are separated from the mixed waste at the receiving facility, and transported to a MRF. This option is effective only if the MRF is located in close proximity to the disposal site to minimize transportation costs.

The advantages listed for the use of recycling containers also apply to special plastic bags. Storage in the home may not, however, be as convenient with bags as with a rigid container.

The advantages of curbside collection include:

- Low capital and operating costs for processing if materials are highly sorted
- Negligible technical risk
- Typically high quality of recycled materials if materials are highly sorted
- Higher participation by generators than drop-off centers due to the convenience of curbside collection
- Flexibility in responding to changes in waste composition or participation rates
- Flexibility in changing targeted recyclable materials

The disadvantages of curbside collection include:

- Collection capital and O&M costs are high, expressed on a per collection stop and per ton basis. Operating costs for curbside sorting by collection crews are higher than for collection of intensive source separated materials
- Participation rates for source separation may be low due to the behavioral change required by waste generators
- Practical limitations on the number of compartments on vehicles (along with sorting participation and collection costs) restrict the degree of separation possible at the curbside, thereby requiring further processing at the MRF
- To standardize set-outs, communities or private collection companies normally provide each household with one bin for each separation required. This adds to the program costs. In addition, there is limited experience on the long term durability of recycling bins or on vandalism and theft rates

No comprehensive survey data are available on the number and performance of curbside sorting programs in the United States. However, Snow (327) conducted an in-depth survey of 24 sample programs in 1989; data are summarized in Table E-5. The study indicates a variety of materials, separation approaches, collection techniques, and public/private contracting arrangements. It appears that waste reduction of 10 to 12 percent is attainable (327).

Powell (669) has reported that as of early 1991 about 2,000 U.S. communities collect recyclables from residences, and that the majority of these programs require the separation of paper, bottles, and cans. The trend, however, appears to be toward the commingling of recyclables in one bin at the curb followed by separation at a MRF.

E.2.2.1.1 New Jersey Programs. A study was conducted in 1990 on 12 New Jersey recycling programs in communities whose populations ranged from 5,000 to 300,000 residents. The survey results are presented in Tables E-6 and E-7 (669).

The results show that the average overall cost of a program using the commingled collection scheme was 41 percent higher than that of a program using complete material separation due to the high costs of the requisite MRF. The recovery for commingled collection programs was 15 percent higher than that for complete separation systems, probably due to lower participation because of the increased set out requirements. Conversely, the material revenues from complete separation programs were higher than those from commingled programs, a fact attributed to less glass contamination. Additional survey results are presented in Table E-8. These results are average values for both program types.

E.2.2.1.2 San Jose, California. As part of a comprehensive waste reduction program, the City of San Jose, California, has conducted an intensive curbside recycling program since 1986. As of April, 1989, recyclables were collected from more than 70 percent of the city's 180,000 households, diverting more than 10 percent of the residential refuse from the landfill (334). Residential generators set out three separate stackable bins, one containing bi-metal and aluminum cans, one containing mixed glass containers, and one containing newspapers. A private hauler collects the materials in a dedicated, three-bin vehicle for transport to a MRF.

San Jose reports that approximately 57 percent of households served by the program actually participate (291), although no data has been reported on estimates of material capture rates for the participating households. The City of San Jose estimates that the program recycles about 22,000 tons per year.

TABLE E-5. COMPARATIVE DATA, CURBSIDE RECYCLING PROGRAMS (327)

Program	Start-Up Year	Population Served	Households Served	Voluntary Or Mandatory?	Coll't	Refuse Coll't?	Freq. Of Refuse Coll't	Containers Provided	Type	Program Operator	Vehicle	Sorting	Marketing	Refuse Disposal Price $/ton	Refuse Disposal Distance Miles
Barrington, RI	1972	17,700	5,600	mandatory	monthly	yes	once/week	in future	12 gal blue	municipal crews	Ford F-350 w/ dividers	kept separate	mun. rec. ctr.	30(ts)	2
Broome County, NY	1987	37,200	13,500	voluntary	weekly	yes & no	once/week	yes	5 gal black	municipal crews & w/refuse hauler	truck & trailer	commingled	mun. rec. ctr.	12(lf)	11
Bucks County, PA	1989	115,000	29,500	mandatory	weekly	yes	twice/week	yes	6 gal green & red	contract w/refuse hauler	recycling truck	kept separate	mun. rec. ctr.	51(lf)	20
Deschutes County, OR	1985	25,000	10,000	voluntary	weekly,N monthly, cans & bottles	yes	once/week	yes (pilot area only)	5 gal	contract w/refuse hauler	refuse trucks & recycling trucks	kept separate	nonprofit rec. ctr.	10(lf)	3
Hamburg, NY	1981	11,500	3,350	mandatory	weekly	yes	once/week	no	n/a	municipal crews	truck & trailer	cans & bottles mixed; paper & oil kept separate	mun. rec. ctr.	66(ts)	3
Longmeadow, MA	1984	15,971	5,672	mandatory	weekly	yes	once/week	no	n/a	private contract	refuse truck	kept separate	mill direct	19(wte)	5
Mecklenburg Cnty, NC	1987	40,000	9,166	voluntary	weekly	yes	twice/week	yes	10 gal red	municipal crews	recycling truck	commingled	mun.. rec. ctr.	18(lf)	
Metro Toronto, ONT	1988	800,000	250,000	voluntary	weekly	yes	twice/week	yes	1.5 cf	municipal crews	refuse truck & recycling truck	commingled by resident & sorted truck-side	private rec. ctr.	50(lf) 65(ts)	
Montclair, NJ	1971	38,600	14,500	mandatory	bi-weekly	no	twice/week	no	n/a	municipal crews	step van & trailer	cans & bottles commingled; news kept separate	private rec. ctr. & mun. rec. ctr.		
Newport, RI	1988	24,200	9,700	mandatory	weekly	yes	twice/week	yes	10 gal blue	contract w/refuse hauler	recycling truck	bottles & cans commingled;paper sorted truck-side	municipal "MRF"	11(lf)	39
Onondaga County, NY	1988			voluntary; will be mandatory	weekly	yes	once/week	yes	10 gal blue	contract w/refuse hauler; private contract; & mun. crews		kept separate	private rec. ctr. & mun. rec. ctr.	28(ts)	
Orlando, FL	1987	151,654	38,114	voluntary	weekly	yes	twice/week	yes	12 gal blue	municipal crews	borough truck	kept separate	private rec. ctr.	15(lf) 18(ts) 25(lf)	16 8 35
Prairie du Sac, WI	1982	2,290	1,100	mandatory	weekly	no	once/week	yes	33 gal clear bags						
Roanoke, VA	1987	pilot area	1,000	voluntary	weekly	yes	once/week	yes	3-10 gal: bl,grn & or	municipal crews	renovated truck	kept separate	private rec. ctr.	16(lf)	
St. Cloud, MN	1983	43,000	10,107	mandatory	monthly	no	once/week	no	n/a	municipal crews	recycling truck	kept separate	private rec. ctr.	50(ts)	5
Sarasota, FL	1986			voluntary	weekly	yes	twice/week	yes	14 gal red	private contract	noncompacting side loader	n/a	private rec. ctr.	14(lf)	8
Sauk County, WI	1979	12,000	3,000	varies	weekly	varies	once/week	yes	clear bags	varies	varies	kept separate & commingled	nonprofit rec. ctr.		
Seattle, WA	1988	500,000	147,000: eligible; 94,101: service	voluntary	1/2 wkly; 1/2 mthly	varies	once/week	yes	1/2 60 or 90 gal; 1/2 3-bins	contract with refuse haulers	refuse truck & recycling truck	1/2 kept separate; 1/2 commingled	private rec. ctr.	62(ts) 32(lf)	30
Sunnyvale, CA	1982	114,000	28,000	voluntary	weekly	yes	once/week	yes	burlap bags	municipal crews	recycling truck	al., tin & plastic commingled; the rest kept separate	mun. rec. ctr.	30(lf)	
Upper Arlington, OH	1988	36,000	12,000	voluntary	weekly	yes	once/week	no	n/a	municipal crews	refuse truck	kept separate	private rec. ctr.		
Wilkes Barre, PA		50,500	13,500	mandatory	weekly	no	once/week	no	n/a	municipal crews	recycling truck	kept separate	private rec. ctr.	60(ts)	2
Woodbury, NJ	1981	10,353	4,200	mandatory	weekly	no	once/week	no	n/a	municipal crews	refuse truck & recycling truck	kept separate	private rec. ctr.	60(lf)	27
Somerset County, NJ	1986	220,000	80,000	mandatory	bi-weekly	varies	varies	no	n/a	municipal crews	recycling truck & step van	commingled	mun. rec. ctr.	126(ts)	
Hempstead, NY	1987	55,000	14,500	voluntary	weekly	yes	twice/week	yes	10 gal. blue	municipal crews	recycling truck	commingled & sorted truckside	private rec. ctr.	66(ts)	3

TABLE E-6. COMPARISON OF CURBSIDE RECYCLING OPTIONS (669)

	Commingled	Complete Separation
Household	Less storage space needed Fewer containers to set out	More storage space needed More container to set out
At the curb	Fewer containers to dump and return to curb	More containers to dump and return to curb
Quantity	More weight per container	Less weight per container
In Transit	Better truck utilization can serve longer route before unloading	Poorer truck utilization, shorter route before needing to unload
Unloading	Less time needed	More time needed
Processing	More costly	Less costly
Residue	More residue (15 to 30 percent)	Less residue (5 to 10 percent)

TABLE E-7. COMPARISON OF NEW JERSEY CURBSIDE COLLECTION PROGRAMS (669)

	Commingled	Complete Separation
Average cost of collection and processing	$129/ton	$91/ton
Collection cost savings	$10-$15/ton	$0
Processing plant for complete separation	$0	$63/ton
Average recovery, lb/capita/year	171	148

TABLE E-8. AVERAGE CHARACTERISTICS OF NEW JERSEY COLLECTION PROGRAMS (669)

Hauler operated programs	4
Municipality operated programs	8
Collection efficiency	125-500 lb/capita/yr
Unloading trips per day	1.5
Average household cost	$23/yr
Average households serviced per day	330
Average households per stop	1.2
Collection time at curb	59 seconds/stop
Travel between stops	45 seconds
Unloading	
Round trip transit time	15 minutes
Set up for unloading	9 minutes/trip
Unloading	15 minutes/trip

E.2.2.2 Drop-off Centers

Drop-off centers are centralized locations where a specified class of waste generators, typically residential generators, may voluntarily bring certain recyclable materials. Generators are not compensated for materials deposited at a drop-off center. A drop-off center can be as simple as several small capacity containers that temporarily store the materials for regular pickup and transportation to market or a central consolidation facility or it can consist of the central consolidation facility itself. Because programs of this nature are voluntary, participation is often poor. However, participation can be enhanced by public education, economic incentives (e.g., incorporating a buy-back feature), and ordinances that increase the difficulty to otherwise dispose of recyclable materials. Both buy-back centers and drop-off centers seldom capture as much as 10 percent of the waste stream (547).

Prosser (185) recently projected a 20 percent recycling rate for glass containers in the United Kingdom based on collection at voluntary drop-off centers. It was noted that this recycling rate can only be achieved by increasing the density of drop-off sites to 1 per 2,000 households or greater. Also, in 1990, the EPA noted that in the U.S., approximately 20 percent of glass was recycled based on all recycling sources, not just drop-off sites (777).

The physical layout of a drop-off center varies by location, the volume and number of recyclable materials processed, and level of supervision. A conventional drop-off center would be centrally-located within a service area and provide bins or compartmentalized containers for waste generators to deposit recyclable materials. To ensure material quality and public safety as well as to prevent scavenging, many drop-off centers have controlled access, limited hours of operation, and are monitored by attendants. Once a sufficient quantity of a material has been collected, it can be shipped to end-users or intermediaries in the container in which it was collected or, more often, transferred to a larger container. Correct sizing and type of containers are key design features to address, along with traffic access and security.

The smallest drop-off center might be a neighborhood "kiosk-like" or igloo container, unattended and conveniently located to maximize its use. These containers typically are satellite operations for a centralized facility where further consolidation and repackaging would occur to achieve maximum quantities for resale. However convenient these unattended containers, they are vulnerable to contamination, odors, vectors, and vandalism, aside from adding additional transportation and handling costs. The successful development and implementation of drop-off programs is highly dependent on other program factors and local conditions.

Advantages of drop-off centers include:

- o Low capital and operating costs
- o No technical risk
- o No mandatory change in waste generator behavior
- o Flexibility in responding to changes in waste composition or participation rates
- o Flexibility in changing targeted recyclable materials

Disadvantages of drop-off centers include:

- o Lower participation rates due to the voluntary nature of the program and the inconvenience associated with sorting and transporting materials to a remote location
- o Low quantities of materials collected thereby limiting marketing with respect to price and prospective users
- o Low quality of materials, especially when center is unattended

A limited survey conducted by Biocycle in 1988 (779) is reproduced as Tables E-9, E-10, and E-11, illustrating the scope and performance of selected drop-off programs nationwide. Convenient siting, more efficient equipment, public education, and economic incentive programs are cited as key elements in successful programs (779).

