Description of the Material Recovery Facilities Process Model

Design, Cost, and Life-Cycle Inventory

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TABLE OF CONTENTS

Appendices

1 Introduction

The objective of the Materials Recovery Facility (MRF) process model is to calculate the cost and life-cycle inventory (LCI) parameters for materials recovery from municipal solid waste (MSW). Cost and LCI coefficients are calculated as a function of the quantity and composition of waste processed and are based on both user-input and default information on the design of a MRF. These coefficients are used in a model of MSW management alternatives to identify management scenarios that are favorable with respect to cost and environmental burdens. The overall MSW system considered by the management model, and the role of MRFs in this system, is illustrated in Figure 1. As illustrated in Figure 1, several different types of MRFs are included in the management model as different MRFs are required based on the manner in which MSW is collected. The different types of MRFs represented in the process model are described in the following section.

The design of each type of MRF and the equations used to calculate its cost are presented in Chapters 2 to 6. The equations used to calculate the LCI coefficients are presented in Chapter 7. Default values for each MRF process model parameter are presented in the appendices. These parameters may be changed by the user based on site-specific data.

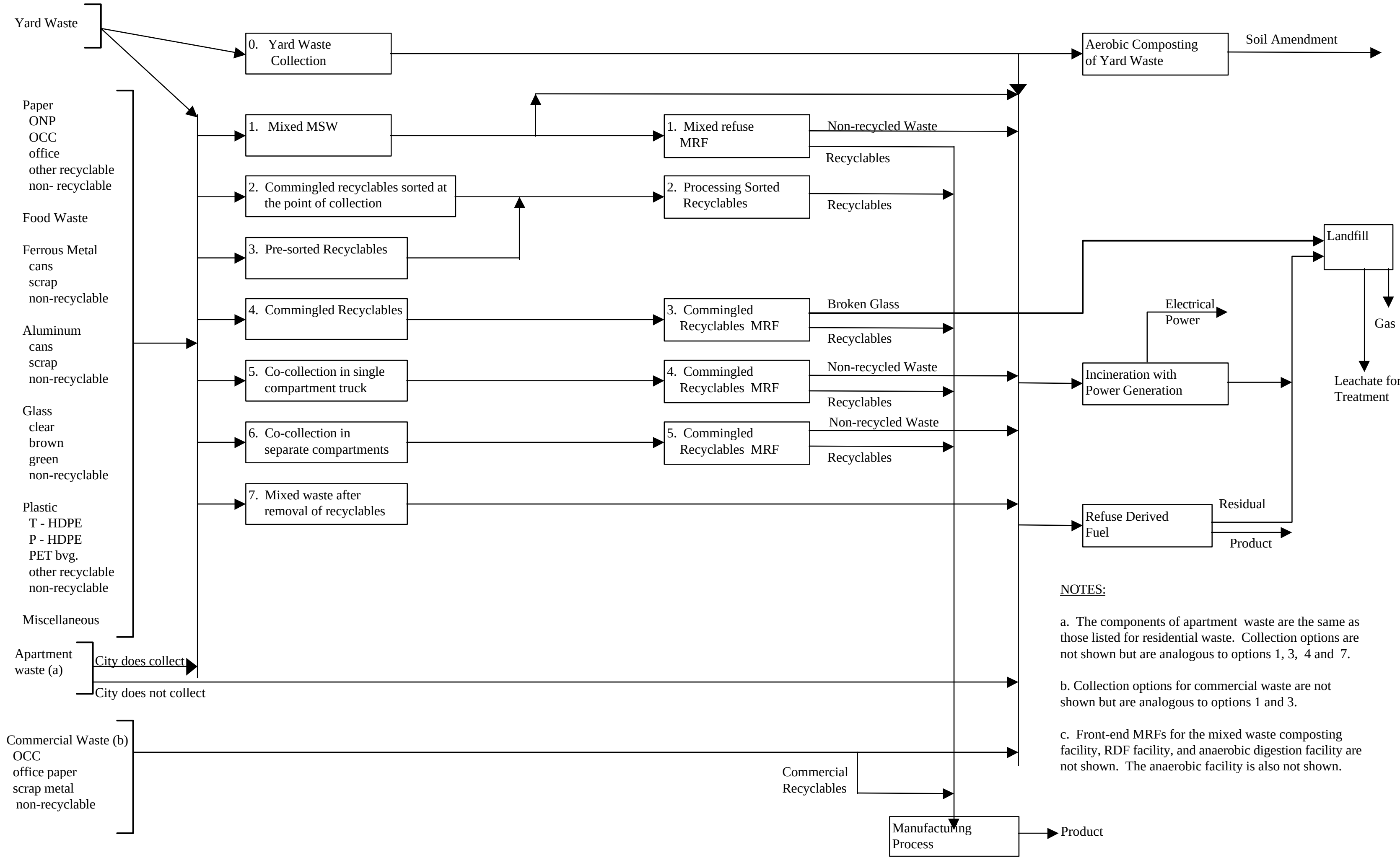


Figure 1. Alternatives for Integrated Solid Waste Management

1.1 Types of Material Recovery Facilities

The waste management system encompasses a wide variety of waste generation points: single family dwellings, multi-family dwellings, and commercial sectors. There are 21 collection options to collect waste and recyclables from these generation points in the system. To recover recyclables from these collection alternatives, 8 different types of MRFs are included in the waste management system as described below.

1. A mixed waste MRF in which mixed MSW is processed.

2. A presorted recyclables MRF in which presorted recyclables are processed. These recyclables are collected either presorted by the resident or sorted at the curbside by the collection crew.

3. A commingled recyclables MRF in which commingled recyclables are processed.

4. A co-collection MRF which receives commingled recyclables and mixed waste delivered in a single compartment truck. Recyclables are collected in a color coded bag (blue) with mixed waste collected in a bag of another color (black). All paper recyclables are collected in one bag, and the remaining non-paper recyclables are collected in a separate bag. The colors of bags used in a city can be different, but blue and black are the colors used for purposes of illustration in this document.

5. A co-collection MRF which receives commingled recyclables and mixed waste delivered in a three compartment truck – one compartment for mixed waste, one for paper recyclables, and the third compartment for non-paper recyclables. Recyclables are collected in blue bags and mixed waste is collected in black bags.

6. A front end MRF to a mixed waste composting facility. This MRF is at the front-end of a mixed waste composting facility, i.e., the material recovery operations precede composting operations. The MRF is similar to a mixed waste MRF, but includes provisions for additional sorting to remove contaminants from mixed waste that affect the composting product.

7. A front end MRF to an anaerobic digestion facility: This MRF is at the front end of an anaerobic digestion facility, i.e., material recovery operations precede anaerobic digestion operations. The MRF is similar to a mixed waste MRF, but includes additional sorting to remove contaminants that could adversely affect the anaerobic digestion process, or the quality of the digested solids.

8. A front-end MRF to a refuse derived fuel (RDF) facility. This MRF is at the front end of an RDF facility, i.e., material recovery operations precede RDF operations.

1.2 Mixed Paper, Plastic, and Glass

The model includes three components: PMIX (mixed paper), PLMIX (mixed plastic) and GMIX (mixed glass) that are defined by the user and include mixtures of waste components. The meaning of PMIX will be described first and then this term will be extended to PLMIX and GMIX.

The model user will be given the opportunity to define the composition of PMIX once for the residential and multi-family dwelling sectors and once for the commercial sector. Within a sector type, the model user may select which items, if any, should be considered as part of the mixed component. For example, the user may include third class mail and phone books in PMIX. All paper types not included in the user's definition of PMIX will be treated as individual components by the solid waste management model. Paper types that are included in PMIX cannot be analyzed as individual components. The definition of mixed paper is similarly extended to mixed plastic and mixed glass. For example, if the user included brown and green glass as GMIX, then the two types of glass that would be considered for recycling are clear glass and a mixture of brown and green glass. Based on the practicality of recycling many different types of paper and plastic, the total number of materials that can be recycled at each MRF type is restricted as follows:

Mixed Waste MRF: Residential/Multi-family:
Paper: ONP, OCC, Paper Other (2 categories), and PMIX:
Plastic: t-HDPE, p-HDPE,PET, Plastic Other (2 categories), and PLMIX

Commercial:
Paper: OCC, ONP, Paper Other (2 categories), PMIX
Plastic: t-HDPE, p-HDPE, PET, and PLMIX

Presorted MRF: Up to five types of paper and five types of plastic including PMIX and PLMIX.

Other MRFs: No limit on number of materials recycled

There are no limitations on GMIX processing at any MRF.

Note: Plastic Other categories were not included as recoverable in the commercial sector as these components are not defined for commercial waste.

2 Mixed Waste MRF Design

2.1 Introduction

The objective of this section is to present a design for a MRF in which recyclables are recovered from mixed waste. Based on this design, a cost function is derived to relate the cost of the MRF to the quantity and composition of the waste components to be processed therein. This design will also be used to derive the LCI parameters for the mixed waste MRF as presented in Chapter 7.

Note: The term "model solution" used frequently in this chapter refers to the waste management solution suggested by the decision support tool