E.2.2.2.1 Wellesley, Massachusetts. A longstanding, successful operation is in Wellesley, Massachusetts, a community of 27,000 located southwest of Boston. This town has capitalized on the logistical patterns of residents by establishing a drop-off center at the town's transfer station, the sole location for residents to dispose of MSW (no municipal collection is provided). Residents are able to recycle old newspaper (ONP), old corrugated cardboard (OCC), mixed paper, three colors of glass, aluminum cans, ferrous bimetal cans, high density polyethylene (HDPE) containers, waste motor oil, tires, batteries (automotive and household), scrap metals, wood, yard wastes, books, clothing, and bulky wastes at an attended center comprised of assorted bins and roll-off containers. In 1989, approximately 19 percent of wastes were recycled and thus diverted from the adjacent transfer station (291).

TABLE E-9. DROP-OFF PROGRAMS – GENERAL CHARACTERISTICS (779)

Location	Population Served (Estimated)	# of Sites	Pop Served/ Site	Materials Collected	Participation Rate
Champaign Co., IL	171,000	15	3,000-20,000	N, G, A, T, HDPE, OCC, MO	18%
Columbia Co., PA	50,000	17	3,000 (Ave)	N, G, A, T, OCC	25-30%
Cook & Lake Co., IL	270,000	18	N/A	N, G, A, T	N/A
Delaware Co., PA	500,000	50	10,000 (Ave)	Glass only	25%
Durham Co., NC	120,000	10	10,000-15,000	N, G, A	8%
Fairfax Co., VA	75,000	8	N/A	N, G, A, BI-M	10%
Kent/Ottawa Co., MI	650,000	30	N/A	N, G, A, T HDPE, OCC	4%
Santa Monica, CA	70,000	66	Up to 2,000	N, G, A, T	28%
Snohomish Co., WA	N/A	15	1000-2000	N, G, A	N/A
Wayne Co., NY	30,000	4	N/A	N, T, OCC	N/A

Key: N -Newsprint; G—Glass; A—Aluminum; T—Tin & Bi-Metal Cans; BI-M—Bi-Metal Cans; OCC—Corregated Cardboard; MO—Motor Oil

TABLE E-10. DROP-OFF PROGRAMS – AMOUNTS OF MATERIALS RECYCLED (779)

		ANNUAL TONNAGE									
	All Materials	News		Glass		Aluminum		Tin		Others	
Location	(Tons)	Tons	%	Tons	%	Tons	%	Tons	%	Tons	%
Champaign Co., IL	1000	750	75	160	16	5	.5	15	1.5	70 (OCC)	7
Columbia Co., PA	469	271	58	88	19	6	1	19	4	85	18
Cook & Lake Co., IL	7140	5800	81	1200	17	75	1	65	1	–	–
Delaware Co., PA	1800	–	–	1800	100	–	–	–	–	–	–
Durham Co., NC	1200	900	75	300	25	–	–	–	–	–	–
Fairfax Co., VA	1000	721	72	271	27	–	–	–	–	–	–
Kent/Ottawa Co., MI	3200	2225	70	669	20	1	–	158	5	157	5
Santa Monica, CA	1398	1032	74	360	25.5	–	–	–	–	–	–
Snohomish Co., WA	233	67	29	159	68	7	3	–	–	–	–

TABLE E-11. DROP-OFF PROGRAMS – SITE AND COLLECTION CHARACTERISTICS (779)

Location	Type Container	Storage Capacity/ Site	Collection Equipment	Crew Size	Collection Frequency
Champaign Co.	Compartment container/ lugger & barrel	15 cy-40 cy	Multi-lift/lugger truck & van	1	1/wk-1/mo
Columbia Co.	Shelters	7 cy	Van	2	2-3/wk-1/wk
Cook & Lake Co.	Compartment container	N/A	Multi-lift	N/A	N/A
Delaware Co.	Dome	6.6 cy	Tractor & trailer	2	1-2/wk
Durham Co.	Shelters	Up to 21 cy	Flatbed/forklift	2	1/wk
Fairfax Co.	Roll-off	120 cy	Tractor & trailer	1	1/wk-max.
Kent & Ottawa Co.	Roll-off, bins & barrels	N/A	Straight truck/van	2	3/wk-1/wk
Santa Monica	Bins	6 cy (at least)	Truck & trailer	2	2/wk (at least)
Snohomish Co.	Dome	16 cy	Truck & trailer	1	1/10-14 days
Wayne Co.	Bins	12-24 cy	Packer	1	1/2 wks.

E.2.2.2.2 Concord, New Hampshire. A municipally-sponsored outdoors drop-off center has been in operation at the Concord, New Hampshire landfill since 1989. Opened by an attendant twice weekly, residents of this 35,200 person city can deliver ONP, OCC, aluminum, three colors of glass, and ferrous containers. The City provides weekly collection of residential wastes to its residents as well. In the first full year of operations (1990), this center processed 547 tons of materials, representing about 2 percent of the overall residential and commercial waste generated annually, or 4 percent of the residentially generated MSW. A pilot curbside recycling program was initiated in 1991 for approximately one-fifth of the City's households without any material impact on the quantity of materials received at the drop-off center (780).

E.2.2.3 Buy-Back Centers

Buy-back centers are similar to drop-off centers, with the exception that the generators are paid for the materials left at the center. However, the quantity of materials recycled does not necessarily increase if compensation is provided. A study was conducted in Washington State in which four methods of recycling were tested: weekly curbside collection, monthly curbside collection, drop-off center, and buy-back center (764). The study found that the buy-back centers had the lowest participation rate and accordingly collected the least amount of materials of the four collection methods used. Because they are selectively purchased from customers, the quality of buy-back center materials is generally very high. The materials do not require further processing other than consolidation for shipping, and therefore are usually shipped directly to market and not to a MRF.

E.2.2.4 Collection Vehicles

Recyclables can be collected by conventional waste collection vehicles, standard commercial trucks, or specialized recycling vehicles. Conventional waste collection vehicles usually require fitting with trailers or racks for transporting commingled materials. For reasons of productivity, the number of separate compartments on a specialized recycling vehicle is usually limited to a maximum of five or six. In order to avoid damaging the recyclables, these truck bodies typically do not compact the materials. The specialized vehicles usually have a low profile body for ease in filling the compartments. The degree of sorting that can be accomplished at curbside is somewhat limited. If glass is a target material, then a product with greater quality and quantity can be recovered if it is sorted into three discrete colors at curbside. Separation of glass into its three colors would mean that all other containers (e.g., ferrous, aluminum, and mixed plastic) and paper (e.g., newspaper, corrugated, and magazines) would occupy the remaining two compartments in a conventional five-compartment truck. Table E-11 includes the type of vehicle used in ten sample collection programs.

E.2.3 Material Recovery Facilities

The term "material recovery facility" (MRF) includes a broad range of process designs and technologies ranging from simple, predominantly manual sorting and repackaging facilities ("low tech") to complex, highly mechanized processes that separate, beneficiate, and repackage a wide range of recyclable components of MSW ("high tech") (181, 316, 339, 774). In addition to the level of technology used, MRFs can also be classified by the degree of separation and preparation incorporated, which is determined by the characteristics of the materials received and the product purity required by the market. The level of technology used is primarily a function of the required facility throughput. At low throughput rates in the range of 2 to 3 tons per hour, a simple low tech process is sufficient (339). At higher throughput rates, a high tech process is more appropriate. Table E-12 lists all existing and planned MRFs throughout the U.S. as of 1989 by status and degree of mechanization (386).

E.2.3.1 MRF Vendors

Table E-13 identifies the owners, operators, and designers of the MRFs in operation, construction, shakedown, advanced planning, and concept stage. Over 50 percent of the owners are private, and approximately 80 percent of the operators are private. Private owners and operators are typically the MRF system vendor, as indicated in the table. As shown in the table, 34 of the 62 MRFs (55 percent) use the technology of only seven vendors. The remaining 28 MRFs all have unique vendors. Waste Management of North America, Inc., with one facility in construction and thirteen in operation, has the most facilities by far. Second is Browning-Ferris, Inc with a total of five facilities, followed by RRT/Empire Returns, Resource Recovery Systems, Inc., and New England CRInc, all with four. REI Distributors and Reuter Recycling, Inc. round out the top seven with two facilities each.

E.2.3.2 Low Technology MRFs

Low technology MRFs use primarily manual labor to separate the feed stream into its individual components. Such a system usually consists of a series of belt conveyors from which recyclables are manually removed. Mechanical processing is usually limited to magnetic separation for ferrous removal and volume reduction equipment such as a baler, glass crushers, and an aluminum flattener/blower.

TABLE E-12. EXISTING AND PLANNED MRFs, 1989 DATA (386)

NAME	YEAR	CITY	STATE	DESIGN TPD	RESIDUE TPD	CO-MINGLE %	SOURCE SEP %
Operational - Low Tech							
Phoenix	89	Phoenix	AZ	10	0.30	100.00	0.00
San Mateo County (BFI - Recyclery)	89	Belmont	CA	75	2.30	40.00	60.00
East Bay Disposal (Durham Rd.)	89	Fremont	CA	55	5.50	26.00	74.00
Waste Management of Santa Clara	86	San Jose	CA	70	2.00	30.00	70.00
Empire Waste Management	78	Santa Rosa	CA	80	0.00	15.00	85.00
Garden City Disposal	88	Bensenville	IL	2	0.10	35.00	65.00
Meyer Brothers Scavenger Service	89	Chicago Ridge	IL	11	0.60	20.00	80.00
Waste Management of McHenry County	88	McHenry County	IL	4	0.10	6.00	94.00
Buffalo Grove/Wheeling Disposal	88	Wheeling	IL	21	0.00	5.00	95.00
Waste Management (Blaine)	88	Blaine	MN	25	0.00	5.00	95.00
Dakota County	89	Burnsville	MN	40	0.60	2.00	98.00
Ramsey County (Super Cycle MRF)	86	St. Paul	MN	43	0.40	7.00	93.00
Atlantic County	88	Atlantic City	NJ	37	0.90	30.00	70.00
Somerset County	87	Bridgewater	NJ	125	5.00	30.00	70.00
Susquehanna County	87	Susquehanna County	PA	5	0.10	53.00	47.00
York County (Recycle America)	89	York	PA	30	2.40	15.00	85.00
York Waste Disposal	89	York	PA	2	0.00	48.00	52.00
Seattle (Recycle America)	88	Seattle	WA	110	1.10	33.00	67.00
WMI Recycling of Wisconsin	89	Milwaukee	WI	21	0.60	33.00	67.00
Operational - High Tech							
Marin Recycling & R.R. Center	81	San Rafael	CA	100	10.00	60.00	40.00
Groton (SECRRRA)	82	Mystic	CT	23	7.10	100.00	0.00
Camden County	86	Camden	NJ	70	13.00	100.00	0.00
Monmouth County Recycling Corp.	87	Long Branch	NJ	43	4.30	100.00	0.00
Distributors Recycling	85	Newark	NJ	250	5.00	100.00	0.00
Monmouth County	89	Ocean Township	NJ	25	0.60	100.00	0.00
West Paterson (WPAR)	87	West Paterson	NJ	70	5.60	100.00	0.00
New York City (East Harlem)	88	New York	NY	55	11.70	73.00	27.00
Syracuse	89	Syracuse	NY	400	20.00	40.00	60.00
Westbury	88	Westbury	NY	75	0.80	100.00	0.00
Bristol (Otter Recycling)	88	Bristol	PA	45	3.60	100.00	0.00
Bucks County Satellite Facility	89	Bucks County	PA	45	0.50	23.00	77.00
Philadelphia Transfer & Recycling	89	Philadelphia	PA	35	2.80	60.00	40.00
Johnston MRF	89	Johnston	RI	130	13.00	42.00	58.00
Seattle (Rabanco)	88	Seattle	WA	85	4.30	40.00	60.00
Operational - Other							
Eden Prairie (Reuter)	86	Eden Prairie	MN	470	56.40	100.00	0.00
Temporary Shutdown - Low Tech							
Pinellas County (BFI)	83	Pinellas Park	FL	325	10.00	20.00	80.00
Dixon Recyclers MRF	80	Lebanon County	PA	80	8.00	60.00	40.00
National Temple Recycling Center	88	Philadelphia	PA	40	3.00	50.00	50.00
Temporary Shutdown - High Tech							
Islip (New Facility)	80	Islip	NY	300	9.00	85.00	15.00

TABLE E-12. EXISTING AND PLANNED MRFs, 1989 DATA (cont)

NAME	YEAR	CITY	STATE	DESIGN TPD	RESIDUE TPD	CO-MINGLE %	SOURCE SEP %
Advanced Planning - Low Tech							
Huachuca City		Huachuca City	AZ	42	3.00	64.00	36.00
Eden Prairie (BFI)		Eden Prairie	MN	150	38.00	10.00	90.00
Invergrove (BFI)		Invergrove Heights	MN	150	38.00	10.00	90.00
St. Louis (BFI)		St. Louis	MO	150	0.00	0.00	0.00
Sussex County		Lafayette Township	NJ	140	14.00	15.00	85.00
Lackawanna County		Lackawanna County	PA	125	10.00	40.00	60.00
Advanced Planning - High Tech							
TURF (Total Urban Renewal Facility)		San Francisco	CA	150	15.00	50.00	50.00
Capitol Region MRF (Hartford)		Manchester	CT	200	2.50	50.00	50.00
DuPage County (New England CRInc.)		Carol Stream	IL	150	14.00	30.00	70.00
DuPage County (Waste Management)		S.C. DuPage County	IL	150	14.00	30.00	70.00
Cumberland County		Deerfield Township	NJ	80	8.00	62.00	38.00
Brookhaven		Brookhaven	NY	120	12.00	25.00	75.00
Hempstead		Hempstead	NY	100	5.00	55.00	45.00
Westchester County		Yonkers (proposed)	NY	200	15.00	50.00	50.00
Advanced Planning - Other							
Broward County		Pembroke Pines	FL	660	132.00	100.00	0.00
Construction - Low Tech							
San Jose (BFI - Newby Island)		Milpitas	CA	200	50.00	30.00	70.00
Pinellas Park (Recycle America)		Pinellas Park	FL	175	0.00	10.00	90.00
Lewis County		Lowville	NY	50	0.00	32.00	68.00
Jefferson County		Pamelia	NY	100	1.00	5.00	95.00
Mecklenberg County		Charlotte	NC	120	5.00	15.00	85.00
Centre County		Centre County	PA	60	0.00	12.00	88.00
Construction - High Tech							
Springfield		Springfield	MA	240	24.00	40.00	60.00
Rosetto Recycling Center		Dover Township	NJ	250	17.50	50.00	50.00
Cape May County		Woodbine (Borough of)	NJ	225	14.90	55.00	45.00
Oneida-Herkimer Counties		Utica	NY	200	20.00	37.00	63.00
Akron		Akron	OH	10	0.00	50.00	50.00
Karta Container & Recycling		Peekskill	NY	145	0.00	85.00	15.00

TABLE E-12. EXISTING AND PLANNED MRFs, 1989 DATA (cont)

NAME	YEAR	CITY	STATE	DESIGN TPD	RESIDUE TPD	CO-MINGLE %	SOURCE SEP %
Conceptual Planning -							
City of Los Angeles (1)		Los Angeles	CA	100	0.00	50.00	50.00
City of Los Angeles (2)		Los Angeles	CA	100	0.00	50.00	50.00
City of Los Angeles (3)		Los Angeles	CA	100	0.00	50.00	50.00
City of Los Angeles (4)		Los Angeles	CA	100	0.00	50.00	50.00
City of Los Angeles (5)		Los Angeles	CA	100	0.00	50.00	50.00
L.A. County Sanitation Districts		Los Angeles County	CA	600	9.00	60.00	40.00
Ventura Region Sanitation District		Ventura County	CA	500	0.00	90.00	10.00
Housatonic Res. Recovery Authority		Cent. Naugatuck Valley	CT	180	0.00	0.00	0.00
MRF/Transfer Station/Composting		Champaign	IL	385	0.00	90.00	10.00
Montgomery County (Shady Grove Rd.)		Montgomery County	MD	250	25.00	46.00	54.00
Prince George's Co., Municipalities		Prince George's County	MD	20	2.00	68.00	32.00
Southwest Solid Waste Mgt. District		(Southwestern)	NH	80	0.00	0.00	0.00
Ocean County		Lakewood	NJ	225	0.00	0.00	0.00
Mercer County		Mercer County	NJ	180	0.00	0.00	0.00
Warren County		White Township	NJ	80	0.00	65.00	35.00
West Finger Lakes		Canandaigua	NY	75	0.00	48.00	52.00
Cortland County		Cortland	NY	50	2.50	42.00	58.00
Oswego County		Fulton	NY	100	5.00	42.00	58.00
Ontario County		Hopewell (or Seneca)	NY	20	0.00	35.00	65.00
Monroe County		Rochester	NY	280	28.00	50.00	50.00
Berks County		Cumru	PA	150	15.00	60.00	40.00
Monroe County		East Stroudsburg	PA	80	0.00	40.00	60.00
Quonset Point		North Kingston	RI	160	16.00	50.00	50.00
Pulaski County		Radford	VA	140	84.00	0.00	0.00
Conceptual Planning - Low Tech							
Prince George's County		Prince George's County	MD	200	30.00	0.00	0.00
Hennepin County		Brooklyn Park	MN	200	35.00	0.00	0.00
Orange County		Goshen	NY	65	6.50	47.00	53.00
Madison County		Lincoln	NY	65	0.00	50.00	50.00
King of Prussia		King of Prussia	PA	170	8.00	0.00	0.00
Knoxville		Knoxville	TN	90	0.00	30.00	70.00
Pierce County		Ellsworth	WI	70	21.00	50.00	50.00
Conceptual Planning - High Tech							
Greater Bridgeport Region		Fairfield County	CT	275	7.00	35.00	65.00
Palm Beach County (North)		West Palm Beach	FL	250	0.00	30.00	70.00
SEMASS (MRF)		Rochester	MA	100	10.00	0.00	0.00
Oakland County		Auburn Hills	MI	200	20.00	28.00	72.00
Gloucester County		Gloucester County	NJ	150	0.00	0.00	0.00
Dutchess County		Poughkeepsie	NY	75	7.50	30.00	70.00
New York City (Staten Island)		Staten Island	NY	200	0.00	0.00	0.00

TABLE E-13. MRF OWNERS/OPERATORS/DESIGNERS (386)

NAME	OWNER	OPERATOR	DESIGNER
Operational - Low Tech			
Phoenix	St. Vincent DePaul Society	St. Vincent DePaul Society	(Not Available)
San Mateo County (BFI - Recyclery)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
East Bay Disposal (Durham Rd.)	Oakland Scavenger/Waste Management	Waste Management/Oakland Scavenger	Waste Management/Oakland Scavenger
Waste Management of Santa Clara	Waste Management of North America	Waste Management of Santa Clara	Waste Management of North America, Inc.
Empire Waste Management	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
Garden City Disposal	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
Meyer Brothers Scavenger Service	Waste Management of North America	Meyer Brothers Scavenger Service	Waste Management of North America, Inc.
Waste Management of McHenry County	Waste Management of North America	Waste Management of McHenry County	Waste Management of North America, Inc.
Buffalo Grove/Wheeling Disposal	Waste Management of North America	Buffalo Grove/Wheeling Disposal	Waste Management of North America, Inc.
Waste Management (Blaine)	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
Dakota County	Dakota County/RMR	Recycle Minnesota's Resources (RMR)	RIS/Dakota County
Ramsey County (Super Cycle MRF)	Ramsey County	Super Cycle	Ramsey County/Super Cycle
Atlantic County	Atlantic County Utilities Authority	Atlantic County Utilities Authority	Atlantic County
Somerset County	Somerset County	Somerset County	(Not Available)
Susquehanna County	Susquehanna County	Susquehanna County	Susquehanna County
York County (Recycle America)	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
York Waste Disposal	York Waste Disposal, Inc.	York Waste Disposal, Inc.	York Waste Disposal, Inc.
Seattle (Recycle America)	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
WMI Recycling of Wisconsin	Waste Mgmt. Recycling of Wisconsin	Waste Mgmt. Recycling of Wisconsin	Waste Management of North America, Inc.
Operational - High Tech			
Marin Recycling & R.R. Center	Marin Recycling & R.R. Association	Marin Recycling & R.R. Association	Marin Recycling & Res. Recovery Center
Groton (SECRRRA)	SE CT Regional R.R. Agency/Groton	Resource Recovery Systems, Inc.	Resource Recovery Systems, Inc.
Camden County	Camden County (equipment)	Resource Recovery Systems, Inc.	JCA Engineering
Monmouth County Recycling Corp.	Monmouth Recycling Corporation	Monmouth Recycling Corporation	Count Company
Distributors Recycling	REI Distributors, Inc.	REI Distributors, Inc.	REI Distributors, Inc.
Monmouth County	Monmouth Processing	Monmouth Processing	Monmouth Processing
West Paterson (WPAR)	WPAR	WPAR	WPAR
New York City (East Harlem)	City of New York	Resource Recovery Systems, Inc.	Resource Recovery Systems/New York City
Syracuse	RRT/Empire Returns Corporation	RRT/Empire Returns Corporation	RRT Design & Construction Corporation
Westbury	OMNI Recycling of Westbury, Inc.	OMNI Recycling of Westbury, Inc.	OMNI Recycling of Westbury, Inc.
Bristol (Otter Recycling)	Otter Recycling	Otter Recycling	Otter Recycling
Bucks County Satellite Facility	Bucks County	RRT/Empire Returns Corporation	RRT/Empire Returns Corporation
Philadelphia Transfer & Recycling	Waste Management of North America	Waste Management of North America	Waste Management of North America, Inc.
Johnston MRF	RI Solid Waste Management Corp.	New England CRInc.	James C. Anderson Associates
Seattle (Rabanco)	Rabanco, Ltd.	Rabanco, Ltd.	Rabanco Recycling Company
Operational - Other			
Eden Prairie (Reuter)	Reuter Recycling, Inc.	Reuter Recycling, Inc.	Reuter Recycling/Buhler-Miag, Inc.
Temporary Shutdown - Low Tech			
Pinellas County (BFI)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
Dixon Recyclers MRF	Dixon Recyclers	Dixon Recyclers	Dixon Recyclers
National Temple Recycling Center	National Temple Non-Profit Corp.	National Temple Non-Profit Corp.	Advent Design
Temporary Shutdown - High Tech			
Islip (New Facility)	Town of Islip	Town of Islip	OMNI Technical Services/Town of Islip

TABLE E-13. MRF OWNERS/OPERATORS/DESIGNERS (cont)

NAME	OWNER	OPERATOR	DESIGNER
Advanced Planning - Low Tech			
Huachuca City	Cochise Landfill Recycling Center	Cochise Landfill Recycling Center	Cochise Landfill Recycling Center, Inc.
Eden Prairie (BFI)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
Invergrove (BFI)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
St. Louis (BFI)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
Sussex County	Sussex Co. Municipal Util. Auth.	Sussex Co. Municipal Util. Auth.	Sussex County Municipal Utilities Auth.
Lackawanna County	Lackawanna County	Lackawanna County	Kutch, Brocavich & Associates
Advanced Planning - High Tech			
TURF (Total Urban Renewal Facility)	Norcal Solid Waste, Inc.	West Coast Salvage Company	Norcal Solid Waste/GEZ Associates
Capitol Region MRF (Hartford)	REI Distributors, Inc.	REI Distributors, Inc.	REI Distributors, Inc.
DuPage County (New England CRInc.)	DuPage County	New England CRInc.	Camp, Dresser & McKee
DuPage County (Waste Management)	DuPage County	Waste Mgmt./Naper. Area Recycling	Camp, Dresser & McKee
Cumberland County	Cumberland Co. Improvement Auth.	Cumberland Co. Improvement Auth.	New England CRInc.
Brookhaven	Town of Brookhaven	New England CRInc./Mat. Rec. of NY	New England CRInc./Materials Rec. of NY
Hempstead	Nassau County/Hempstead/Em. Returns	RRT/Empire Returns Corporation	RRT/Empire Returns Corporation
Westchester County	Westchester Co. Solid Waste Dist.	(Private Firm)	(To Be Determined)
Advanced Planning - Other			
Broward County	Reuter Recycling, Inc.	Reuter Recycling, Inc.	Reuter Recycling, Inc.
Construction - Low Tech			
San Jose (BFI - Newby Island)	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
Pinellas Park (Recycle America)	Waste Management of North America	Waste Management of Pinellas, Inc.	Waste Management of North America, Inc.
Lewis County	Lewis County	Lewis County	Barton & Loguidice
Jefferson County	Jefferson County	Jefferson County	Barton & Loguidice
Mecklenberg County	Fairfield County Redemption, Inc.	Fairfield County Redemption, Inc.	R.V. Ridberg & Associates
Centre County	Centre County Solid Waste Authority	Centre County Solid Waste Authority	Gershman, Brickner & Bratton/Blazosky
Construction - High Tech			
Springfield	State of Massachusetts/RRS	Resource Recovery Systems, Inc,	Resource Recovery Systems, Inc.
Rosetto Recycling Center	Rosetto Recycling Corporation	Rosetto Recycling Corporation	Rosetto Recycling Corporation
Cape May County	Cape May Co. Municipal Util. Auth.	RRT/Empire Returns Corporation	RRT/Empire Returns Corporation
Oneida-Herkimer Counties	Oneida-Herkimer Counties	Oneida-Herkimer S.W.M. Authority	W.F. Cosulich/Oneida-Herkimer S.W.M.A.
Akron	WTE Corporation	WTE Corporation	WTE Corporation
Karta Container & Recycling	Karta Container & Recycling	Karta Container & Recycling	(Not Available)

TABLE E-13. MRF OWNERS/OPERATORS/DESIGNERS (cont)