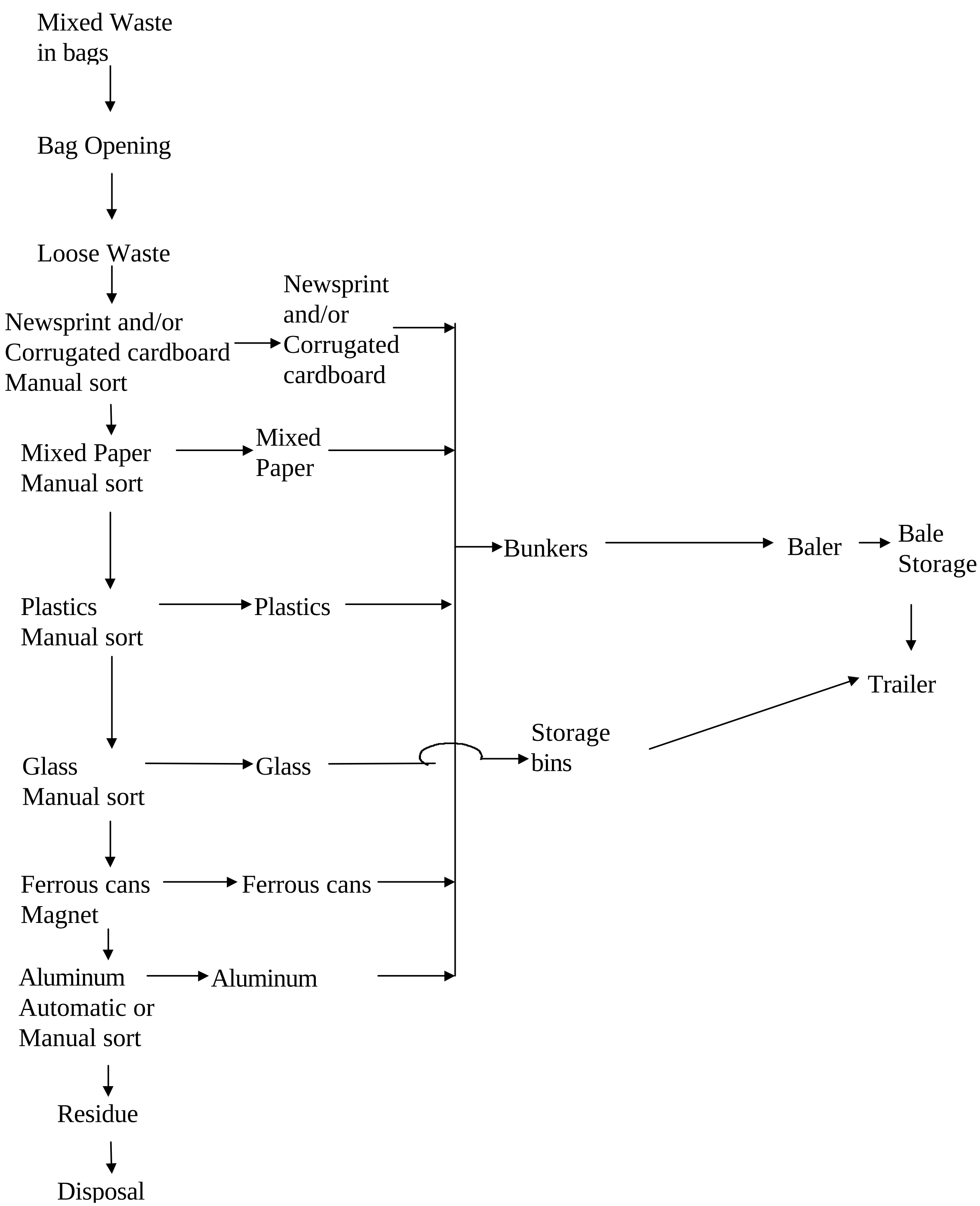
2.2 Description of process flow

The design of the mixed waste MRF is applicable to residential, multi-family, and commercial mixed waste. The process flow diagram that describes the recovery process in this type of MRF is presented in Figure 2-1. Mixed waste is typically collected at curbside and dumped on a tipping floor at the MRF. It is then loaded on to a conveyer by using a front-end loader or Bobcat^{TM}. This conveyer feeds a bag opening station as most waste is collected in bags. Undesirable items in the waste (e.g. white goods, bulky items, etc.,) are removed from mixed waste before and after the bag opening point in the MRF. Bags can be opened either manually or mechanically as selected by the user. New developments in bag opener technology make mechanical bag opening a technically feasible and an economically attractive option. Loose waste from the bag opening operation is then conveyed into an elevated and enclosed sorting room where the recyclables are recovered. An enclosed sorting room is used because workers are provided with air-conditioning and heating during sorting operations. The elevation of the sort room allows for space underneath for placement of bunkers or bins into which separated recyclables are dropped. The waste components that can be recovered from mixed waste are shown in Table 2.1

Table 2.1 Components of Mixed Waste that can be Recovered in the Mixed Waste MRF

Waste Component	Variable Name
Old Newsprint	ONP
Old Corrugated Cardboard	OCC
Office Paper	OFF
Phone Books	PBK
Books	BOOK
Old Magazines	OMG
3rd Class Mail	MAIL
Paper Other #1	PAOT1
Paper Other #2	PAOT2
Paper Other #3	PAOT3
Paper Other #4	PAOT4
Paper Other #5	PAOT5
Combustible Compostable Recyclable Other	CCR_O
Mixed Paper	PMIX
HDPE – Translucent	HDT
HDPE – Pigmented	HDP
PET	PPET
Plastic - Other #1	PLOT1
Plastic - Other #2	PLOT2
Plastic - Other #3	PLOT3
Plastic - Other #4	PLOT4
Plastic - Other #5	PLOT5
Mixed Plastic	PLMIX
Combustible Compostable Non-Recyclable Other	CNR_O
Ferrous Cans	FCAN
Ferrous Metal – Other	FMOT
Aluminum Cans	ACAN
Aluminum - Other #1	ALOT1
Aluminum - Other #2	ALOT2
Glass – Clear	GCLR
Glass – Brown	GBRN
Glass – Green	GGRN
Mixed Glass	GMIX
Combustible Noon-Compostable Recyclable Other	NNR_O
Paper - Non-Recyclable	PANR
Combustible Compostable Non-Recyclable Other	CCN_O
Plastic - Non-Recyclable	PLNR
Miscellaneous	MIS_CNN
Combustible Compostable Non-Recyclable Other	CNN_O

Figure 2-1 Process Flow Diagram of the Mixed Waste MRF



In the sort room, pickers are positioned on both sides of a conveyer. This staggered arrangement of sorters at the conveyer belt allows for a compact sort room and reduces the floor area requirement of the MRF. The distance between adjacent pickers is 4 feet and is such that pickers do not compete with each other for the same item. Similarly, the width of the conveyer is 4 feet in all the MRFs to minimize sorter fatigue in reaching for items on the conveyer and to reduce spillage from the conveyer. Recyclables picked from mixed waste on the conveyer are dropped into chutes that lead into "bunkers" under the sort room. When a bunker is full, recyclables are emptied into the hopper of a baler by using moving floors. Bunkers are not used for glass recyclables. Glass recyclables are not crushed and are dropped into storage bins that are emptied into trailers when full. Bales are loaded into trailers at a loading dock. Temporary storage space for bales is provided till a sufficient number of bales to fill a trailer are ready.

Newsprint (ONP), old corrugated cardboard (OCC), and Paper Other (2 categories) can be picked from the mixed waste as individual components. Because other paper components are present in small quantities and are likely to be wet and contaminated, they can only be recovered as mixed paper.

Metal cans remain in the refuse on the conveyer at the end of the sort room. Here cross belt arrangements are provided so that metal cans in the residue from all sort lines can be recovered by the same equipment (magnet for ferrous cans and eddy current separator for aluminum cans). Separation of aluminum cans can be manual or automated. If automated, an eddy current separator is used to recover aluminum cans. The choice of separation process used for aluminum recovery is a user option. It is recommended that the manual option be selected because from mixed MSW, aluminum cans separated with an eddy current separator will be contaminated. Ferrous metal is assumed to be recovered by a magnet.

As with any other industrial process, the price negotiated for a recyclable is based on certain quality requirements and quality control is an important consideration for recyclables in a MRF. Quality control is often maintained by a second sort of recyclables in each storage area. The second sort of recyclables can be done at the beginning or end of the work day. The user can specify the time required to remove contaminants from recovered materials. The second sort is discussed in the section dealing with working day length. Conveyers can then be used to route recyclables directly to a baler after a second sort.

Recyclables are baled and stored after recovery. Residue may be shipped to an incinerator, or a landfill as suggested by the management model. The transportation and disposal cost of residue is not included in the MRF cost. The cost of transportation of residue from a MRF to a disposal site is calculated in the transportation process model.

2.3 Determination of cost function for a mixed waste MRF

The annual cost of a mixed waste MRF has two components: capital cost amortized over the life of the MRF and the annual operating cost. The capital cost of a MRF is calculated from a unit capital cost with units of dollars per ton/year processed. In addition, it can be expressed in annual terms using a capital recovery factor that is dependent upon a book lifetime and discount rate. Both of these numbers are input parameters for which default data are available. The operation and maintenance (O&M) cost of a MRF includes the labor, overhead, taxes, administration, insurance, indirect costs, electricity cost and maintenance cost. It does not include the cost for disposing of the residue, nor does it include the revenue from recyclables sales. The O&M cost coefficient depends upon the unit O&M cost and the quantity of waste processed. The annual cost of a MRF is expressed in Equation 2-1.

Equation 2-1

$$Annual\ cost\ of\ MRF = CRF \times Capital\ cost + Annual\ Operating\ cost$$

Annual cost of MRF: expressed in $/ton
Capital Recovery Factor (CRF), units of 1/year

CRF is the capital recovery factor that enables the conversion of the capital costs into annual terms. It is a function of the facility or equipment life, *(lifetime)* and an appropriate *Discount_rate*. For a *Discount_rate* ≠ 0, CRF is calculated as follows:

$$CRF = \frac{Discount\_rate \cdot (1 + Discount\_rate)^{lifetime}}{1 - (1 + Discount\_rate)^{lifetime}}$$

Capital cost: is the capital cost per ton per year of waste component processed by the MRF. To convert capital cost from $/Ton per day to $/Ton per year, the following equation is used:

$$\frac{\$}{Ton/Year} = \frac{\$}{Ton/Day} \times \frac{year}{days}$$

Days per year are the number of operating days per year of the MRF.

Annual operating cost: expressed in $/ton

2.4 Capital cost

Capital cost consists of construction, land acquisition, engineering and equipment cost, as expressed in Equation 2-2.

Equation 2-2

$$Capital\ cost_i = Construction\ cost_i + Land\ cost_i + Engineering\ cost_i + Equipment\ cost_i$$

i: Cost is expressed per ton of waste component i

2.4.1 Construction cost

Construction cost includes the cost of the structure, access roads, fencing, landscaping, etc. The cost of the structure includes support facilities such as office space, a weigh station, and the loading conveyer. Loading conveyer is the length of conveyer from the debagging point into the elevated sort room and the conveyer leading into the hoppers of the balers. Total conveyer length in the sort room is discussed further in the following sections.

Construction cost is obtained by multiplying the floor area of the MRF by the construction cost rate ($/sq ft). Default values are provided for the construction cost rate. The EPA Handbook on MRFs [1] provides a range of 28-60 $/sq ft for the construction cost rate. A detailed estimate to calculate the construction cost rate is presented in Appendix 4, and the default value calculated is 40 $/sq ft. Upon analysis, it was found that the change in construction cost rate was not significant for the range of facility sizes that are likely to be encountered (50 TPD to 350 TPD). Construction cost is calculated using Equation 2-3. The construction cost rate includes the cost of office equipment.

Equation 2-3

$$Construction\ cost_i = Floor\ area\ of\ MRF_i \times const\_rate$$

Construction $cost_i$: Cost of construction of MRF for waste item i, $/TPD
const_rate: Construction cost rate, default value is 40 $/sq ft
Floor area of MRF_i: Floor area of facility for waste item i, sq ft/TPD from

Floor area of the MRF is a function of the quantity of waste processed in a day. It is also a function of the recyclables recovered. The area required for the MRF is estimated using Equation 2-4. The floor area of the MRF consists of the tipping floor, processing floor, and officespace area. All area estimates include a maneuverability factor (MF), that allows for vehicle, machinery and maintenance access.

Equation 2-4

$$Floor\ area\ of\ MRF_i = Tipping\ floor\ area_i + Processing\ floor\ area_i + Office\ area_i + Storage\ area_i$$

i: Area is expressed per ton of waste component i

Tipping floor area of the MRF

Mixed waste is unloaded from collection vehicles onto the tipping floor. The tipping floor should be big enough to accommodate more than one truck unloading in the MRF during peak hours. The tipping floor allows for downtime of equipment by including a storage requirement in the estimate. It should be noted that mixed waste should not be stored for more than a day due to potential health and odor problems. The area required for the tipping floor is calculated assuming an average waste density and a waste pile height. Equation 2-5 is used to calculate the tipping floor area.

Equation 2-5

$$Tipping\ floor\ area_i = \frac{MF1 \times tipp\_stor \times 2000}{n1 \times ref\_height}$$

Tipping floor $area_i$: Area of tipping floor, sq ft/TPD
MF1: Maneuverability factor for the tipping floor, value 2.5, [8]
tipp_stor: Storage requirement to allow for equipment downtime, default value is 0.5 days
n1: Loose density of waste on the tipping floor, default value is 12 lb/cu ft, [8]
ref_height: Height of refuse on the tipping floor, default value is 10 ft, [8]
2000 lb/ton

Processing floor area
The processing floor is used for separation and baling operations. The processing floor area consists of sort room, area required for balers, and area for loading loose refuse. The loading area includes some area for debagging. The processing area is calculated in Equation 2-7.