NAME	OWNER	OPERATOR	DESIGNER
Conceptual Planning -			
City of Los Angeles (1)	(Private Firm)	(Private Firm)	(To Be Determined)
City of Los Angeles (2)	(Private Firm)	(Private Firm)	(To Be Determined)
City of Los Angeles (3)	(Private Firm)	(Private Firm)	(To Be Determined)
City of Los Angeles (4)	(Private Firm)	(Private Firm)	(To Be Determined)
City of Los Angeles (5)	(Private Firm)	(Private Firm)	(To Be Determined)
L.A. County Sanitation Districts	L.A. County Sanitation Districts	L.A. County Sanitation Districts	(To Be Determined)
Ventura Region Sanitation District	Ventura Region Sanitation District	(To Be Determined)	(To Be Determined)
Housatonic Res. Recovery Authority	(To Be Determined)	(To Be Determined)	(To Be Determined)
MRF/Transfer Station/Composting	Intergovernmental S.W. Disp. Assn.	(Private Firm)	(To Be Determined)
Montgomery County (Shady Grove Rd.)	Montgomery County	(Private Firm)	(To Be Determined)
Prince George's Co., Municipalities	Maryland Environmental Service	Maryland Environmental Service	Maryland Environmental Service
Southwest Solid Waste Mgt. District	(To Be Determined)	(Private Firm - To Be Determined)	(To Be Determined)
Ocean County	Ocean County	(Private Firm)	(To Be Determined)
Mercer County	Mercer Co. Improvement Authority	(Private Firm)	(To Be Determined)
Warren County	(To Be Determined)	(To Be Determined)	(To Be Determined)
West Finger Lakes	Solid Waste Management Authority	(Private Firm)	(To Be Determined)
Cortland County	Cortland County	(Cortland County or Private Firm)	(To Be Determined)
Oswego County	(Oswego Co., Private Firm or ARC)	(Oswego Co., Private Firm or ARC)	(To Be Determined)
Ontario County	Ontario County	(Private Firm)	(To Be Determined)
Monroe County	Monroe County	(Private Firm)	(To Be Determined)
Berks County	(Berks County or Private Firm)	(Private Firm)	J.A. Hayden Associates (procurement)
Monroe County	Monroe County General Authority	(Private Firm)	(To Be Determined)
Quonset Point	RI Solid Waste Management Corp.	(Private Firm)	(To Be Determined)
Pulaski County	(To Be Determined)	(Private Firm)	(To Be Determined)
Conceptual Planning - Low Tech			
Prince George's County	(To Be Determined)	(Private Firm)	(To Be Determined)
Hennepin County	Hennepin County	(Private Firm)	(To Be Determined)
Orange County	Orange County	Orange County	Wehran Envirotech
Madison County	Association for Retarded Citizens	Association for Retarded Citizens	Barton & Loguidice/ARC
King of Prussia	O'Hara Sanitation Company, Inc.	O'Hara Sanitation Company, Inc.	(To Be Determined)
Knoxville	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.	Browning-Ferris Industries, Inc.
Pierce County	(To Be Determined - Prefer County)	(To Be Determined)	(To Be Determined)
Conceptual Planning - High Tech			
Greater Bridgeport Region	(Private Firm)	(Private Firm)	(To Be Determined)
Palm Beach County (North)	Palm Beach County S.W. Authority	(Private Firm)	(To Be Determined)
SEMASS (MRF)	Materials Recovery/Recycling Corp.	Energy ANSWERS Corporation	Smith & Mahoney (probably)
Oakland County	Oakland County	(Private Firm - To Be Determined)	(To Be Determined)
Gloucester County	Gloucester County	(Private Firm)	(To Be Determined)
Dutchess County	Dutchess Co. Res. Recovery Agency	(Private Firm)	(To Be Determined)
New York City (Staten Island)	City of New Yrok	(Private Firm)	(To Be Determined)

E.2.3.3 High Technology MRFs

MRFs employing a highly mechanized process line have been developed for processing large quantities of recyclables from commingled feed streams. Several vendors such as New England CRInc, Waste Management, Inc, and Resource Recovery Systems (RRS) offer automated MRFs that minimize the manual labor required. New England CRInc is the exclusive North American licensee for the technology developed by Maschinenfabrik Bezner of Germany. Twenty MRFs using the Bezner process are in operation throughout Europe (332). Waste Management, Inc.'s automated MRF uses the Swedish BRINI system.

E.2.3.3.1 Johnston, Rhode Island. The Johnston, Rhode Island MRF, owned by the Rhode Island Solid Waste Management Corporation (RISWMC), was designed and is operated by New England CRInc (CRInc). As an example of an automated MRF, the process is shown in Figure E-2. This facility was designed to process 130 tons per day of commingled recyclables received in co-collected, separate fractions of mixed paper (ONP and OCC) and mixed containers (ferrous, HDPE, PET, three colors of glass, and aluminum).

As of 1990, the facility throughput was increased to approximately 200 TPD by operating a second shift. Mixed paper is removed from the tip floor and manually sorted on conveyors prior to baling into its constituent fractions. Commingled containers are loaded onto a computer-regulated conveyor that senses the quantity of materials fed per lineal foot in order to maintain a steady feedrate. Ascending to elevated separation stations, material is initially visually inspected for gross contaminants and hazardous materials, which are removed manually. After magnetic belts separate ferrous materials, the remaining fraction cascades downwards on the conveyor and through a series of suspended metal bars that, relying on the weight, particle size, and aerodynamic differences of aluminum and plastic containers separates them from glass. Also, due to gravity, glass continues down the line with other containers diverted to either side. Glass is screened, with the overs manually sorted by color and the unders remaining as mixed cullet. Clear glass overs are negatively sorted and visually inspected to assure high quality of this most valuable glass color. Containers on the diverted line pass through an eddy current separator to remove aluminum, and plastics are manually sorted by resin type.

Materials are prepared for market as follows. Ferrous is shredded in a flail mill (which also removes and separates the aluminum tops of bi-metal cans) and is containerized in loose form. Aluminum is shipped similarly after passing through a can flattener. Glass is crushed and boxed or shipped loose in truckload quantities. PET is perforated and baled, while HDPE is shredded and shipped in gaylord-style boxes. Papers are baled.

The RISWMC facility has experienced a high on-line performance. Residue, primarily mixed glass cullet from the screen unders, is estimated to be 10 percent of the daily throughput. Operating management envisions expansion of interior storage and tipping floor room to improve maneuverability and material climatic protection in this 40,000 square foot building.

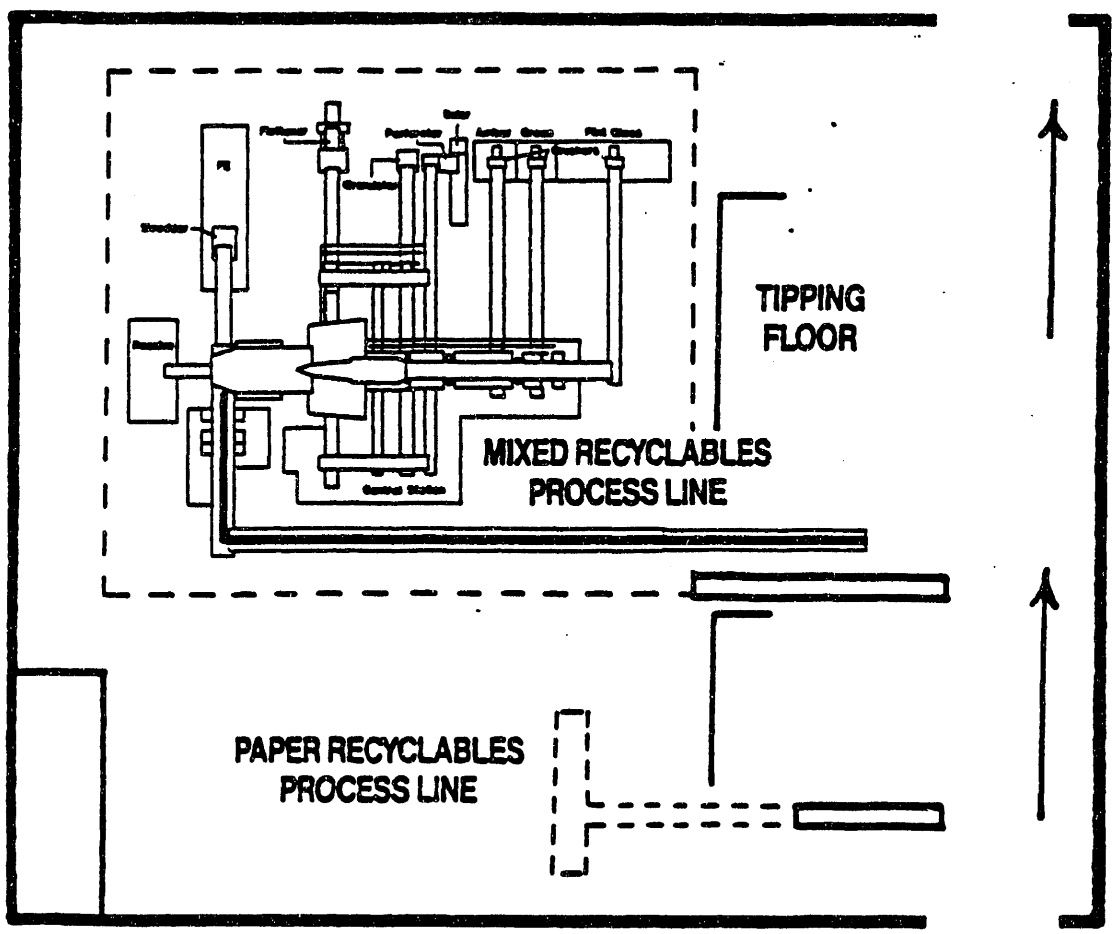

Figure E-2. Johnston, Rhode Island MRF Process Plan

E.2.3.4 MRF Processing Highly Separated Materials

Infeed materials from drop-off centers, buy-back centers, and curbside collection programs requiring complete separation generally do not require extensive processing to prepare them for markets. MRFs processing such materials may act more like consolidation facilities. Drop-off center materials may require steps to ensure product quality control since contamination may have been introduced at either the source or the center. Buy-back center material generally does not end up at a MRF unless the buy-back center is part of the MRF.

Collection vehicles deliver materials to the centralized processing location, where separated materials are consolidated in larger containers or otherwise packaged for resale and shipment. Depending on the quantity and type of material collected, it may be desirable to invest in special repackaging equipment such as paper and plastic balers or glass crushers. In the event that certain truck compartments contain commingled materials requiring separation (e.g., mixed containers or mixed paper), further sorting can be done either manually or, if quantities warrant, manually with mechanical assistance. For example, sorting of mixed containers might warrant channeling of materials onto a conveyor for magnetic separation of ferrous metals and then manual picking of aluminum and plastics (mixed or by HDPE and PET fractions). For small volumes, an existing drop-off center might serve as the centralized processing center.

E.2.3.4.1 Delaware Recycling Centers. In late 1990, the Delaware Solid Waste Authority (DSWA) contracted for the establishment, operation, and maintenance of a statewide system of drop-off centers and the marketing of the products (770). The DSWA had an initial goal of 50 operating centers by the end of 1991 and 100 centers by the end of 1992. However, because of active citizen participation, 80 centers were established and in operation by the end of June 1991 (904). An additional 10 satellite sites continue in operation for the collection of clear, green, and amber glass.

The drop-off centers, located within a 5-mile radius of most homes, use color-coded igloos for the collection of separated recyclable materials such as glass, ferrous metal cans, nonferrous metal cans, plastics, newspapers, used motor oil, and batteries. Browning-Ferris Industries collects and markets the materials received at the centers. A centrally located facility for storing, sorting, and shipping the materials provides the necesary consolidation systems for effective marketing of recyclables as well as product enhancement to remove contaminants.

E.2.3.4.2 San Jose, California. San Jose's three-bin collection trucks are unloaded successively at the processing facility where a computerized scale enables the vendor, Waste Management, Inc. (WMI) to record tonnage information by load and by waste fraction. Newspaper is baled for shipment. Glass is hand-sorted by color and contaminants are removed on a conveyor prior to containerization for shipment. Instead of densification in a glass crusher, WMI relies on natural handling procedures to densify glass from its original 300 pounds per cubic yard to about 1000 pounds per cubic yard. Metal containers are separated into ferrous and aluminum fractions by passes under a series of magnets on a conveyor. Approximately 20 percent of bimetal cans are rejected because labels have not been removed (723). The MRF also recovers HDPE and PET plastics. Total residue amounts are reported as 2 tons per day or about 3 percent of the design capacity (386).

E.2.3.5 Mixed Waste MRFs

As discussed in Section 1.1, the inclusion of mixed waste MRFs in this report reflects their primary function -- to remove recyclables from the mixed municipal solid waste (MMSW) stream. In fact, such front-end processing systems have several functions, including:

- Recovery, for subsequent resale, of marketable recyclable materials from the MMSW stream
- Segregation of materials from the waste stream that are unprocessible by the waste-to-energy (W-T-E) facility or have a low heating value (e.g., yard wastes, oversized bulky wastes)
- Delivery of non-recoverable, combustible materials to the W-T-E facility

In the following sections, examples of both a labor-intensive MRF (766) and a mechanized MRF (767) are presented. In addition to a brief process description, included also is a list of the materials recovered and pertinent operating and performance parameters. Since the current design and operating plans for these two projects have not been reported in the open literature, the information presented is derived from the respective Request for Proposals.

E.2.3.5.1 Gaston County Mixed Waste MRF (766). The mixed waste MRF planned for Gaston County is a front-end processing (FEP) system for a previously contracted waste-to-energy facility; both facilities are currently on hold. The MRF features a relatively low technology, labor-intensive process that relies heavily on manual inspection and picking of recyclable products from conveyors. It is supplemented by two-stage screening for size classification and magnetic separation of ferrous metals.

Designed to process up to 50 TPH of mixed municipal solid waste (MMSW), the Gaston FEP not only can recover recyclables from MMSW but is also capable of separating them from commingled "batch" loads of recyclables should a recyclables collection program be established at a future date. Materials to be recovered include: ferrous metals and aluminum; HDPE, PET and mixed film plastics; amber, green and flint glass; and corrugated, newsprint and fine paper. Recovery of household batteries is a design option.

The proposed process as depicted in Figure E-3 shows the FEP and W-T-E (with by-pass) sharing a common tip floor where MMSW is received and initial segregation of OBW takes place. After loading onto the inclined infeed conveyor, the MMSW reports to final OBW segregation and bag opening stations, where MMSW is liberated and the bags removed. A disc screen then mechanically separates MMSW to a +/- 5 inch size. The oversized material, consisting of corrugated, newsprint, and fine (office) paper is manually separated in that order. Ferrous metals are then magnetically separated, film plastic is picked and the remainder (i.e., nonrecoverable, combustible residual) is conveyed to the W-T-E plant, or diverted from the conveyor to the tipping floor for use as future W-T-E feedstock.

Undersized material from the primary disc screen proceeds to three glass picking stations where manually-removed green, amber and flint glass report to individual storage bins, followed by crushing and screening prior to loadout. Ferrous metals are magnetically separated from the primary undersized material; the unders then report to a secondary screen with +/- 2 inches separation. The secondary unders are conveyed to the common refuse loadout conveyor; secondary overs report to aluminum picking stations, followed by manual separation of PET, HDPE and LDPE.

The unit processes described above are amenable to handling both MMSW and commingled recyclables, and closely resemble those used to produce compost or RDF, albeit without the size reduction (shred) step. As such, additional information on the energy and environmental considerations for these unit process operations can be found in Appendices B and G.

GASTON MRF 3500 TPW

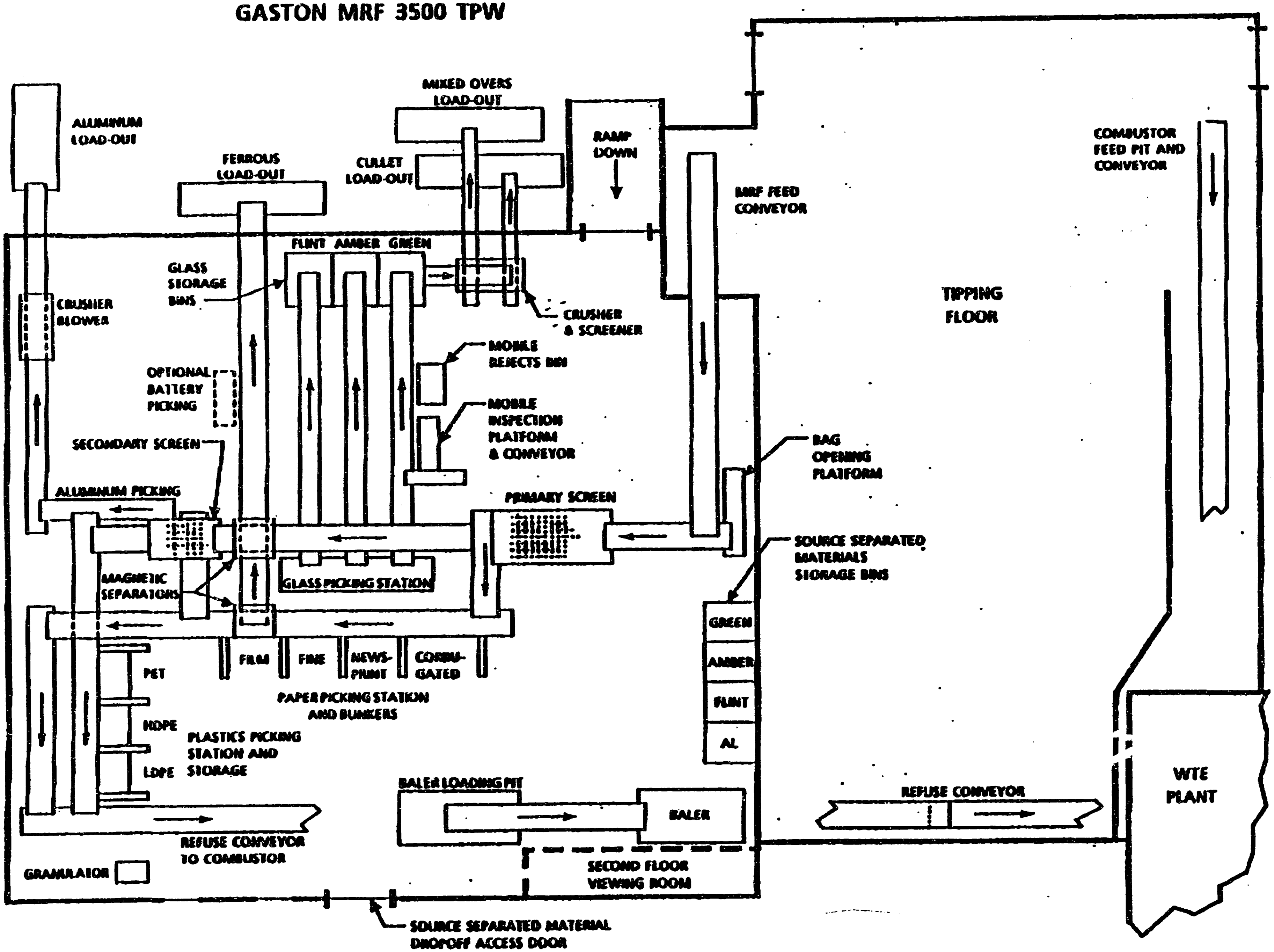

Figure E-3. Floor Plan for Proposed Gaston County, North Carolina, Mixed Waste MRF

E.2.3.5.2 Monmouth County Mixed Waste MRF (767). In the advanced stages of planning and preliminary design, the Monmouth County MRF, or FEP, which will be co-located with a mass burn W-T-E facility, is designed to process 1700 TPD of MMSW, separating out recyclables and noncombustibles. This is a highly mechanized front-end processing design utilizing trommels and multiple product separations in three parallel processing lines, supplemented by manual picking. The following recyclables are intended to be recovered: corrugated boxboard, ferrous metals, aluminum cans, film plastic, HDPE, PET and household batteries.

The MRF is to be located in a 60,000 square foot building adjacent to the tipping floor where front-end loaders will initially screen out unacceptable or nonprocessible waste and corrugated prior to loading the infeed conveyors which transport the MMSW to the MRF. Additional corrugated is removed at the first picking station in the MRF and conveyed to a baler. Waste not removed at the corrugated picking station will be size separated by a trommel equipped with bag-breaking bars to liberate bagged MSW.

Ferrous metals will be removed with a suspended magnet from the trommel undersized material, followed by manual removal of aluminum and magnetic (head pulley) separation of ferrous metal cans inadvertently picked with the aluminum. The aluminum is then flattened and blown to a loadout area. The ferrous metals separated by the suspended magnet are sent to loadout after reporting to the household battery picking station.

Oversized materials, consisting of PET, HDPE and film plastics are picked in that order and conveyed to dedicated balers for subsequent loadout. Ferrous metals will be removed by suspended belt magnets and combined with the undersized ferrous stream to loadout, while the remaining oversized material combines with unrecovered undersized material and conveyed to the refuse pit.

The Monmouth County FEP is unique in that it is the first mixed waste MRF dedicated to recyclables separation from mixed waste in a community that already collects selected recyclables curbside.

E.2.3.6 Small-Scale MRFs

Small-scale MRFs and mobile MRFs are two recent developments. Count Recycling Systems offers a "McMRF" system with a capacity of up to 20 tons per 8 hour shift (769). The system requires a volume only 70 feet by 40 feet by 16.5 feet high. The system uses variable speed conveyors, air classification, and a variable speed screen to supplement hand picking.

New England CRInc offers a mobile 20 ton-per-shift MRF built by the Ptarmigan Equipment Corporation (769). The Ptarmigan system is highway-towable at 8 feet wide by 48 feet long and 22,000 pounds. It can accomodate six or eight picking stations. Approximately 40 of these systems are in operation throughout the country.

E.2.4 Products

Table E-14 presents data on materials which are being recovered or are planned to be recovered at operating and planned U.S. MRFs (386). These materials and the percentages of the facilities reported to recover them are: tin cans - 97 percent, clear glass - 97 percent, brown glass - 94 percent, green glass - 94 percent, aluminum - 93 percent, bi-metal cans - 91 percent, newspaper - 89 percent, HDPE - 82 percent, PET - 79 percent, cardboard - 66 percent, ferrous scrap - 30 percent, computer paper - 29 percent, mixed paper - 9 percent, and other materials - 9 percent.

Successful MRFs are highly responsive to location-specific needs and especially to the requirements of the markets (164). Recognizing the lack of design standardization and the material-specific, end-use specifications, the following description of recovery techniques is presented on a material-specific basis.

E.2.4.1 Sample Product Specifications

The following are sample product specifications taken from a MRF Request for Proposals (765). They are considered to be typical of that required by end users.

E.2.4.1.1 Newsprint. Newsprint shall be separated from all non-paper products and baled so as to be suitable for overseas export. The density of the bales shall be approximately 25 pounds per cubic foot, yielding an average weight of 1,100 pounds per bale. Non-newsprint contamination is limited to a maximum of 2 percent "out throws paper" and "prohibitive material" as defined by the Paper Stock Institute of America (PS-86), "Special News" No. 7. The newsprint bale should consist of baled, sorted, fresh, dry newspaper, not sunburned and free from paper other than news, containing not more than the percentage of rotogravure and colored sections normally contained in newspaper delivered to the household.

TABLE E-14. MRF PRODUCTS (386)

NAME	DESIGN TPD	MIXED PAPER	NEWS PAPER	COMPTR PAPER	CARD-BOARD	MIXED GLASS	CLEAR GLASS	BROWN GLASS	GREEN GLASS	ALUM	SCRAP FE	BI-METAL	PET	HDPE	OTHER MAT'L	TIN
Operational - Low Tech																
Phoenix	10		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
San Mateo County (BFI - Recyclery)	75		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
East Bay Disposal (Durham Rd.)	55		Y			Y	Y	Y	Y	Y		Y	Y	Y		Y
Waste Management of Santa Clara	70		Y				Y	Y	Y	Y			Y	Y		Y
Empire Waste Management	80		Y	Y	Y		Y	Y	Y	Y			Y	Y		Y
Garden City Disposal	2						Y	Y	Y	Y		Y		Y		Y
Meyer Brothers Scavenger Service	11		Y				Y	Y	Y	Y		Y				Y
Waste Management of McHenry County	4		Y				Y	Y	Y	Y						Y
Buffalo Grove/Wheeling Disposal	21		Y				Y	Y	Y	Y		Y		Y		Y
Waste Management (Blaine)	25		Y		Y	Y	Y	Y	Y	Y	Y	Y	Y			Y
Dakota County	40		Y				Y	Y	Y	Y		Y				Y
Ramsey County (Super Cycle MRF)	43		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Atlantic County	37		Y				Y	Y	Y	Y			Y	Y		
Somerset County	125		Y		Y		Y	Y	Y	Y						
Susquehanna County	5		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
York County (Recycle America)	30	Y	Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
York Waste Disposal	2		Y		Y		Y	Y	Y	Y		Y				Y
Seattle (Recycle America)	110	Y	Y				Y	Y	Y	Y		Y	Y	Y		Y
WMI Recycling of Wisconsin	21		Y			Y	Y	Y	Y	Y		Y	Y	Y		Y
Operational - High Tech																
Marin Recycling & R.R. Center	100		Y	Y	Y		Y	Y	Y	Y	Y		Y		Y	Y
Groton (SECRRRA)	23						Y	Y	Y	Y		Y				Y
Camden County	70						Y	Y	Y	Y		Y	Y	Y		Y
Monmouth County Recycling Corp.	43					Y				Y		Y				Y
Distributors Recycling	250					Y	Y	Y	Y	Y	Y	Y	Y			Y
Monmouth County	25						Y	Y	Y	Y		Y				Y
West Paterson (WPAR)	70					Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
New York City (East Harlem)	55		Y			Y	Y	Y	Y	Y		Y	Y	Y		Y
Syracuse	400		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Westbury	75					Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
Bristol (Otter Recycling)	45						Y	Y	Y	Y		Y	Y	Y		Y
Bucks County Satellite Facility	45		Y				Y			Y	Y	Y				Y
Philadelphia Transfer & Recycling	35		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
Johnston MRF	130		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Seattle (Rabanco)	85	Y	Y		Y		Y	Y	Y	Y		Y				Y
Operational - Other																
Eden Prairie (Reuter)	470				Y					Y	Y	Y	Y	Y		Y
Temporary Shutdown - Low Tech																
Pinellas County (BFI)	325		Y	Y	Y		Y					Y	Y	Y	Y	Y
Dixon Recyclers MRF	80		Y		Y		Y	Y	Y	Y	Y		Y	Y		Y
National Temple Recycling Center	40		Y				Y	Y	Y	Y		Y	Y	Y		Y
Temporary Shutdown - High Tech																
Islip (New Facility)	300	Y	Y		Y	Y	Y	Y	Y	Y		Y	Y	Y		Y