Sort room
The sort room where manual recovery of recyclables takes place is approximately 12 ft above the floor, enclosed, heated and air-conditioned. The length of the sort room is equal to the sorting length of the conveyer. The sort room width accommodates 3 conveyer belts, 4 ft wide, and room for pickers working beside these belts. The sorting length of the conveyer is a function of the composition and quantity of recyclables that are recovered in the MRF and is calculated in Equation 2-8. The width of the sort room is user input.

For a given speed of a conveyer, width of conveyer, thickness and density of waste on the conveyer, there is a maximum capacity that the conveyer can carry. If this maximum capacity is exceeded, then another conveyer is added in the sort room. In this MRF design, the speed of the sorting conveyer is assumed to be 30 ft/min, the width of the conveyer is 4 ft, the thickness of waste on the conveyer is 6 inches, and the density of waste on the conveyer is assumed to be 10 lb/cu ft. Using these data, and a 7 hr/day effective work day length, the carrying capacity of the conveyer is calculated as:

Equation 2-6

$$Conveyer\ capacity = \frac{4^{ft} \times 30^{ft/min} \times 0.5^{ft} \times 60^{min/hr} \times 7^{hr/day} \times 10^{lb/cu\_ft}}{2000^{lb/ton}}$$
$$= 126 \quad TPD$$

In order to derive the sort room width, a waste generation rate of 3 lb/person-day was used, and it was assumed that all the waste generated is processed in the mixed waste MRF 5 days per week. 126 TPD, the mass of mixed waste corresponds to a city with a population of approximately 60,000. Thus, for populations less than 180,000, the default sort room width of 28 ft (for 3 conveyers) is adequate. If the user expects more than 378 TPD (= 3 x 126 TPD) to be processed in the MRF, the sort room width should be increased accordingly. It is suggested that for every extra conveyer added, the width of the sort room be increased by 8 ft.

The estimate for processing floor area does not include floor area for a magnet and an eddy current separator. It is assumed that area for the magnet and the eddy current separator is small compared to the rest of the processing area and can be neglected.

Equation 2-7

$$\begin{aligned} Processing\ area_i &= Sortroom\ area_i + Floor area\ \ for\ 2\ balers_i + Loading\ area_i \\ &= (n3 \times conveyer\_sort\_length_i) + (MF2 \times f1) + (f2) \end{aligned}$$

Processing $area_i$: Area required to process a ton of recyclable i, sq ft/TPD
f1: Factor for calculating floor area required for balers, default value 8 sq ft/ TPD baled
f2: Factor for calculating area required for opening of bags, default values are 20 and 15 sq ft/TPD for mechanical and manual bag opening respectively
n3: Width of sort room, default value is 28 ft
MF2: Maneuverability factor for processing area, default value 2.5 [1]
$conveyer\_sort\_length_i$: Length of conveyer required for picking recyclable i, ft/TPD

Conveyer sort length
The conveyer sort length used in Equation 2-7, is obtained from Equation 2-8. Conveyer sort length is proportional to the number of pickers. Picker stations are 4 ft apart, on both sides of the belt in a staggered formation, hence only 4 ft of conveyer length are required to accommodate 2 pickers. The sorting conveyer length is multiplied by a redundancy factor. This extra conveyer length is split between the conveyers equally. It is intended to allow for cross belt connections and operational flexibility such as addition of new recyclables to the list of materials recovered.

Equation 2-8

$$Conveyer\_sort\_length_i = \frac{nP_i \times 4 \times Redundancy\ Factor}{2}$$

$conveyer\_sort\_length_i$: Length of conveyer required for picking recyclable i, ft/TPD
nP_i: Number of pickers for recyclable i, pickers per TPD, from Equation 2-10
4: 4 feet of conveyer length are required per picker
2: conveyer length is divided by 2 since pickers are positioned on both sides of belt
Redundancy factor: Extra conveyer length required for conveyers, default value 2

Picking rate for a recyclable

Picking rate (PR), is defined as the weight of a recyclable (in tons) that is recovered by a picker in one hour. The DST requires a PR for each recyclable to be specified in the separation process model. These data determine the cost and LCI for recovery of recyclables. The cost and LCI coefficients are used by the optimization model to decide which recyclables are to be recovered in a MRF. If the user specifies mechanical recovery of aluminum cans, then the PR specified for aluminum cans is not used for calculation of the cost of recovery of aluminum cans. Default values are listed in Table 2.2.

Table 2.2 Picking Rate (PR) for Recyclables in Mixed Waste MRF

Waste Component	Variable Name	Picking rate (Tons per hour)
Old Newsprint	ONP	0.250
Old Corrugated Cardboard	OCC	0.250
Office Paper	OFF	0.250
Phone Books	PBK	0.250
Books	BOOK	0.250
Old Magazines	OMG	0.250
3rd Class Mail	MAIL	0.250
Paper Other #1	PAOT1	0.250
Paper Other #2	PAOT2	0.250
Paper Other #3	PAOT3	0.250
Paper Other #4	PAOT4	0.250
Paper Other #5	PAOT5	0.250
CCCR Other	CCR_O	0.025
Mixed Paper	PMIX	0.500
HDPE – Translucent	HDT	0.025
HDPE – Pigmented	HDP	0.040
PET	PPET	0.025
Plastic – Other #1	PLOT1	0.025
Plastic – Other #2	PLOT2	0.025
Plastic – Other #3	PLOT3	0.025
Plastic – Other #4	PLOT4	0.025
Plastic – Other #5	PLOT5	0.025
Mixed Plastic	PLMIX	0.025
CCNR Other	CNR_O	0.025
Ferrous Cans	FCAN	Magnet
Ferrous Metal - Other	FMOT	Magnet
Aluminum Cans	ACAN	0.010
Aluminum – Other #1	ALOT1	0.010
Aluminum – Other #2	ALOT2	0.010
Glass - Clear (unbroken)	GCLR	0.150
Glass – Brown (unbroken)	GBRN	0.100
Glass – Green (unbroken)	GGRN	0.025
Mixed Glass	GMIX	0.025
CNNR Other	NNR_O	Not Recoverable
Paper - Non-recyclable	PANR	Not Recoverable
CCCN Other	CCN_O	Not Recoverable
Plastic - Non-Recyclable	PLNR	Not Recoverable
Miscellaneous	MIS_CNN	Not Recoverable
CCNN Other	CNN_O	Not Recoverable

Work day length

The length of the effective work day is given by Equation 2-9. Recovery facilities are usually operated on a one shift basis, but the length of the single shift may vary. To allow the user to choose the length of a shift, the effective work day length is a user input. This effective work day length is used to calculate the time that a picker has to separate recyclables from the conveyer belt. If two shifts are desired, the value of WD (Equation 2-9) can be increased by the user.

Equation 2-9

$$WDe = WD - (break\_time) - (sec\_sort\_time)$$

WDe: Effective work day length, hr/day
WD: Work day length, default value is 8 hr/day
break_time: Time when the conveyer is temporarily stopped, usually to provide rest for pickers, default value is 0.5 hr/day
sec_sort_time: Time allocated for a negative sort for contaminants in sorted recyclables, default value is 0.5 hr/day

A second sort can be done to assure the quality of recyclables after the initial separation. This second sort may be essential to meet the standards set by the buyer of recovered materials. Breaks are usually provided for the pickers and the conveyer belt is stopped during this time. The time entered should include all times when picking does not occur. Similarly, time is deducted when the conveyer may be stopped during loading operations. The default values for WD, breaks and stoppages, second sort time, and WDe in Equation 2-9 apply for a one shift operation.

Number of pickers

The number of pickers required for recovering a ton of recyclable is calculated in Equation 2-10. PR is used to calculate the number of pickers to recover incoming recyclables in mixed waste.

Equation 2-10

$$nP_i = \frac{SE_i}{PR_i \times WDe}$$

nP_i: Pickers required for the recyclable i, pickers/TPD
SE_i: Sorting efficiency for recyclable, fraction, default values are provided
PR_i: Picking rate for recyclable i, Tons/picker-hr, default values are provided
WDe: Effective work day length, default value is 7 hr/day

In calculating the number of pickers required for a MRF, it is assumed that fractional pickers can be used. This is justified because during the course of a shift, picker assignment to recyclables is flexible, and pickers help each other when working at less than maximum capacity. It is also assumed that part-time services can be employed. Pickers are not assigned for ferrous cans in the sort room because ferrous cans are recovered with a magnet at the end of the sorting conveyer. Depending on the option the user chooses, aluminum cans are recovered either manually or by using an eddy current separator. If manual aluminum sortation is specified by the user, then ‘nP’ will include the sorters required for picking aluminum cans in the sort room.

Floor area for balers

The area required for the balers is estimated by the second term of Equation 2-7. Factor 'f1' relates the capacity of the MRF to the floor area required for the balers. The default value of 8 sq ft/ TPD baled is developed in Appendix 5.

Floor area of loading conveyer

The area required for loading is estimated by multiplying the total weight of mixed waste processed by factor 'f2.' Default values for 'f2' are 20 and 15 sq ft/ TPD for mechanical and manual bag opening, respectively. These values are developed in Appendix 5.

Recyclable recovery equations used in model

The weight of non-glass recyclables recovered ($Weight_b$) is given by Equation 2-11. Sorting Efficiency (SE) of a recyclable is defined as the maximum weight of recyclable that can be recovered from the conveyer divided by the weight of that recyclable that enters the MRF. It is assumed that broken glass is not recoverable. Thus, sorting efficiency for a glass recyclable includes breakage. SE is a user input, and default values are included in the DST. Recyclables not recovered, along with all nonrecyclables are disposed off as residue. Recy_Reci is the quantity of a recyclable that is recovered in the MRF. The default sorting efficiencies for materials in a mixed waste MRF are shown in Table 2.3.

Table 2.3 Sorting Efficiency for Materials in a Mixed Waste MRF

Material	Variable Name	Sorting Efficiency (percentage)
Old News Print	ONP	70
Old Corrugated Cardboard	OCC	70
Office Paper	OFF	70
Phone Books	PBK	70
Books	BOOK	70
Old Magazines	OMG	70
3rd Class Mail	MAIL	70
Paper Other #1	PAOT1	70
Paper Other #2	PAOT2	70
Paper Other #3	PAOT3	70
Paper Other #4	PAOT4	70
Paper Other #5	PAOT5	70
CCCR Other	CCR_O	70
Mixed Paper	PMIX	70
HDPE - Translucent	HDT	70
HDPE - Pigmented	HDP	70
PET	PPET	70
Plastic - Other #1	PLOT1	70
Plastic - Other #2	PLOT2	70
Plastic - Other #3	PLOT3	70
Plastic - Other #4	PLOT4	70
Plastic - Other #5	PLOT5	70
Mixed Plastic	PLMIX	70
CCNR Other	CNR_O	70
Ferrous Cans	FCAN	Recovered by magnet
Ferrous Metal - Other	FMOT	70
Aluminum Cans	ACAN	70
Aluminum - Other #1	ALOT1	70
Aluminum - Other #2	ALOT2	70
Glass - Clear	GCLR	70
Glass - Brown	GBRN	70
Glass - Green	GGRN	70
Mixed Glass	GMIX	70
CNNR Other	NNR_O	70
Paper - Non-recyclable	PANR	Not Recoverable
Food Waste	FW	Not Recoverable
CCCN Other	CCN_O	Not Recoverable
Plastic - Non-Recyclable	PLNR	Not Recoverable
Miscellaneous	MIS_CNN	Not Recoverable
CCNN Other	CNN_O	Not Recoverable
Ferrous - Non-recyclable	FNR	Not Recoverable
Al - Non-recyclable	ANR	Not Recoverable
Glass - Non-recyclable	GNR	Not Recoverable
Miscellaneous	MIS_NNN	Not Recoverable
CNNN Other	NNN_O	Not Recoverable

If an equality sign (instead of the less than or equal to) is used in Equation 2-11, then all possible recyclables sent to this MRF by the management model will be recovered to the maximum possible extent. An inequality constraint allows less than the maximum possible quantity of recyclable to be recovered. For example, if the market value of green glass is considerably less than that of brown glass, then more brown glass is likely to be recovered in this MRF. An equality constraint in Equation 2-11 would force maximum possible recovery of both green and brown glass irrespective of market value or other considerations. Thus, the inequality constraint is necessary because one of the objectives of the waste management model is to recover only those recyclables that provide the least cost alternative for management of the waste stream when cost is the objective function. In Equation 2-11, because sorting efficiency of a recyclable is a fixed quantity, the inequality constraint might result in a least cost solution (for the overall waste management system) that suggests recovery of only a fraction of the weight of a particular recyclable processed in a day. For example, if this solution fraction were 0.5 for aluminum cans, then the pickers would have to pick every other aluminum can, which is not practical. This might be resolved by only routing 50% of a community's waste through a mixed waste MRF, or by only picking aluminum cans every other day. This type of solution might occur when the model is constrained by a minimum recycling constraint and recycling is not economical.

Equation 2-11

$$Recy\_Total_r \leq Weight_b + Weight_g$$

$$Recy\_Total_r = \sum_i Recy\_Rec_i$$

$$Recy\_Rec_i \leq SE_i \times Recy\_Total_i$$

$Recy\_Total_r$: Total weight of all recyclables recovered, Tons, model solution
$Weight_b$: Total weight of all non-glass recyclables to be baled, Tons, model solution
$Weight_g$: Weight of glass recyclables recovered, Tons, model solution
Σ_i: Summation for all recyclables in mixed waste
SE_i: Sorting efficiency for recyclable, fraction, default values are provided
$Recy\_Total_i$: Weight of recyclable that enters the MRF, Tons, model solution
$Recy\_Rec_i$: Weight of recyclable that is recovered, Tons, model solution

Office area

Office area of the MRF includes front office, meeting rooms, employee rest areas, changing rooms, and restrooms. Office area required per TPD of material processed in the MRF is estimated in Equation 2-12.

Equation 2-12

$$Office\ area_i = n4$$

$Office\ area_i$: Office area required per ton of material, sq ft/TPD
n4: Office area factor, default value is 11 sq ft/ TPD, developed in Appendix 5

Storage area

Storage area is required for baled recyclables. Storage area for baled recyclables is the area required to store all the bales made in one day. The number of bales of a recyclable, produced in a day, is given by Equation 2-13. The footprint of each bale is a user input and the default value is 20 sq ft. The bales are assumed to be stacked 3 high. The storage area per ton per day of recyclables is given by Equation 2-13.

Equation 2-13

$$Storage\_area_{bi} = \frac{MF2 \times footprint \times SE_i \times No.\ days}{3 \times BW_i}$$

Storage_area $_{bi}$: Storage area required for bales of recyclable *i*, sq ft/TPD
MF2: Maneuverability factor for storage area, value 2.5
No. days: Number of days bales are stored, default value is 1 day
footprint: Area occupied by a bale, default value 20 sq ft
SE_i: Sorting efficiency, tons of material recovered per ton of material processed
3: bales are assumed to be stacked 3 high
BW_i: Weight of a bale of non-glass recyclable, default values are provided, Tons

This concludes the section on the equations for calculating the floor area of a MRF.

2.4.2 Land Acquisition Cost

The floor area of a MRF is used to calculate the total area of the facility. The floor area is multiplied by a factor (multiplying_factor) to give the total area of the recovery facility. Total area includes area for the structure, access roads, fencing, weigh station, landscaping, etc. The cost of acquiring land for the MRF for a ton of material is calculated based on Equation 2-14.

Equation 2-14

$$Land\ aquisition\ cost_i = \frac{Floor\ area\ of\ MRF \times multiplying\_factor \times land\_acq}{43560\ {}^{sq\ ft}\!/_{acre}}$$

Land acquisition $cost_i$: Cost of acquiring land for MRF per ton of material; $/TPD
Floor area of MRF: Floor area of MRF required per ton of material processed Equation 2-4, sq ft/TPD
multiplying_factor: Multiplying factor for total area of MRF, default value is 4 sq ft total area/ sq ft floor area
land_acq: Cost of land, default value 500 $/acre
43560 sq ft/acre

2.4.3 Engineering cost

Engineering cost consists of the fees paid for consulting and technical services for the MRF planning and construction. Engineering cost is estimated to be a fraction of the construction cost, and is expressed by Equation 2-15.

Equation 2-15

$$Engineering\,cost_i = eng\_cost \times Construction\ cost_i$$

Engineering $cost_i$: Cost of engineering services expressed per TPD of material processed, $/TPD
Construction cost: Cost of MRF construction per ton of material, $/TPD
eng_cost: Engineering cost factor, default value is 30%, [1]

2.4.4 Equipment Cost

Equipment cost consists of the capital cost of equipment plus installation. Equipment cost per ton of material processed is calculated using Equation 2-16.

Equation 2-16

$$Total\ equipment\ cost_i = Equipment\ cost_i + Equipment\ installation\ cost_i$$

Equipment installation cost is a fraction (equip_inst) of equipment cost. Installation cost is given by Equation 2-17.

Equation 2-17

$$Equipment\ installation\ cost_i = equip\_inst \times Equipment\ cost_i$$

Equipment installation $cost_i$: Cost of installing equipment per TPD of material i, $/TPD
equip_inst: Equipment installation cost as a percent of equipment cost, default value is 10%, [1]
Equipment cost: Capital cost of equipment, from , $/TPD

Equipment Capital Cost
Equipment capital cost per TPD of material ‘i’ is estimated using Equation 2-18. The cost of a magnet is included only if ferrous cans are recovered per the management model solution. The cost of an eddy current separator is included in equipment cost only if the user selects mechanical separation of aluminum and aluminum cans are recovered per the model solution. The magnet and eddy separator cost are inclusive of all other equipment required for their operation, including conveying equipment, etc. Equipment cost does not include the cost of trailers used for transport of separated recyclables. It is assumed that the buyer of recyclables will provide trailers for recyclables in the MRF.

Equation 2-18

$$\begin{aligned} Equipment\ cost_i = {} & Conveyer\ cost_i + bunkers\ cost_i + storage\ bins\ cost_i + chute\ cost_i + magnet\ cost_i + \\ & eddy\ current\ separator\ cost_i + rolling\ stock\ cost_i + baler\ cost_i + bag\ opener\ cost_i \end{aligned}$$

Conveyer cost

The cost of conveyers is given by Equation 2-19. The unit cost of a conveyer (convey_cost), is an average for the loading conveyer, cross belts, and the sorting conveyer.

Equation 2-19

$$Conveyer\ cost_i = Conveyer\_sort\_length_i \times convey\_cost$$

Conveyer $cost_i$: Cost of conveyer for a ton of material 'i', $/TPD
$Conveyer\_sort\_length_i$: Sort length of conveyer for a ton of material, from Equation 2-8, ft/ TPD
convey_cost: Cost of conveyer, default value is 1200 $/ linear ft, [1]

Bunkers Cost

Bunkers are located under the elevated sorting room. Sorted recyclables are dropped into these bunkers. The number of bunkers is assumed to be proportional to the number of pickers. The cost of a bunker includes the cost of the moving floor required for its operation. The cost of bunkers per TPD of material processed is given by Equation 2-20.

Equation 2-20

$$Bunker\_cost_i = \frac{Bunker\_cost \times nP_i}{2}$$

Bunker_ $cost_i$: Cost of bunkers for material 'i', $/ TPD
Bunker _cost: Cost of a bunker, default value is $30000
nP_i: Pickers for material 'i', pickers/ TPD
2: One bunker for every two pickers

Storage bins cost

Storage bins are required for glass recyclables until glass is emptied into trailers. The number of bins required is proportional to the number of pickers for glass. There is one bin for each picker dedicated to glass recyclables. The cost of storage bins for recyclables is estimated using Equation 2-21.

Equation 2-21

$$Storage\ bins\ cost_i = bin\_cost \times nP_{gi}$$

Storage bins $cost_i$: Cost of storage bins for material 'i', $/ TPD
bin_cost: Cost of a bin, default value is $400, [2]
nP_{gi}: Number of pickers required for glass recyclable i, pickers/TPD

Chutes cost

Chutes are required for guiding recyclables as they drop into bunkers placed under the sorting room. The number of chutes in the MRF is equal to the number of pickers per shift. The cost of chutes is given by Equation 2-22.

Equation 2-22

$$Chute\ cost_i = nP_i \times chute\_cost$$

$Chute\ cost_i$: Cost of chute for recyclable 'i', $/ TPD
nP_i: Number of pickers for recyclable 'i', pickers/ TPD
chute_cost: Cost of a chute, default value is 200 $/chute

Magnet cost
If recycled, ferrous cans are recovered by a magnet at the end of each sorting line. The cost of a magnet is given by Equation 2-23. The magnet cost includes some conveyer length required for operation.

Equation 2-23

$$Magnet\ cost_i = magnet\_cost$$

$Magnet\ cost_i$: Cost of a magnet to recover ferrous recyclable 'i', $/ TPD
magnet_cost: Cost of the magnet, default value is $3200/ TPD of ferrous metal processed, [2, 6]

Eddy current separator cost
Aluminum cans can be recovered manually or by using an eddy current separator. If the user opts for automated separation, the cost of an eddy current separator is given Equation 2-24.

Equation 2-24

$$Eddy\ current\ separator\ cost_i = eddy\_cost$$

$Eddy\ current\ separator\ cost_i$: Cost of an eddy current separator, $/ TPD
eddy_cost: cost of an eddy current separator, default value is 14290 $/ TPD of aluminum processed, developed in Appendix 5

Rolling stock cost
Three types of vehicles are likely to be used in the MRF: a front-end loader that pushes waste onto the sorting conveyer, fork-lifts that move bales and a skidloader which performs the functions of both a front-end loader, and a fork-lift. Usually the skidloader is the smallest and least expensive of the three types of vehicles used in a MRF. In smaller facilities, a skidloader can substitute for a fork-lift and a front-end loader. In large facilities, dedicated equipment is required, and rolling stock may include floor scrubbers, etc. The cost of rolling stock is given by Equation 2-25.