TABLE E-14. MRF PRODUCTS (cont)

NAME	DESIGN TPD	MIXED PAPER	NEWS PAPER	COMPTR PAPER	CARD-BOARD	MIXED GLASS	CLEAR GLASS	BROWN GLASS	GREEN GLASS	ALUM	SCRAP FE	BI-METAL	PET	HDPE	OTHER MAT'L	TIN
Advanced Planning - Low Tech																
Huachuca City	42		Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
Eden Prairie (BFI)	150		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Invergrove (BFI)	150		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
St. Louis (BFI)	150		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Sussex County	140		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Lackawanna County	125	Y	Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Advanced Planning - High Tech																
TURF (Total Urban Renewal Facility)	150		Y		Y	Y	Y	Y	Y	Y	Y	Y				Y
Capitol Region MRF (Hartford)	200		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
DuPage County (New England CRInc.)	150	Y	Y		Y		Y	Y	Y	Y		Y	Y	Y	Y	Y
DuPage County (Waste Management)	150	Y	Y		Y		Y	Y	Y	Y		Y	Y	Y	Y	Y
Cumberland County	80		Y				Y	Y	Y	Y		Y	Y			Y
Brookhaven	120		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Hempstead	100		Y				Y	Y	Y			Y				Y
Westchester County	200		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Advanced Planning - Other																
Broward County	660				Y					Y	Y	Y	Y	Y		Y
Construction - Low Tech																
San Jose (BFI - Newby Island)	200		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Pinellas Park (Recycle America)	175		Y	Y	Y		Y	Y	Y	Y			Y	Y		Y
Lewis County	50		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Jefferson County	100		Y	Y	Y		Y	Y	Y			Y		Y		Y
Mecklenberg County	120		Y			Y	Y	Y	Y	Y		Y	Y	Y		Y
Centre County	60		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Construction - High Tech																
Springfield	240	Y	Y		Y	Y	Y	Y	Y	Y		Y				Y
Rosetto Recycling Center	250		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Cape May County	225		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Oneida-Herkimer Counties	200		Y	Y	Y		Y	Y	Y		Y	Y	Y	Y		Y
Akron	10		Y				Y	Y	Y	Y		Y	Y	Y		Y
Karta Container & Recycling	145		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y

TABLE E-14. MRF PRODUCTS (cont)

NAME	DESIGN TPD	MIXED PAPER	NEWS PAPER	COMPTR PAPER	CARD-BOARD	MIXED GLASS	CLEAR GLASS	BROWN GLASS	GREEN GLASS	ALUM	SCRAP FE	BI-METAL	PET	HDPE	OTHER MAT'L	TIN
Conceptual Planning -																
City of Los Angeles (1)	100		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
City of Los Angeles (2)	100		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
City of Los Angeles (3)	100		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
City of Los Angeles (4)	100		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
City of Los Angeles (5)	100		Y			Y	Y	Y	Y	Y	Y	Y	Y	Y		Y
L.A. County Sanitation Districts	600		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Ventura Region Sanitation District	500				Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Housatonic Res. Recovery Authority	180		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
MRF/Transfer Station/Composting	385		Y	Y	Y		Y	Y	Y	Y		Y		Y		Y
Montgomery County (Shady Grove Rd.)	250		Y				Y	Y	Y	Y		Y	Y	Y		Y
Prince George's Co., Municipalities	20		Y				Y	Y	Y	Y		Y	Y	Y		Y
Southwest Solid Waste Mgt. District	80	Y	Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Ocean County	225		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Mercer County	180		Y				Y	Y	Y	Y		Y	Y	Y		Y
Warren County	80		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
West Finger Lakes	75		Y		Y		Y	Y	Y	Y		Y	Y	Y	Y	Y
Cortland County	50		Y		Y		Y	Y	Y			Y		Y		Y
Oswego County	100		Y		Y		Y	Y	Y			Y		Y		Y
Ontario County	20		Y		Y		Y					Y		Y		Y
Monroe County	280		Y		Y		Y	Y	Y	Y	Y	Y	Y	Y		Y
Berks County	150		Y				Y	Y	Y	Y	Y	Y	Y	Y		Y
Monroe County	80		Y				Y	Y	Y	Y		Y	Y	Y		Y
Quonset Point	160		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y	Y	Y
Pulaski County	140		Y		Y		Y	Y	Y	Y		Y				Y
Conceptual Planning - Low Tech																
Prince George's County	200		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Hennepin County	200		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Orange County	65		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Madison County	65		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
King of Prussia	170		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Knoxville	90		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Pierce County	70		Y	Y	Y		Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Conceptual Planning - High Tech																
Greater Bridgeport Region	275		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Palm Beach County (North)	250		Y		Y		Y	Y	Y	Y		Y	Y	Y	Y	Y
SEMASS (MRF)	100		Y		Y		Y	Y	Y	Y		Y	Y	Y		Y
Oakland County	200		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y
Gloucester County	150		Y	Y			Y	Y	Y	Y						
Dutchess County	75		Y				Y	Y	Y	Y		Y	Y	Y		Y
New York City (Staten Island)	200		Y	Y	Y		Y	Y	Y	Y		Y	Y	Y		Y

E.2.4.1.2 Glass Cullet. The glass product shall be separated from non-container type glass material with the exception of paper labels. The glass shall be segregated by color (amber, flint, and green) prior to crushing. The cullet size shall be greater than 0.25 inch in diameter and less than 2.0 inches in diameter. Flint cullet shall contain not more than 5 percent other glass colors by weight, amber cullet shall contain not more than 5 percent other glass colors by weight, and green cullet shall contain not more than 5 percent other glass colors by weight. No stones, ceramics, or non-container glass shall be contained in the outbound product. Non-glass contaminants shall not exceed 1 percent of the total product weight.

E.2.4.1.3 Aluminum. Aluminum used beverage containers (UBCs) shall be separated from all non-aluminum and other aluminum material and baled. All non-aluminum contamination, including moisture shall be less than 1.5 percent of total product weight. Minimum bale density shall be 20 pounds per cubic foot. The other aluminum should be separated into cast and foils fractions and shipped loose in palletized gaylords (as a minimum).

E.2.4.1.4 Tin Plated Steel Cans. Tin plated steel cans shall be separated from all other material and shredded. The cans, initially up to 1 gallon in size, shall be shredded to a maximum dimension of 2 inches and a minimum density of 65 pounds per cubic foot. Non-tin plated steel can contamination (including foil, food, aluminum, labels and plastic) shall be less than 2 percent of total product weight.

E.2.4.1.5 PET Plastic. PET plastic shall be separated from all non-plastic material and further sorted from high-density polyethylene prior to perforation and baling. All PET beverage bottles shall be perforated and baled to a minimum density of 20 pounds per cubic foot. Contamination of all non-PET beverage bottle material shall be less than 3 percent by weight of total product weight.

E.2.4.1.6 HDPE Plastic. HDPE plastic translucent "milk jug-type" containers shall be separated from all non-plastic material and further sorted from other plastic prior to baling. Colored HDPE content shall not exceed 10 percent by weight. Non-HDPE and non-plastic contamination shall not exceed 1.0 percent by weight.

E.2.4.1.7 Mixed Rigid Plastic. Mixed rigid plastic containers shall be separated from all non-plastic material and from PET and translucent HDPE prior to perforation and baling. Contamination of all non-plastic material shall be less than 3 percent by total product weight.

E.2.4.2 Paper Recovery

Old newspaper (ONP), old corrugated cardboard (OCC), high grade office paper, mixed paper, and specialty cellulosic materials can be recycled for a variety of uses. To make use of recycled paper, manufacturers usually must employ specialized equipment to re-pulp, remove ink and other contaminants, screen, and otherwise refine fibre for mixing with virgin feedstock (301, 782). Certain high grade office papers can be remixed directly and therefore command a higher secondary market price than commodity-grade ONP and OCC. Specifications for grades of waste paper are well-developed with guidelines for numerous grades of used paper stock. These specifications focus on percentages of "prohibitive materials" and "outthrows" for any contaminants that render the recyclable paper unusable in reprocessing. Depending on the reprocessor's needs, paper is sold baled or loose.

To prevent contamination from glass, moisture, and beverage and food residue, source separation of paper is the preferred alternative. Even in source separation of commingled recyclables, paper is best recycled if separated from the remaining fraction. A MRF processing capability affords a program the opportunity to collect more than one grade of paper in its paper fraction. Incoming mixed papers would typically be isolated on the MRF tipping floor and pushed onto a box conveyor for manual picking by paper grade. Paper grades then would be baled or containerized (e.g., truckload, container, shrinkwrap) for shipment.

Typical problems encountered in mixed paper separation include cross-contamination or moisture in the material from exposure to precipitation at the curbside. Separation of paper grades from totally commingled recycling streams conceptually is less effective due to the risk of residue contamination. If necessary from a collection standpoint, manual sorting on a conveyor is the preferred method (301).

E.2.4.3 Ferrous Metal Recovery

Recovered ferrous metals can be resold to detinning facilities or directly to steel mills for their smelting operations. Detinners are sensitive to contaminants that can impede processing (e.g., aluminum) or exacerbate effluent problems (e.g., labels in sludge) (782). Steel mills are constrained by their basic manufacturing process, metallurgical requirements of end products, and emission and effluent problems. Oxygen furnace mills can usually use up to 30 percent scrap material, but electric arc furnace mills can use up to 100 percent scrap materials (782).

Bi-metal cans are the primary source of post-consumer ferrous metal. These materials can be recovered relatively easily from commingled recyclables by stationery or belt magnets. The recovered product can be baled, shredded, or nuggetized in commercially available devices. According to the Steel Can Recycling Institute (782), the ferrous product must be free of all non-metallic, non-ferrous materials other than paper labels. As a result of declining domestic steel production and the availability of other ferrous scrap sources, the post-consumer recovery of ferrous has lagged (301). For example, the San Jose, California project has reported problems with the market acceptance of even label-contaminated ferrous (723).

E.2.4.4 Aluminum Recovery

Aluminum, primarily recovered in the form of used beverage containers (UBCs), can be resold directly to aluminum processors who reprocess it as container flat-rolled stock. Depending on specific alloy specifications, post consumer aluminum can be re-used in amounts up to 100 percent of finished product with substantial energy savings and conservation of the mineral bauxite (782, 336). The recovered aluminum product is preferred by processors to be densified in bales or biscuits (i.e., nuggets) of specific size and to be free of excess moisture and contaminants (782). Although aluminum only comprises a small fraction of MSW, recovery is highly desirable. Aluminum is easy to recover from commingled recyclables and its high resale value helps to subsidize the recycling of other materials (301).

The most common methods of separating aluminum from other recyclables is manual picking from a conveyor belt or use of an eddy current separator. Air classification also can be used, depending on whether the feed stream also contains plastics, which have comparable aerodynamic characteristics to aluminum beverage containers. Small pieces of broken glass can also carry over with the aluminum materials in an air classifier. Other methods for aluminum separation include electrostatic separation and several wet processes (jigging, water elutriation, and heavy media separation) (301).

Repackaging of recovered aluminum for resale involves the flattening of cans in a press or by rollers positioned above a conveyor. Flattened cans can then be baled or compressed into biscuits, or blown into trailers for loose shipment. All of the packing equipment is commercially available as standard items.

E.2.4.5 Glass Recovery

Recovered glass beverage and food containers can be resold to glass container manufacturers for substitution of up to 100 percent for virgin materials or to building material manufacturers for inclusion in road surfacing, glass wool insulation, or aggregate-based products. Substitution of recycled glass enables container manufacturers to operate at lower furnace temperatures and improve emission characteristics. Container manufacturers will accept recycled material in whole container, irregularly broken, or crushed form. Two critical specifications have a direct affect on recycling practices:

- o Glass must be sorted by color (i.e., flint, green, and brown) to control the cosmetic appearance of end products, and

- o Recycled glass must be free of all contaminants, including paper, plastics, metals, textiles, and rocks (782).

As glass containers break during the trip from the point of consumer discard through collection and centralized processing, colors can become mixed and chards of glass can collect the residue of other materials. Vestiges of metallic tops and paper labels can also remain if not removed by the generator or the centralized processing system. Chards of glass also become imbeded in other recyclables with which they come in contact, thereby reducing the marketability of the other material. Glass-impregnated papers, for example, damage rollers and other processing equipment in the manufacture of recycled papers.

If glass is to be separated from mixed waste without subsequent color separation, trommeling, screening, air classification, or combinations thereof are used (181, 316). Froth flotation also has been demonstrated (301). These techniques simultaneously break and densify the mixed glass cullet, thereby possibly avoiding the necessity for a discrete densification step. Certain proprietary processes have been developed and are used commercially (164, 783) to beneficiate glass prior to shipment, by removing excessive contaminants through trommeling and wet processes.

By contrast, most processes to recover glass by color avoid breakage to facilitate visual recovery. Manual picking of glass colors from a conveyor is the most common method of recovery, although optical scanning and certain proprietary processes have been demonstrated (301). Densification of the recovered product can occur naturally by handling or use of a glass crusher, which is a commercially-available device.