Equation 2-25

$$Rolling\ stock\ cost_i = roll\_cost$$

$Rolling\ stock\ cost_i$: Cost of rolling stock for material 'i', $/ TPD
roll_cost: Cost of rolling stock, default value is $700/ TPD processed, developed in Appendix 5

For a MRF of capacity 50 TPD, Equation 2-25 estimates the rolling stock capital cost as $35,000. A MRF of this size can be served by one skidloader for handling the bales and mixed waste. The cost of a skidloader is 30,000-40,000 $/unit, [2].

Balers cost
A minimum of two balers will be used in the facility. Two balers are used because a baler is critical equipment in a MRF and a backup is required in case a baler breaks down. The cost of balers is given by Equation 2-26. The two balers may be different. For example a horizontal frictional baler may be dedicated to one recyclable, and a two ram baler may be used to compact the rest of the recyclables. The baler cost is in units of $/ TPD baled. Thus, in a large capacity MRF, the cost could result in the purchase of more than two balers.

Equation 2-26

$$Baler\ cost_i = baler\_cost \times SE_i$$

Baler $cost_i$: Cost of baler for material 'i' processed, $/ TPD
baler_cost: Cost of balers, default value is $1500/ TPD baled, developed in Appendix 5
SE_i: Sorting efficiency, tons of material recovered per ton of material processed

Bag opener cost
Mixed waste enters the MRF in bags. The bags can be opened manually or by using a mechanical bag opener. The choice of bag opening method used is a user option. The cost of a mechanical bag opener is given by Equation 2-27. The mechanical bag opener used as the default in the model consists of alternating rows of tines (pointed projecting part or spike) moving at different speeds to open bags moving on a conveyer, [6]. The spikes rip the bag open and the bag's contents are deposited on a conveyer.

Equation 2-27

$$Bagopener\ cost_i = bagopen\_cost$$

Bag opener $cost_i$: Cost of a bag opener for material 'i', $/ TPD
bagopen_cost: Cost of a debagger, default value is 1500 $/ TPD, developed in Appendix 5

2.5 Operating Cost

The operating cost of the MRF includes wages, overhead, equipment and building maintenance, and utilities. The operating cost for a processing a ton of material in the mixed waste MRF is given by Equation 2-28.

All the equations for operating cost in this chapter are derived on dollars per ton ($/Ton) of component basis.

Equation 2-28

$$Operating\ cost_i = Labor\ cost_i + Overhead\ cost_i + Maintenance\ cost_i + Utilities\ cost_i$$

2.5.1 Labor Cost

The cost of labor is given by Equation 2-29. Labor required for the MRF consists of management, drivers and operators, bag openers, and pickers. Small facilities may require only part-time managerial services, but bigger MRFs require full time managers, secretaries, and supervisors. In estimating the labor wages, it is assumed that part-time services can be hired.

Equation 2-29

$$Labor\ cost_i = Management\ wages_i + Picker\ wages_i + Driver\ and\ Operator\ wages_i + Bagopener\ wages_i$$

Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to pickers, drivers and operators, and bag openers. This fraction is user input. Management wages are estimated in Equation 2-30**.**

Equation 2-30

$$Management\ wages_i = man\_wage \times (Picker\ wages_i + Driver\ and\ Operator\ wages_i + Bagopener\ wages_i$$

Management wages$_i$: Management wages for recovering waste component i, $/ Ton
man_wage: Management wage rate, default value is 25%
Picker wages$_i$: Picker wages for recovering waste component i, $/Ton from Equation 2-31
Driver and operator wages$_i$: Driver & Operator wages for recovering waste component i, $/Ton from Equation 2-32
Bag opener wages$_i$: Bag Opener wages for recovering waste component i, $/Ton from Equation 2-33.

Picker wages
Wages paid to pickers for recovering recyclable ‘i’ are calculated using Equation 2-31.

Equation 2-31

$$Picker\ wages_i = \frac{pick\_wage \times SE_i}{PR_i}$$

Picker wages$_i$: Wages paid to pickers for recovering recyclable ‘i’, $/Ton
SE$_i$: Sorting efficiency for recyclable, fraction, default values are provided
pick_wage: Picker wage rate, default value is 6 $/hr
PR$_i$: Picking rate of recyclable ‘i’, Tons/hr

Driver and Operator wages
The number of drivers and operators is small for a small capacity mixed waste MRF. Larger capacity MRFs require specialized labor. Operators are required for the operation

of the two balers and for operation of the weighing station. The wages of operators and drivers are estimated by Equation 2-32. Factor ‘f3’ is used to obtain the number of working hours of drivers and operators based on the weight of material processed in the MRF.

Example:

estimate 32 hours of drivers and operators (including breaks and stoppage time). Assuming a default 8 hour working day, 4 drivers and operators are estimated for a 100 TPD facility. This number can be justified by 2 baler operators, 1 driver, and 1 weigh station operator.

Equation 2-32

$$Driver\ and\ Operator\ wages_i = driv\_wage \times f3$$

Driver and operator wages$_i$: Wages paid to drivers and operators for recyclable ‘i’, $/Ton
driv_wage: Wage rate for drivers and operators, default value is 10 $/hr
f3: Factor used to obtain the working hours of drivers and operators, default value is 0.32 hr/Ton, developed in Appendix 5

Bag opener wages

If bags that enter the MRF are to be opened manually per user choice, then the cost of labor for bag opening is given by Equation 2-33. Bags are opened manually with the help of a sharp instrument or a heated knife.

Equation 2-33

$$Bag\ Opener\ wages_i = \frac{bag\_open\_wage}{n10}$$

Bag opener wages$_i$: Wages for bag openers for processing recyclable ‘i’, $/Ton
bag_open_wage: Bag opener wages, default value is 6 $/hr
n10: Capacity of a bag opener, default value is 4 Ton/hr

2.5.2 Overhead cost

Overhead costs for labor are calculated as a fraction of labor wages. Overhead includes overtime, office supplies, insurance, social security, vacation, sick leave, and other services. Overhead costs for a ton of material processed are calculated in Equation 2-34.

Equation 2-34

$$Overhead\ cost_i = lab\_overh \times Labor\ cost_i$$

Overhead cost$_i$: Overhead cost, $/ton
lab_overh: Overhead rate, default value is 40%, [1], %
Labor cost$_i$: Labor cost for processing waste component ‘i’, from Equation 2-29

2.5.3 Utility costs

The cost of utilities (power, fuel, oil, etc.) is proportional to the weight of recyclables processed in the MRF. The cost of utilities for a ton of material recovered is estimated by Equation 2-35.

Equation 2-35

$$Utility\ costs_i = util\_cost$$

Utility $costs_i$: Cost of utilities for processing recyclable 'i', $/Ton
util_cost: Cost of utilities, default value is 1.5 $/Ton, [1]

2.5.4 Maintenance cost

The cost of maintenance of equipment and structure is assumed to be proportional to the weight of material processed in the MRF. The maintenance cost is given by Equation 2-36**.**

Equation 2-36

$$Maintenance\ cost_i = main\_cost$$

Maintenance $cost_i$: Cost of maintenance for material 'i', $/Ton
main_cost: Maintenance cost, default value 5 $/Ton, [1]

2.6 Residue in MRF

Residue in the MRF is a result of the sorting efficiency (SE) being less than 100% and the presence of non-recyclables in the incoming material. Note that for non-recyclables, residue is 100% of the incoming material. The cost of disposal of residue depends on the disposal facility used and will be accounted for at the downstream processing alternative selected by the model. The quantity of residue for a recyclable i is given by Equation 2-37

Equation 2-37

$$Residue_i = Weight_i - Recy\_Rec_i$$

$Residue_i$: Weight of residue for a waste item 'i', Tons
$Weight_i$: Weight of item 'i' processed, Tons, model solution
$Recy\_Rec_i$: Weight of item 'i' recovered, Tons, model solution

2.7 Front End MRF to Composting and Anaerobic Digestion Facilities

Two special types of mixed waste MRFs are the front end MRFs for mixed waste composting and the RDF facility. In these front end MRFs, the same process as that described above is used to recover recyclables and process waste, with some small modifications. These modifications and their implications are described in the next paragraph.

2.7.1 Front End MRF to Composting Facility and Anaerobic Digestion Facility

The degree to which materials must be removed upstream of a mixed waste composting facility (T7) or an anaerobic digestion facility (T8) are a function of the intended use of the solids after biodegradation. Because there are several potential uses of the decomposed material, specialized mixed waste MRFs (S1T7 and S1T8) are required and will be used as follows:

If the user specifies that the decomposed solids are to be used as daily cover at a landfill, then the model solution will only specify the removal of materials from mixed refuse when their removal is consistent with the model objective function (minimize cost or an LCI parameter across the solid waste management system). If recyclables removal is consistent with the objective function, then recyclables will be removed in S1T7 or SIT8 in exactly the same way as they would be at the standard mixed waste MRF (S1). If the model solution determines that no recyclables should be removed, then waste could be routed from mixed waste collection (C1) directly to a mixed waste compost or anaerobic digestion facility.

If the user specifies that the decomposed solids are to be used in an application where product quality is important, then the user must specify sorting efficiencies for materials to be removed by hand sorting at S1T7 and S1T8 MRFs. The MRF design equations will calculate the MRF cost on the basis of removing the specified materials even if they are not recyclable.

The difference between the standard S1 MRF and the specialized MRFs S1T7 and S1T8 are that in the latter two MRFs, materials are removed as a result of product quality specifications irrespective of whether their removal is suggested by the objective function.

2.7.2 Front End MRF to RDF Plant

Waste may flow to an RDF plant (T5) either directly from mixed waste collection (C1) or after processing in a specialized mixed waste MRF that is only located upstream of an RDF plant (S1T5).

The model solution will specify whether waste is processed through the specialized MRF or routed directly to an RDF plant. The model decision will be based upon whether removal of recyclables at a MRF is consistent with the model objective function. If cost is the objective function, then recyclables will only be removed at the specialized MRF if it is economical to do so. If energy is the objective function, then recyclables will only be removed at the specialized MRF if it is more beneficial to recover the materials as recyclables than it is to recover them as fuel.

2.8 References

1. Materials Recovery Facilities for Municipal Solid Waste, Handbook, USEPA, 1991.

2. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H., Vigil, S., A., McGraw Hill Inc., 1993, p 933.

3. Personal communication with Mr. Keith Hannah of McDonalds Services, Charlotte, NC

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5. Personal communication with Sales Personnel, Eirez Magnetics, Erie, PA

6. Personal communication with sales representatives, Debagit, Memphis, TN.

3 Presorted Recyclables MRF Design

3.1 Introduction

The objective of this chapter is to present a design for a MRF receiving presorted recyclables. Based on this design, the cost and LCI of a presorted recyclables MRF is derived as a function of the quantity and composition of the waste components processed therein.