As more post-consumer glass has become available from MRFs, container manufacturers have become considerably more selective of materials available for sale. More than a phenomenon of increased supply exceeding demand, this has been in response to excessive contamination in post-consumer glass products (784). Glass recycling can significantly contribute to machinery downtime in a MRF, as the abrasive quality of the material causes accelerated wear of conveyor systems and glass crushers.

E.2.4.6 Plastics Recovery

All plastics represent only about 7 percent of all MSW by weight (774). Plastic containers and packaging (those applications found in the MRF stream) represent about 3 percent of all MSW by weight (774). The variety of resins and colors often makes it difficult for the generator, curbside collection crew, MRF workers, or MRF mechanical devices to distinguish one type from another. Although of likely resale value, the quantities of certain plastics in the waste stream have precluded recycling at any reasonable net cost. Consequently, plastics recycling technology has been slow to develop (301).

Primarily because of their high volume and relative ease of identification, containers made from high density polyethylene (HDPE) and polyethylene terephthalate (PET) are the most commonly recycled plastics. Comprised largely of milk containers and soft drink base cups, HDPE can be sold as-is or granulated. The primary source of PET is two-liter soda bottles that can be granulated and shipped loose, shredded and baled, or baled whole. Recycled PET containers can be used in the manufacture of a variety of items such as fiberfill cushioning, geotextile membranes, or industrial strapping. PET can be processed, mixed with virgin resin, and re-extruded. Several intermediate plastic processors serve as value-added reprocessors to recycle post consumer PET in proprietary processes (involving air classification, froth flotation, electrostatic separation, washing, and extrusion) for such re-use applications.

Because of classification difficulty, plastics typically are best separated by primary resin type through manual sorting on a conveyor belt prior to shredding and baling or granulation and packing in gaylord containers for shipment to market. In addition to manual sorting, plastics also can be separated from other materials by air classification or vibration screening. Use of any mechanically-assisted separation depends largely on the design approach to glass recycling, its breakage and cross-contamination.

E.2.4.7 Recovery of Other Materials

Other materials that are subjected to more intensive, centralized mixed-waste processing include wood and yard wastes, construction and demolition wastes (C&D), tires, and waste oil. Each of these materials can be source separated and collected in a variety of dedicated vehicles or self-delivered to a processing location. Except for waste oil, these materials are processed through large scale grinders, shredders, hammermills, or flail mills for size reduction. Certain grades of waste oil can be co-fired in heating systems or are processed first in specialized filtration systems to remove particulate matter and excess moisture.

End markets for these orphan waste streams are very localized and without any general specifications for size, density, composition, or packaging. In general, markets and applications consist of:

- Wood: Compost, decorative landscaping chips, biomass fuel
- C&D: Building material aggregate, landfill cover
- Tires: Boiler fuel supplement, road surfacing bulking material, supplement to virgin tire rubber
- Waste oil: Fuel supplement, asphalt additive, road dust surpressant

E.3 ECONOMIC PERFORMANCE

A wide range of process and program costs for recycling technologies have been reported (785, 148, 386) that reveal inconsistencies and little or no emerging pattern of costs (785). This phenomenon can be attributed to a variety of factors:

- Early programs and facilities have had a convoluted history (785) that make expended costs different than replication costs
- Private vendors have been unwilling to provide proprietary information (785)
- Programs vary widely in target materials, collection methods, and levels of processing (785)

o Documentation of costs is poor and/or reporting is inconsistent (e.g., exclusion of collection costs, shared overhead, residue disposal charges, material resale credits)

Several emerging databases are available (148, 386) but data collection is inconsistent and the facility classifications are broad, making comparative analysis by program or technology type difficult.

E.3.1 Facility Costs

Table E-15 (386) provides original and adjusted (to 1989 cost levels) capital costs for 28 existing and 45 planned (circa 1989) MRF facilities that process recyclable materials from a variety of curbside programs (including intensive curbside and commingled source separation). Planned facilities reflect a higher cost per ton likely attributable to the inclusion of a greater number of higher technology, larger scale plants in the sample. Special note should be made of the range and standard deviation of the facilities polled for this survey, which highlights the variations and inconsistencies in the available database (386). Table E-16 provides the detailed data supporting the summary statistics presented above.

For the same facility population above, Table E-17 presents plant capital cost ranges as a function of design capacity. Planned facilities average 162 tons per day compared to 89 tons per day for existing facilities (386). The effect on capital cost ranges on the degree of mechanization is illustrated in Table E-18. iThe number of facilities is approximately evenly split between high and low technology types, with a greater concentration of high technology MRFs in the Northeast.

The same survey (386) was only able to collect O&M cost data from fourteen existing and nine planned facilities as shown in Table E-19. In this limited sample, the costs per ton for planned facilities is lower than existing facilities, likely reflecting economies of scale from larger facilities (386)

The capital cost for the small scale McMRF offered by Count Recycling Systems is $99,500. The mobile Ptarmigan system's capital cost is approximately $75,000 (769).

TABLE E-15. CAPITAL COSTS AND BOND ISSUES* (386)

Sample	Mean	Sum	Standard Deviation	Minimum	Maximum	N
ORIGINAL CAPITAL COSTS						
All Facilities	$4,684,260	$341,951,000	7,050,131	$11,000	$48,000,000	73
Planned	$6,166,667	$277,500,000	8,099,193	$300,000	$48,000,000	45
Existing	$2,301,821	$64,451,000	4,012,160	$11,000	$20,000,000	28
ADJUSTED CAPITAL COSTS (1989 DOLLARS)						
All Facilities	$4,727,158	$345,082,536	7,109,979	$11,000	$48,000,000	73
Planned	$6,169,185	$277,613,333	8,098,522	$300,000	$48,000,000	45
Existing	$2,409,614	$67,469,203	4,346,051	$11,000	$22,[illegible]6,672	28
ADDITIONAL OR RETROFIT COSTS						
Existing	$3,001,667	$18,010,000	3,636,990	$120,000	$9,500,000	6
BOND ISSUES						
All Facilities	$13,888,889	$125,000,000	28,762,669	$200,000	$90,000,000	9
Planned	$18,983,333	$113,900,000	34,987,965	$200,000	$90,000,000	6
Existing	$3,700,000	$11,100,000	3,897,435	$400,000	$8,000,000	3
RATIO OF ADJUSTED CAPITAL COSTS: DESIGN CAPACITY (TONS PER DAY)						
All Facilities	$33,223	-	29,716	$1,100	$200,000	73
Planned	$37,477	-	31,920	$6,000	$200,000	45
Existing	$26,387	-	24,814	$1,100	$79,981	28

* No information was available form 19 planned and 12 existing MRFs with regard to original capital costs. Only minimal information was available on retrofit costs and the size of bond issues and these data have been presented for illustrative purposes only.

TABLE E-16. DETAILED COST DATA (386)

NAME	DESIGN TPD	ORIGINAL CAPITAL COSTS	YEAR	1989 ADJUSTED COST	ADDED CAPITAL COST	YEAR	O&M COST PER TON W/DEBT $	YEAR	O&M COST PER TON NO DEBT $	YEAR
Operational - Low Tech										
Phoenix	10	11000	89	11000					49	
San Mateo County (BFI - Recyclery)	75									
East Bay Disposal (Durham Rd.)	55	375000	89	375000						
Waste Management of Santa Clara	70									
Empire Waste Management	80									
Garden City Disposal	2	100000	89	100000					55	89
Meyer Brothers Scavenger Service	11	250000	88	257083					27	
Waste Management of McHenry County	4									
Buffalo Grove/Wheeling Disposal	21									
Waste Management (Blaine)	25									
Dakota County	40								23	
Ramsey County (Super Cycle MRF)	43	450000	82	540326			60	89		
Atlantic County	37	230000	89	230000					46	
Somerset County	125	1000000	87	1051401	4900000	90			130	
Susquehanna County	5	40000	87	42056						
York County (Recycle America)	30	1500000	89	1500000						
York Waste Disposal	2	150000	89	150000						
Seattle (Recycle America)	110	500000	88	514167			30	89		
WMI Recycling of Wisconsin	21									
Operational - High Tech										
Marin Recycling & R.R. Center	100				9500000	86				
Groton (SECRRRA)	23				290000	87	8		5	
Camden County	70	700000	86	753172					69	
Monmouth County Recycling Corp.	43	1500000	87	1577102					21	
Distributors Recycling	250	900000	87	946261						
Monmouth County	25	120000	88	123400			23	89		
West Paterson (WPAR)	70	1100000	88	1131167						
New York City (East Harlem)	55	3600000	88	3702000					61	
Syracuse	400	3500000	88	3599167						
Westbury	75	400000	88	411333						
Bristol (Otter Recycling)	45	3500000	88	3599167			67			
Bucks County Satellite Facility	45				120000	89			7	
Philadelphia Transfer & Recycling	35	400000	89	400000						
Johnston MRF	130	4150000	89	4150000	2200000	90			29	
Seattle (Rabanco)	85	6000000	88	6170000						
Operational - Other										
Eden Prairie (Reuter)	470	20000000	85	22006672						
Temporary Shutdown - Low Tech										
Pinellas County (BFI)	325	875000	83	980562	1000000	89			7	
Dixon Recyclers MRF	80									
National Temple Recycling Center	40	1700000	88	1748167						
Temporary Shutdown - High Tech										
Islip (New Facility)	300	8400000	89	8400000					27	

TABLE E-16. DETAILED COST DATA (cont)

NAME	DESIGN TPD	ORIGINAL CAPITAL COSTS	YEAR	1989 ADJUSTED COST	ADDED CAPITAL COST	YEAR	O&M COST PER TON W/DEBT $	YEAR	O&M COST PER TON NO DEBT $	YEAR
Advanced Planning - Low Tech										
Huachuca City	42	1000000	89	1000000					11	
Eden Prairie (BFI)	150	2100000	89	2100000			40	90		
Invergrove (BFI)	150	2100000	89	2100000			40	90		
St. Louis (BFI)	150	1300000	89	1300000						
Sussex County	140	1500000	89	1500000						
Lackawanna County	125	3000000	90	3000000						
Advanced Planning - High Tech										
TURF (Total Urban Renewal Facility)	150									
Capitol Region MRF (Hartford)	200									
DuPage County (New England CRInc.)	150	9000000	89	9000000						
DuPage County (Waste Management)	150	9000000	89	9000000						
Cumberland County	80	3000000	89	3000000					25	
Brookhaven	120	8200000	89	8200000					38	
Hempstead	100									
Westchester County	200	10000000	89	10000000			36			
Advanced Planning - Other										
Broward County	660	48000000	89	48000000						
Construction - Low Tech										
San Jose (BFI - Newby Island)	200	12000000	90	12000000					15	
Pinellas Park (Recycle America)	175									
Lewis County	50	300000	90	300000						
Jefferson County	100	1000000	89	1000000						
Mecklenberg County	120	2500000	89	2500000						
Centre County	60	1800000	89	1800000						
Construction - High Tech										
Springfield	240	6650000	89	6650000					22	
Rosetto Recycling Center	250	6600000	89	6600000						
Cape May County	225	4900000	89	4900000					28	
Oneida-Herkimer Counties	200	7000000	89	7000000						
Akron	10	2000000	89	2000000						
Karta Container & Recycling	145	3000000	89	3000000						

TABLE E-16. DETAILED COST DATA (cont)

NAME	DESIGN TPD	ORIGINAL CAPITAL COSTS	YEAR	1989 ADJUSTED COST	ADDED CAPITAL COST	YEAR	O&M COST PER TON W/DEBT $	YEAR	O&M COST PER TON NO DEBT $	YEAR
Conceptual Planning -										
City of Los Angeles (1)	100									
City of Los Angeles (2)	100									
City of Los Angeles (3)	100									
City of Los Angeles (4)	100									
City of Los Angeles (5)	100								11	
L.A. County Sanitation Districts	600	9000000	91	9000000						
Ventura Region Sanitation District	500	30000000	91	30000000						
Housatonic Res. Recovery Authority	180									
MRF/Transfer Station/Composting	385	7500000	93	7500000						
Montgomery County (Shady Grove Rd.)	250	7700000	89	7700000			30	89	15	89
Prince George's Co., Municipalities	20	800000	89	800000						
Southwest Solid Waste Mgt. District	80									
Ocean County	225	6000000	89	6000000						
Mercer County	180									
Warren County	80	1000000	91	1000000						
West Finger Lakes	75	4000000	88	4113333						
Cortland County	50									
Oswego County	100									
Ontario County	20	1000000	90	1000000						
Monroe County	280	10000000	91	10000000						
Berks County	150	4500000	89	4500000						
Monroe County	80									
Quonset Point	160	8000000	89	8000000						
Pulaski County	140	2000000	91	2000000						
Conceptual Planning - Low Tech										
Prince George's County	200								19	
Hennepin County	200	3600000	89	3600000						
Orange County	65	4500000	90	4500000			31			
Madison County	65	1000000	90	1000000						
King of Prussia	170	2000000	90	2000000						
Knoxville	90	1200000	90	1200000						
Pierce County	70	1750000	91	1750000						
Conceptual Planning - High Tech										
Greater Bridgeport Region	275									
Palm Beach County (North)	250	7000000	89	7000000						
SEMASS (MRF)	100	5000000	91	5000000						
Oakland County	200	11000000	90	11000000						
Gloucester County	150									
Dutchess County	75	6000000	90	6000000						
New York City (Staten Island)	200									

TABLE E-17. ADJUSTED CAPITAL COSTS BY DESIGN CAPACITY (386)

Adjusted Capital Costs (1989 Dollars)	Design Capacity (Tons Per Day)			
	1 to 99	100 to 199	Over 200	All Facilities
Less Than $1,000,000	54.5%*	10.5%	9.5%	30.1% (22)
$1,000,001 to $5,000,000	39.4	68.4	14.3	39.7 (29)
More Than $5,000,000	6.1	21.1	76.2	30.1 (22)
Total Percent (Total Number**)	100.0 (33)	100.0 (19)	100.0 (21)	100.0 (73)

* Percentage of column.