Note: The term "model solution" used frequently in this chapter refers to the waste management solution suggested by the decision support tool

3.2 Description of process flow

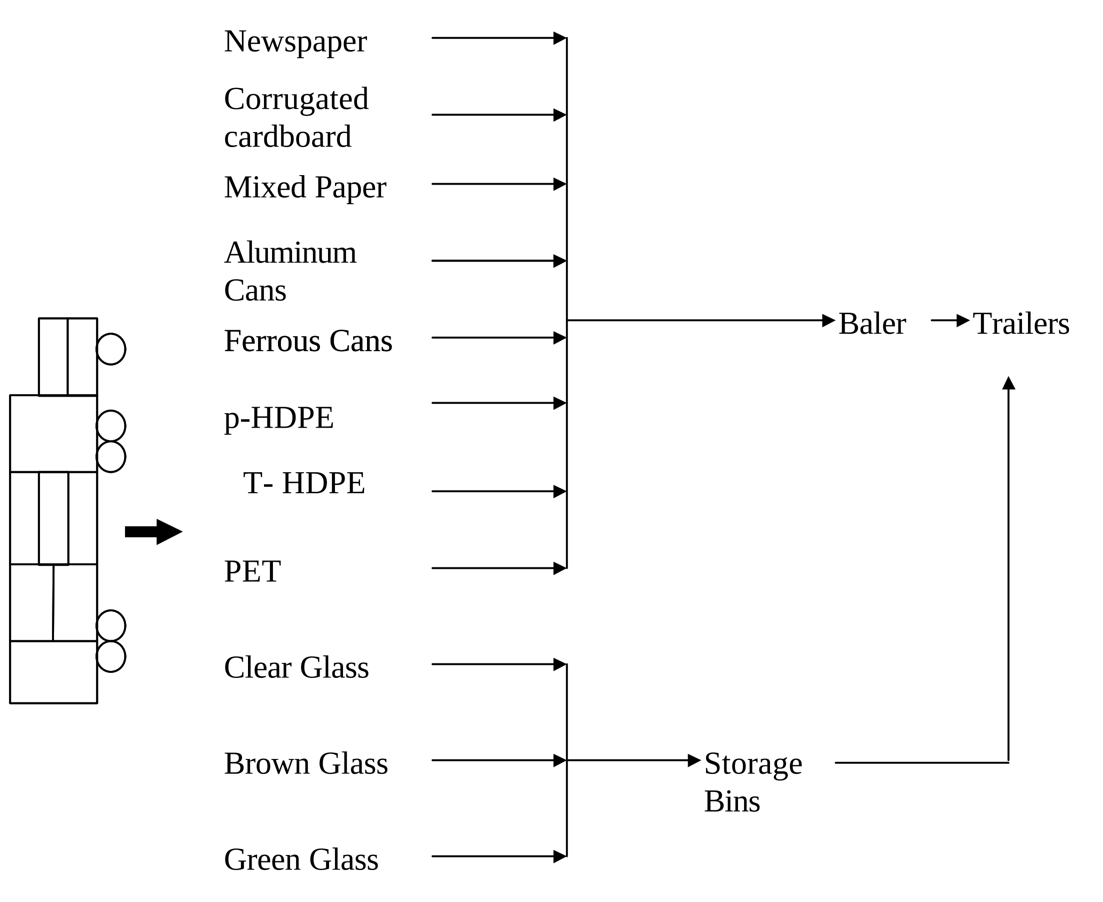
The design is applicable to all possible combinations of incoming recyclables. The waste components that can be recycled are shown in Table 3.1.

Table 3.1 Waste Components that can be recovered in the Presorted Recyclables MRF

Waste Component	Variable Name
Old Newsprint	ONP
Old Corrugated Cardboard	OCC
Office Paper	OFF
Phone Books	PBK
Books	BOOK
Old Magazines	OMG
3rd Class Mail	MAIL
Paper Other #1	PAOT1
Paper Other #2	PAOT2
Paper Other #3	PAOT3
Paper Other #4	PAOT4
Paper Other #5	PAOT5
Combustible Compostable Recyclable Other	CCR_O
Mixed Paper	PMIX
HDPE – Translucent	HDT
HDPE – Pigmented	HDP
PET	PPET
Plastic – Other #1	PLOT1
Plastic – Other #2	PLOT2
Plastic – Other #3	PLOT3
Plastic – Other #4	PLOT4
Plastic – Other #5	PLOT5
Mixed Plastic	PLMIX
Combustible Compostable Non-Recyclable Other	CNR_O
Ferrous Cans	FCAN
Ferrous Metal - Other	FMOT
Aluminum Cans	ACAN
Aluminum - Other #1	ALOT1
Aluminum - Other #2	ALOT2
Glass – Clear	GCLR
Glass – Brown	GBRN
Glass – Green	GGRN
Mixed Glass	GMIX
Combustible Non-Compostable Non-Recyclable Other	CNNR_O

Recyclables that enter the presorted recyclables MRF are sorted either by the resident or the collection crew at curbside. Recyclables are placed in separate compartments on a collection vehicle. It is assumed that a separate collection compartment is available for each recyclable. Recyclables from the collection vehicle are emptied onto the tipping floor in the MRF. The recyclables storage area has partitions to keep recyclables separate. A quality control sort of recyclables is done as they are unloaded on to the tipping floor. Loose recyclables are pushed from the storage areas onto conveyers by a skidloader or a front-end loader. These conveyers lead into the hopper of a baler. A bale is moved into a trailer at a loading dock. Glass recyclables are unloaded into storage bins, which are emptied into a trailer using a fork-lift. There is no sorting or separation of recyclables in this MRF. The process flow diagram for a presorted recyclables MRF is presented in Figure 3-1.

Figure 3-1 Process Flow Diagram in a Presorted Recyclables MRF



It is assumed that there is 100% recovery of all recyclables in this MRF and that the quantity of residue from inappropriate materials will be negligible as these materials will be left at the curb.

3.3 Determination of cost function for a presorted recyclables MRF

The annual cost of a presorted recyclables MRF has two components: capital cost amortized over the life of the MRF and the annual operating cost. The capital cost of a MRF is calculated from a unit capital cost with units of dollars per ton/year processed. In addition, it can be expressed in annual terms using a capital recovery factor that is dependent upon a book lifetime and discount rate. Both of these numbers are input parameters for which default data are available. The operation and maintenance (O&M) cost of a MRF includes the labor, overhead, taxes, administration, insurance, indirect costs, electricity cost and maintenance cost. It does not include the cost for disposing of the residue, nor does it include the revenue from recyclables sales. The O&M cost coefficient depends upon the unit O&M cost and the quantity of waste processed. The annual cost of a MRF is expressed in Equation 3-1.

Equation 3-1

Annual cost of MRF: expressed in $/ton
Capital Recovery Factor (CRF), units of 1/year

CRF is the capital recovery factor that enables the conversion of the capital costs into annual terms. It is a function of the facility or equipment life, *(lifetime)* and an appropriate *Discount_rate*. For a *Discount_rate* ≠ 0, CRF is calculated as follows:

$$CRF = \frac{Discount\_rate \cdot (1 + Discount\_rate)^{lifetime}}{1 - (1 + Discount\_rate)^{lifetime}}$$

Capital cost: is the capital cost per ton per year of waste component processed by the MRF. To convert capital cost from $/Ton per day to $/Ton per year, the following equation is used:

$$\frac{\$}{Ton/Year} = \frac{\$}{Ton/Day} \times \frac{year}{days}$$

Days per year are the number of operating days per year of the MRF.

Annual operating cost: expressed in $/ton

3.4 Capital Cost

Capital cost consists of construction, engineering, and equipment cost, as expressed in Equation 3-2.

Equation 3-2

$$Capital\ cost = Construction\ cost + Land\ cost + Engineering\ cost + Equipment\ cost$$

3.4.1 Construction cost

Construction cost of the MRF includes the cost of the structure, access roads, fencing, landscaping, etc. The cost of the structure includes support facilities such as office space, a weigh station, and the loading conveyer. This includes the length of conveyer required for transport of loose recyclables from the floor of the MRF to a baler.

Construction cost is obtained by multiplying the floor area of the MRF by the construction cost rate. Default values are provided for the construction cost rate. The EPA Handbook on MRFs [1] provides a range of 28-60 $/sq ft for the construction cost rate. A detailed estimate was performed to calculate the construction cost rate in Appendix 4, and the rate calculated is 40 $/sq ft. The construction cost is calculated using Equation 3-3. The construction cost rate of the facility includes the cost of furniture and office equipment.

Equation 3-3

$$Construction\ cost = Floor\ area\ of\ \ MRF \times const\_rate$$

Construction cost: Cost of construction of MRF, $/TPD
Floor area of MRF: Total floor area of MRF from Equation 3-4, sq ft/TPD
const_rate: Construction cost rate, default value is 40 $/sq ft

Floor area

Floor area (sq ft) of the MRF depends on the weight of recyclables processed in a day. It also depends on the composition of the recyclable stream. The area required for the MRF is estimated by Equation 3-4. The floor area of the MRF consists of the tipping floor, processing floor, office, and storage areas. All area estimates include a maneuverability factor (MF), which allows for vehicle and machinery access.

Equation 3-4

$$\begin{aligned} MRF\ \ Floor\ \ area = & Tipping\ floor\ \ area + Processing\ floor\ \ area + Office\ area + \\ & Storage\ area \end{aligned}$$

Tipping floor area

Recyclables are unloaded from collection vehicles onto the tipping floor. The maneuverability factor for the tipping floor (MF1) is 2.5. The tipping floor allows for downtime of equipment by including a storage requirement in the estimate. The storage requirement is a user input. The default value is two days. The area required for the tipping floor is calculated using the loose density of the recyclable and a recyclables pile height. Equation 3-5 is used to calculate tipping floor area.

Equation 3-5

$$Tipping\ floor area_i = \frac{MF1 \times tipp\_stor \times 2000}{loose\_density_i \times height}$$

Tipping floor area: Area of tipping floor where recyclables are unloaded, sq ft/TPD
MF1: Maneuverability factor for the tipping floor, value 2.5, [1]
tipp_stor: Storage requirement to allow for downtime of equipment, default value is 2 days
2000 lb/ton
$loose\_density_i$: Loose density of recyclable i, default value is 5 lb/cu ft, [1]
height: Height of recyclable on the tipping floor, default value is 10 ft, [1]

Processing floor area
The processing floor is used for baling recyclables. The processing floor consists of the area required for loading recyclables onto the conveyer, the conveyer itself and the area for balers. The area for loading and for the conveyer is included in the maneuverability factor. The area required for balers is estimated by factor f1. The processing area is calculated in Equation 3-6.

Equation 3-6

$$Processing\ area = Area\ of\ 2\ balers = MF2 \times f1$$

Processing area: Area used for baling recyclables, sq ft/TPD
MF2: Maneuverability factor for processing area, value 3
f1: Factor relating size of MRF to floor area required for balers, default value 8 sq ft/ ton baled, developed in Appendix 5

Office area
The office area includes the front office, meeting rooms, employee rest areas, changing rooms and rest-rooms. Office area is proportional to the quantity of recyclables processed.

Equation 3-7

$$Office\ area = n3$$

Office area: Floor area of office; sq ft/TPD
n3: Office area factor, default value is 20 sq ft/ TPD, developed in Appendix 5

Storage area
Baled recyclables are moved from the baler to be stored in dedicated trailers outside the MRF. This reduces the required floor area in the MRF, and also has an impact on the heating and air conditioning requirements. A trailer is transported when full, and is replaced by an empty trailer. Thus, trailers for different recyclables may have different replacement rates, depending on the quantity of recyclable processed. Some backup storage area is provided for bales. This backup storage is the area required to store all the bales made in a day. The number of bales of a recyclable i, produced in a day, is given by Equation 3-8. The footprint of each bale is a user

input, and the default value is 20 sq ft. Bales are assumed to be stacked 3 high. The storage area for all non-glass recyclables is given by Equation 3-8.

Equation 3-8

$$Storage\_area_{bi} = \frac{MF3 \times nB_i \times 20 \times No.\ days}{3 \times BW_i}$$

$$nB_i = \frac{1}{BW_i}$$

$Storage\_area_{bi}$: Backup storage area required for non-glass recyclable, sq ft/ TPD
No. days: Number of days bales are required to be stored, default is 1 day
MF3: Maneuverability factor for backup storage area, value 2.5, [1]
BW_i: Weight of a bale of recyclable *i*, default values are provided, tons, [1]

This concludes the section on the equations for calculating the floor area of a MRF.

3.4.2 Land Acquisition Cost

The floor area of a MRF is used to calculate the total area of the facility. The floor area is multiplied by a factor 'n5' to give the total area of the recovery facility. The total area includes the area for structure, access roads, fencing, weigh station, landscaping, etc.

Equation 3-9

$$Land\ aquisition\ cost = \frac{Floor\ area\ of\ \ MRF \times n5 \times land\_acq}{43561}$$

Land acquisition cost: Cost of acquiring land for MRF; $/TPD
Floor area of MRF: Floor area of the MRF, from Equation 3-4, sq ft
n5: Multiplying factor for total area of MRF, default value is 4 sq ft total area/ sq ft floor area
land_acq: Cost of land, default value is 500 $/acre
43561 sq ft/acre

3.4.3 Engineering cost

The engineering cost consists of the fees paid for consulting and technical services for MRF planning, design, and construction. Engineering cost is estimated to be a fraction of the construction cost, and is expressed by Equation 3-10.

Equation 3-10

$$Engineering\ cost = eng\_cost \times Construction\ cost$$

Construction cost: Cost of construction of MRF, given by Equation 3-3, $/TPD
eng_cost: Engineering cost factor, default value is 30%, [1]

3.4.4 Equipment Cost

The equipment cost consists of the capital cost of equipment and installation. The equipment cost for a recyclable 'i' is calculated using Equation 3-11.

Equation 3-11

$$Total\ equipment\ cost_i = Equipment\ capital\ cost_i + Equipment\ installation\ cost_i$$

Equipment installation cost is a fraction (equip_inst) of equipment cost. Installation cost is given by Equation 3-12.

Equation 3-12

$$Equipment\ installation\ cost_i = equip\_inst \times Equipment\ cost_i$$

Equipment installation $cost_i$: Cost of equipment installation for recyclable i, $/TPD
Equipment $cost_i$: Capital cost of equipment, from Equation 3-13, $/TPD
equip_inst: Equipment installation cost factor, default value is 10%, [1, 4]

Equipment Capital Cost

Equipment capital cost for recyclable 'i' is estimated using Equation 3-13.

Equation 3-13

$$Equipment\ cost_i = bins\ cost_i + rolling\ \ stock\ cost_i + baler\ cost_i$$

Bins cost

Bins are required to store glass recyclables in the MRF. The cost of bins is estimated by Equation 3-14.

Equation 3-14

$$Bins\ cost_i = bin\_cost \times Number\ of\ \ bins_i$$

where: $Number of\ bins_i = \dfrac{1}{density \times bin\_vol}$

Bins $cost_i$: Cost of bins, $/TPD
Number of $bins_i$: Number of bins required per day for storing glass recyclable i, bins/day
bin_cost: Cost of bins, default value is $30000/bin
density: Density of glass recyclables, default value is 0.0225 tons/ cu ft
bin_vol: Volume of storage bins, default value is 90 cu ft

Rolling stock cost

Three types of vehicles are likely to be used in the MRF: front-end loaders that push recyclables onto the loading conveyer, fork-lifts that move bales, and skidloaders that perform the functions of both a front-end loader and a fork-lift. Usually, the skidloader is the smallest and least expensive of the three types of vehicles used in a MRF. In smaller facilities, a skidloader can substitute for a fork-lift and a front-end loader. In larger facilities, dedicated equipment is required, and rolling stock may include floor scrubbers, etc. The cost of rolling stock for a recyclable I'is given by Equation 3-15.

Equation 3-15

$$Rolling\ stock\ cost_i = roll\_cost$$

Rolling stock cost$_i$: Cost of rolling stock, $/TPD
roll_cost: Cost of rolling stock, default value is $700/TPD, developed in Appendix 5

For a MRF of capacity 50 TPD, Equation 3-15 gives a rolling stock capital cost as $35,000. A MRF of this size requires only one skidloader for handling the bales and loose recyclables. The cost of a skidloader is $30000-40000. Details are provided in Appendix 5.

Baler Cost
Two balers will be used in the facility, with two loading areas and conveyers that lead into the hopper of the baler. The cost of balers is given by Equation 3-16. The two balers may be different. For example, a horizontal frictional baler may be dedicated to ONP, while a two ram baler is used to compact the rest of the recyclables. As in the mixed waste facility, two balers in the MRF are used to have backup capacity.

Equation 3-16

$$Baler\ cost_i = baler\_cost$$

Baler cost: Cost of balers required for non-glass recyclable I'in MRF, $/TPD
baler_cost: Cost rate of balers, default value is $1500/TPD baled, developed in Appendix 5

3.5 Operating Cost

The MRF operates on all days that recyclables are collected. Operating costs of the MRF include wages, overhead, equipment and building maintenance, and utilities. The total annual operating cost for a recyclable I'in the presorted recyclables MRF is given by Equation 3-17.

Equation 3-17

$$Operating\ cost_i = Labor\ cost_i + Overhead\ cost_i + Maintenance\ cost_i + Utilities\ cost_i$$

3.5.1 Labor Cost

The cost of labor is given by Equation 3-18. Labor required for the MRF consists of management, drivers and operators. Small facilities may require only part-time managerial services, but bigger MRFs require full time managers, secretaries, and supervisors. In estimating the labor wages, it is assumed that part-time services can be hired.

Equation 3-18

$$Labor\ cost_i = Management\ wages_i + Driver\ and\ Operator\ wages_i$$

Management wages

Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to pickers, drivers and operators. This fraction is user input. Management wages are estimated in Equation 3-19.

Equation 3-19

$$Management\ wages_i = man\_wage \times Driver\ and\ operator\ wages_i$$

Management $wages_i$: Wages for management for recyclable i, $/Ton
man_wage: Management wage rate factor, % of driver and operator wages, default value is 25%
Driver and operator wages: Wages paid to drivers and operators for recyclable i, from Equation 3-20, $/Ton

Drivers and operators
The number of drivers and operators is small for a small capacity presorted recyclables MRF. Large capacity MRFs require specialized labor. Operators are required for the operation of the two balers and for operation of the weighing station. The wages of operators and drivers are estimated by Equation 3-20. Factor f2'(hr/Ton) is used to obtain the number of working hours of drivers and operators based on the weight of recyclables processed in a day in the MRF. For a 100 TPD facility, f2' estimates 24 hours/day of drivers and operators. Assuming an 8 hour working day, 3 drivers and operators are estimated for this facility. This number can be justified by 2 baler operators, and 1 driver.

Equation 3-20

$$Driver\ and\ opertor\ wages_i = driv\_wage \times f2$$

Driver and operator $wages_i$: Wages paid to drivers and operators for recyclable i, $/Ton
dri_wage: Wage rate for drivers and operators, default value is 10 $/hr
f2: Factor to obtain the working hours of drivers and operators, default value is 0.24 hr/Ton of recyclable i

3.5.2 Overhead cost

Overhead costs for labor are calculated as a fraction of labor wages. Overhead includes overtime, office supplies, insurance, social security, vacation, sick leave, and other services. Overhead costs are calculated using Equation 3-21

Equation 3-21

$$Overhead\ cost_i = lab\_overh \times Labor\ cost_i$$

Overhead $cost_i$: Labor overhead cost, $/ton
lab_overh: Labor overhead rate, % of labor cost, default value is 40%, [1]
Labor $cost_i$: Annual wages paid to labor, from Equation 3-18

3.5.3 Utility cost

The cost of utilities (power, fuel, oil, etc.,) is proportional to the weight of recyclables recovered in the MRF (which is the capacity of the MRF as recovery is 100%). As explained for the mixed waste MRF, this is done so that the utilities and maintenance cost can be compared for all MRFs. The cost of utilities is estimated by Equation 3-22.

Equation 3-22

$$Utility\ cost_i = util\_cost$$

Utility $cost_i$: Annual cost of utilities for recyclable i, $/ton
util_cost: Utility cost rate, default value is 0.75 $/ton processed, [1]

3.5.4 Maintenance cost

The cost of maintenance of equipment and structure is assumed to be proportional to the weight of recyclables recovered in the MRF. The maintenance cost is given by Equation 3-23.

Equation 3-23

$$Maintenance\ cost_i = main\_cost$$

Maintenance $cost_i$: Cost of maintenance allocated to recyclable i, $/ton
main_cost: Cost rate of maintenance, default value is 4 $/ton processed, [1]
This concludes the description of the process flow diagram, the design considerations and the equations that describe the design of a presorted recyclables facility. The following chapters will describe the designs of other types of MRFs.

3.6 References

1. Handbook Materials Recovery Facilities for Municipal Solid Waste, US EPA, 1991.

2. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H., Vigil, S., A., McGraw Hill Inc., 1993, p 933.

4 Commingled Recyclables MRF Design

4.1 Introduction

The objective of this section is to present a design for a MRF receiving commingled recyclables. Based on this design, a cost function is derived to relate the cost of the MRF to the quantity and composition of the recyclables to be processed therein. This design will also be used to derive the LCI of the commingled recyclables MRF.

Note: The term "model solution" used frequently in this chapter refers to the waste management solution suggested by the decision support tool

Note that the design for this MRF will be similar to those of a MRF receiving commingled recyclables and mixed waste in separate compartments and the MRF that receives commingled recyclables and mixed waste in one compartment. These two facilities are described in Chapters 5 and 6, respectively.