** No information was available from 31 MRFs with regard to adjusted capital costs.

TABLE E-18. ADJUSTED CAPITAL COSTS BY DEGREE OF MECHANIZATION (386)

Adjusted Capital Costs (1989 Dollars)	Degree of Mechanization		
	Low	High*	All Facilities
Less Than $1,000,000	46.7%**	16.7%	31.7% (19)
$1,000,001 to $5,000,000	50.0	36.7	43.3 (26)
More Than $5,000,000	3.3	46.7	25.0 (15)
Total Percent (Total Number***)	100.0 (30)	100.0 (30)	100.0 (60)

* Includes Reuter projects.

** Percentage of column.

***No information was available from 44 MRFs with regard to adjusted capital costs or degree of mechanization.

TABLE E-19. OPERATING COSTS (386)

Sample	Mean	Standard Deviation	Minimum	Maximum	N
ANNUAL O&M COSTS (INCLUDING DEBT SERVICING)					
All Facilities*	$1,261,625	1,458,152	$54,000	$5,000,000	10
Planned	$2,017,600	1,787,587	$168,000	$5,000,000	5
Existing	$505,650	399,690	$54,000	$858,000	5

* No information was available from 59 planned and 35 existing MRFs with regard to O&M costs (including debt servicing).

Sample	Mean	Standard Deviation	Minimum	Maximum	N
ANNUAL O&M COSTS (EXCLUDING DEBT SERVICING)					
All Facilities**	$774,800	765,246	$33,400	$3,000,000	23
Planned	$904,333	585,311	$84,000	$1,900,000	9
Existing	$691,529	872,416	$33,400	$3,000,000	14

** No information was available from 55 planned and 26 existing MRFs with regard to O&M costs (excluding debt servicing).

Sample	Mean	Standard Deviation	Minimum	Maximum	N
O&M COSTS PER TON PROCESSED (INCLUDING DEBT SERVICING)					
All Facilities	$36.51	16.95	$8.15	$66.66	10
Planned	$35.45	4.72	$30.00	$40.00	5
Existing	$37.56	24.92	$8.15	$66.66	5
O&M COSTS PER TON PROCESSED (EXCLUDING DEBT SERVICING)					
All Facilities	$32.29	27.69	$5.43	$130.43	23
Planned	$20.61	8.90	$11.07	$38.46	9
Existing	$39.80	33.06	$5.43	$130.43	14
RESIDUE DISPOSAL COSTS (DOLLARS PER TON)					
All Facilities	$52.49	22.91	$11.00	$114.50	39
Planned	$50.50	21.73	$12.00	$75.00	14
Existing	$53.60	23.91	$11.00	$114.50	25

*** No information was available from 50 planned and 15 existing MRFs with regard to residue disposal fees.

E.3.2 Collection Costs

Collection costs are difficult to generalize due to several location-specific factors that affect collection productivity, including equipment capacities, distance between stops, set-out practices, waste quantities (pounds and containers per stop), distance to the MRF, worker productivity, climate, topography, and traffic. Also, the documentation and reporting practices of public and private sector hauling operations are inconsistent. As a result, little comparative information is available.

By way of illustration, however, Table E-20 summarizes the projected comparative collection costs (as of 1990) for various program alternatives in a New York State suburban setting (i.e., lower Hudson Valley) (786). This analysis highlights the comparative collection costs of intensive and commingled source separation scenarios based on expected participation and separation efficiency rates for each alternative. In this specific case, the operating cost per ton (including debt service) of a MRF to process commingled recyclables compatible with collection alternative number four was estimated to be $68 per ton. Therefore, the total program cost for the commingled curbside program of $113 per ton was only slightly higher than collection costs alone for a comparable intensive curbside program of $99 per ton (excluding processing).

Intuitively, collection costs for the curbside collection of recyclables are higher than for conventional curbside waste collection. Most collection costs are a function of units served or, to a much lesser extent, tons collected. The aforementioned curbside services require a dedicated vehicle of special design, and each truckload processes less tons per unit of time, due to the density of materials and typically the inability to use compaction equipment. Consequently, dedicated collection effectively doubles variable collection costs per stop (e.g., per single family household). Due to the lower tons per vehicle, operating and capital costs per ton increase as well, the amount depending on the density of materials collected, the relative utilization of each vehicle compartment, and the distance from the route to the MRF.

TABLE E-20. COMPARISON OF COLLECTION ALTERNATIVES (786)

(Once per Week Collection)

ALTERNATIVE	COST/TON	COST/HH	LB/HH/DAY
1. Mixed paper and mixed containers in two-compartment vehicle to high tech MRF.	45	27	3.31
2. On route sort of news, brown/green glass, clear glass tin/aluminum to low tech MRF.	103	44	2.32
3. Three-way sort of news, commingled containers, low grade papers, organics to composting and MRF.	48	38	4.32
4. Number 1 with plastics.	45	29	3.50
5. Number 2 with plastics.	99	45	2.51
6. Number 3 with plastics.	46	38	4.50
7. Full sort of news, brown glass, green glass, clear glass, tin, aluminum, PET, HDPE, and yard waste utilizing two trucks.	154	72	2.57

E.4 POTENTIAL ENVIRONMENTAL IMPACTS

Compared to other solid waste management alternatives, recycling, including only the collection and sortation of recyclables, is accepted by many as environmentally benign. There is, however, very limited technical data to support this hypothesis or the environmental impacts that may be associated with separating recylables directly from MSW or from the reformulation of recyclables into new products. For this reason, the U.S. EPA's Environmental Criteria Assessment Office has been studying the potential hazards that may be associated with municipal solid waste recycling (905). Results are expected to be available in mid-1992. Also, the Solid Waste Association of North America, at the request of the U.S. EPA as part of its MITE program, is also planning an evaluation of facilities which process (for the purpose of recycling) materials from MSW. Environmental, process design, and cost data will be evaluated for selected operating MRFs. Results are expected to be available in 1993 (906).

Groundwater resources are largely unaffected by recycling. MRFs for curbside separation programs typically are constructed on a concrete pad that prevents seepage of any waste pollutants into the soils. Moreover, these facilities typically handle pre-cleaned, dry, and solid components of the waste stream. Facilities are usually new and therefore subject to state-of-the-art design and regulatory scrutiny with respect to surface drainage and run-off. Potential groundwater impacts of mixed-waste MRFs would be similar to the fuel preparation module of an RDF facility or front-end processing of a mixed waste composting plant.

Atmospheric emissions from recycling programs are from two sources: collection operations and processing facilities. Curbside recycling programs that employ dedicated vehicles increase vehicular emissions to the atmosphere on a unit basis. Emission data on specially-designed recycling vehicles was not identified in the literature search. Atmospheric emissions data from MRFs processing commingled recyclables also is largely unavailable, except for limited data on a low technology facility in Groton, Connecticut (787), demonstrating low levels of particulate, VOC, and metals emissions.

Dust emissions likewise are minimal on route and in each MRF for curbside sorted materials. Operations usually are conducted indoors where ventilation and localized dust surpression measures are taken as required. Mixed waste MRFs experience greater opportunity for dust, but more sophisticated ventilation and collecting devices are typically used, such as cyclones and fabric filters.

Potential noise impacts are from two sources: collection vehicles and machinery. Collection vehicles are equipped with conventional noise abatement devices. Machinery noise is surpressed by restriction of operations to the interior of buildings.

Potential vector impacts are minimal in front-end processing systems in general due to the enclosure of processing operations, ventilation, and pest control. MRFs for curbside source separation programs also process a cleaner fraction of the waste, which often is pre-washed by the waste generator of food and other organic residues. The putrescible waste content of the commingled source-separated recyclable stream entering a MRF can be virtually eliminated with a carefully-controlled collection program.

Odor emissions are controlled with similar design features for vehicles and machinery as are used to control noise and dust. In addition, in mixed waste processing systems such as front-end systems, the tipping floor areas can be designed to maintain a slightly negative pressure to control odors. Again, due to the minimal putrescible waste content of commingled or source-separated recyclables entering a MRF, odor is typically not a problem.

E.5 ENERGY PRODUCTION REQUIREMENTS

Mixed waste processing facilities have energy requirements comparable to RDF fuel preparation plants, but MRFs servicing curbside source separation programs require conceptually less energy to operate. No information on energy requirements is readily available in the public literature.

One appeal of materials recycling is the reported energy savings available in reprocessing of recycled materials and the avoidance of processing virgin raw materials (295, 723, 774, 271). Table E-21 illustrates energy savings claimed (788, 271) for the substitution of recycled feedstock for virgin material in basic manufacturing processes.

TABLE E-21. ENVIRONMENTAL BENEFITS DERIVED FROM SUBSTITUTING RECYCLED MATERIALS FOR VIRGIN RESOURCES

(modified from 271)

(percentages)

Environmental Benefit	Aluminum	Steel	Paper	Glass
Reduction of Energy Use	90-97	47-74	23-74	4-32
Reduction of Air Pollution	95	85	74	20
Reduction of Water Pollution	97	76	35	--
Reduction of Mining Wastes	--	97	--	80
Reduction of Water Use	--	40	58	50

E.6 INTEGRATION WITH OTHER TECHNOLOGIES

Materials recycling plays an integral role in the overall management of municipal solid wastes:

- o <u>Composting</u>: Requires materials separation to remove impurities, reduce odor, and remove inorganics.

- o <u>Landfilling</u>: Landfilling benefits from recycling in the sense that the landfill life is extended when materials are diverted. A MRF can be located at the landfill, reducing residue disposal time and costs.

- o <u>MSW Combustion</u>: Removal of low Btu materials such as metals and glass improves the fuel quality, whereas removal of high Btu materials such as paper and plastic will reduce the fuel yield. The higher heating value (HHV) of the fuel will be affected.

A study was conducted on the effects of recycling on Massachusetts' solid waste combustion capacity projected to the year 2000 (792). This study considered: 1) the cumulative effects of Massachusetts' goals of 10 percent source reduction and 46 percent recycling by the year 2000; 2) a predicted change in the percentage of plastics in the waste stream from 7.3 percent in 1990 to 9.2 percent in 2000; and, 3) the diversion to landfill of non-combustible materials such as white goods, street sweepings, and unrecycled metals and glass. The net result of these three factors is an estimated increase in the HHV from 4,754 Btu per pound (without recycling) to 5,884 Btu per pound, a 24 percent increase.

Specifically, this increase can be attributed to the removal of low Btu yard waste, metals and glass, and non-recyclable, non-combustibles; and an expected increase in the percentage of plastics in MSW in the year 2000. Removal of high Btu paper and plastic in accordance with the recycling goals is expected to have a much smaller affect on the HHV than that due to the removal of the low Btu materials.

Most of the combustion facilities in Massachusetts are limited on a heat input basis, and therefore the quantity of fuel that can be burned is a function of its Btu content. Any increase in the energy content of the fuel must be accompanied by a corresponding decrease in the feed rate. The Massachusetts study estimated that for every Btu per pound added to the HHV, the processing capability decreases by approximately 640 tons per year. Thus, Massachusetts will need to provide an additional disposal capacity of 723,000 tons per year to meet the expected disposal requirements in the year 2000 if the recycling goals are achieved.

E.7 RESEARCH NEEDS

A relatively emerging technology and immature industry segment, materials recovery requires substantially more research to assess performance and develop improved applications. Primary areas of focus are likely to include:

- o Collection, classification, and analysis of design features, capital costs, operating costs, and operating parameters of facilities. The focus should be on system costs, including collection and processing

- o New materials processing techniques, especially for glass

- o New glass collection techniques

- o New uses and applications for recovered materials of all quality specifications, especially low quality specifications

- o Environmental impact performance of recycling systems, including collection and processing

- o Life cycle costing analysis of recycling versus virgin material use in basic products

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16. Abstract (Limit: 200 words)

The overall objective of the study in this report was to gather data on waste management technologies to allow comparison of various alternatives for managing municipal solid waste (MSW). The specific objectives of the study were to:

1. Compile detailed data for existing waste management technologies on costs, environmental releases, energy requirements and production, and coproducts such as recycled materials and compost.
2. Identify missing information necessary to make energy, economic, and environmental comparisons of various MSW management technologies, and define needed research that could enhance the usefulness of the technology.
3. Develop a data base that can be used to identify the technology that best meets specific criteria defined by a user of the data base.

Volume I contains the report text. Volume II contains supporting exhibits. Volumes III through X are appendices, each addressing a specific MSW management technology. Volumes XI and XII contain project bibliographies.

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