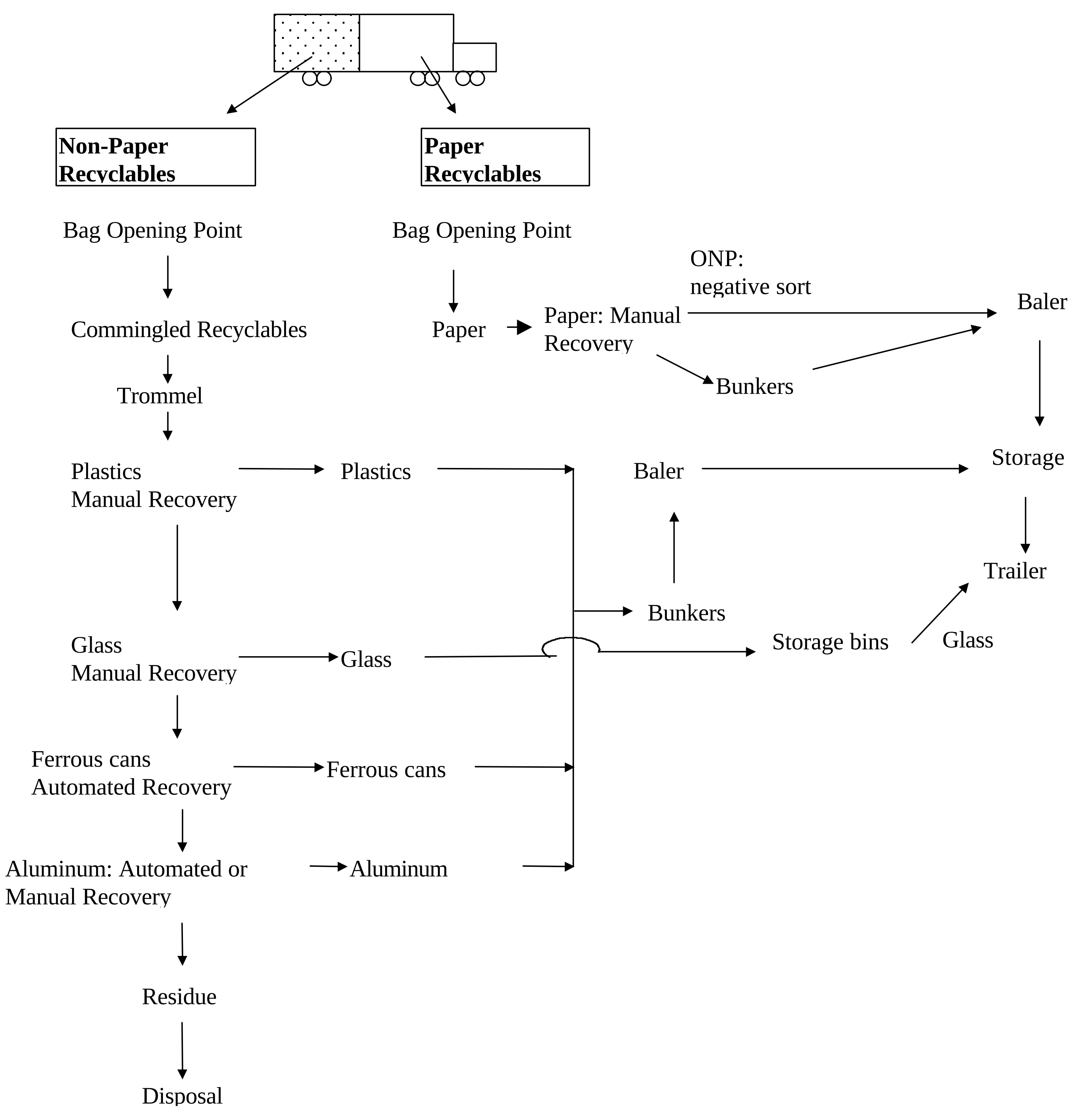
4.2 Description of process flow

The design is applicable to all possible combinations of incoming recyclables. The waste components that can be recycled are shown in Table 4.1.

Table 4.1 Waste Components that can be Recovered from Commingled Recyclables

Waste Component	Variable Name
Old Newsprint	ONP
Old Corrugated Cardboard	OCC
Office Paper	OFF
Phone Books	PBK
Books	BOOK
Old Magazines	OMG
3rd Class Mail	MAIL
Paper Other #1	PAOT1
Paper Other #2	PAOT2
Paper Other #3	PAOT3
Paper Other #4	PAOT4
Paper Other #5	PAOT5
Mixed Paper	PMIX
HDPE - Translucent	HDT
HDPE – Pigmented	HDP
PET	PPET
Plastic - Other #1	PLOT1
Plastic - Other #2	PLOT2
Plastic - Other #3	PLOT3
Plastic - Other #4	PLOT4
Plastic - Other #5	PLOT5
Mixed Plastic	PLMIX
Ferrous Cans	FCAN
Ferrous Metal - Other	FMOT
Aluminum Cans	ACAN
Aluminum - Other #1	ALOT1
Aluminum - Other #2	ALOT2
Glass - Clear (unbroken)	GCLR
Glass - Brown (unbroken)	GBRN
Glass - Green (unbroken)	GGRN
Mixed Glass (unbroken)	GMIX

Figure 4-1 Process Flow Diagram for the Commingled Recyclables MRF



The process for sortation of commingled recyclables is illustrated in Figure 4-1. The collection vehicle includes two compartments, one containing commingled recyclables, either bagged or loose, and a second compartment containing paper, either bagged or loose. Whether recyclables are collected bagged or loose is specified by the user. Here, we refer to bags containing recyclables as blue bags. However, if recyclables are collected loose, then the bag opening step illustrated in Figure 4-1would not be deleted. The paper compartment may contain any combination of the recyclable paper types listed in Table 4.1.

The two categories of recyclables, paper and non-paper are processed in parallel as illustrated in Figure 4-1. Paper recyclables are pushed onto a conveyor that feeds a bag opening station when required. The user may specify either manual or automated bag opening. After bag opening, individual paper components and mixed paper are removed manually. The paper components that are to be treated as mixed paper are specified by the user as explained in Section 1.2. Due to the high proportion of ONP in recyclable paper, ONP is recovered by negative sortation, i.e. pickers are not used to recover ONP. ONP from the conveyor empties directly into the hopper of a baler. Other paper components are dropped into storage bunkers below the elevated sorting line. These paper types are baled at the end of the work day. Bunkers are emptied onto a conveyor by a walking floor and this floor feeds the baler used for ONP.

Blue bags containing non-paper recyclables are pushed onto a conveyor that feeds a debagging station. These bags are opened either manually or automatically as specified by the model user. Loose recyclables are then routed to a trommel for removal of grit, broken glass and the like, after which commingled recyclables are conveyed to an elevated and enclosed sorting room. In the sort room, pickers are positioned on both sides of a conveyer. Recyclables picked from the conveyer are dropped into chutes that lead into bunkers under the sort room. When a bunker is full, recyclables are emptied onto a conveyor that leads to a baler by using moving floors. Bales are loaded into trailers at a loading dock. Temporary storage space for bales is provided until a sufficient number of bales to fill a trailer are ready. Glass recyclables are not crushed, and glass recyclables are dropped into storage bins placed under the conveyer belt. When full, storage bins are emptied into trailers.

Aluminum and ferrous cans remain on the conveyer with some residue at the end of the sort room. Here cross belt arrangements are provided so that metal cans from all sort lines can be recovered by the same equipment (magnet for ferrous cans or eddy current separator for aluminum cans). Separation of aluminum cans can be manual or automated as specified by the user. If automated, an eddy current separator is used to recover aluminum cans. The user can select the process to be used for aluminum recovery. Ferrous cans are recovered by a magnet.

Quality control is often maintained by a second sort of recyclables in each storage area. The second sort of recyclables can be done at the beginning or end of the work day. The user can specify the time required to remove contaminants from recovered materials. The second sort is also discussed in Section 4.4 under Working day length.’ Conveyers can then be used to route recyclables directly to a baler after a second sort. After recovery, recyclables are baled and stored. Residue remaining after all recovery is complete is disposed of at a landfill.

4.3 Determination of Cost function for a Commingled Recyclables MRF

The annual cost of a mixed waste MRF has two components: capital cost amortized over the life of the MRF and the annual operating cost. The capital cost of a MRF is calculated from a unit capital cost with units of dollars per ton/year processed. In addition, it can be expressed in annual terms using a capital recovery factor that is dependent upon a book lifetime and discount rate. Both of these numbers are input parameters for which default data are available. The operation and maintenance (O&M) cost of a MRF includes the labor, overhead, taxes, administration, insurance, indirect costs, electricity cost and maintenance cost. It does not include the cost for disposing of the residue, nor does it include the revenue from recyclables sales. The O&M cost coefficient depends upon the unit O&M cost and the quantity of waste processed. The annualized cost of a MRF is expressed in Equation 4-1.

Equation 4-1

$$Annual\ cost of\ MRF = CRF \times Capital\ cost + Annual\ Operating\ cost$$

Annual cost of MRF: expressed in $/ton
Capital Recovery Factor (CRF), units of 1/yea*r*

CRF is the capital recovery factor that enables the conversion of the capital costs into annual terms. It is a function of the facility or equipment life, *(lifetime)* and an appropriate *Discount_rate*. For a *Discount_rate* ≠ 0, CRF is calculated as follows:

$$CRF = \frac{Discount\_rate \cdot (1 + Discount\_rate)^{lifetime}}{1 - (1 + Discount\_rate)^{lifetime}}$$

Capital cost: is the capital cost per ton per year of waste component processed by the MRF. To convert capital cost from $/Ton per day to $/Ton per year, the following equation is used:

$$\frac{\$}{Ton/Year} = \frac{\$}{Ton/Day} \times \frac{year}{days}$$

Days per year are the number of operating days per year of the MRF.

Annual operating cost: expressed in $/ton

4.4 Capital cost

Capital cost consists of construction, land acquisition, engineering, and equipment cost, as expressed in Equation 4-2.

Equation 4-2

$$Capital\ cost_i = Construction\ cost_i + Land\ cost_i + Engineering\ cost_i + Equipment\ cost_i$$

i: Cost is expressed per ton of waste component i

4.4.1 Construction cost

Construction cost includes the cost of the structure, access roads, fencing, weigh station, landscaping, etc. The cost of the structure includes support facilities such as office space, a weigh station, and those conveyers that are not a function of the type and quantity of recyclable processed. This includes the length of conveyer required for transport of loose recyclables from the floor of the MRF into the elevated sort room, and the conveyer leading into the hoppers of the balers. Conveyer length in the sort room is discussed in the following sections.

Construction cost is obtained by multiplying the floor area of the MRF by the construction cost rate ($/sq ft). Default values are provided for the construction cost rate. The EPA Handbook on MRFs [1] provides a range of 28-60 $/sq ft for the value of the construction cost rate. A detailed estimate was performed to calculate the construction cost rate in Appendix 4 and the calculated value is 40 $/sq ft. Construction cost is calculated using Equation 4-3. The construction cost rate of the facility includes the cost of furniture and equipment for the office.

Equation 4-3

$$Construction\ cost_i = Floor\ area\ of\ MRF_i \times const\_rate$$

Construction cost$_i$: Cost of construction of MRF for waste item i, $/TPD
const_rate: Construction cost rate, default value is 40 $/sq ft
Floor area of MRF: Total floor area of MRF, from **Equation 4-4**, sq ft/ TPD

Floor area

Floor area of the commingled recyclables MRF is a function of the quantity of recyclables processed in a day. It is also a function of the composition of the recyclable stream. The area required for the MRF is estimated using Equation 4-4. The floor area of the MRF consists of the tipping floor, processing floor, office, and storage areas. All area estimates include a maneuverability factor (MF) that allows for vehicle and machinery access.

Equation 4-4

$$Floor\ area\ of\ MRF_i = Tipping\ floor\ area_i + Processing\ floor\ area_i + Office\ area_i + Storage\ area_i$$

Tipping floor area of the MRF

Recyclables are unloaded from collection vehicles onto the tipping floor. The maneuverability factor for the tipping floor (MF1) is 2.5. The tipping floor allows for downtime of equipment by including a storage requirement. This storage requirement is user input. The default value is two days. The area required for the tipping floor is calculated assuming a recyclables loose density and a recyclables pile height on the tipping floor. Equation 4-5 is used to calculate the tipping floor area.

Equation 4-5

$$Tipping\ floor\ area_i = \frac{MF1 \times tipp\_stor \times 2000}{loose\_density_i \times height}$$

Tipping floor area: Area required for tipping floor, sq ft/TPD
MF1: Maneuverability factor for the tipping floor, value 2.5, [1]
tipp_stor: Storage requirement to allow for equipment downtime, default value is 2 days
$loose\_density_i$: Loose density of waste item i, lb/cu ft
height: Height of waste on the tipping floor, default value is 10 ft
2000 lb/ton

Processing floor area
The processing floor is used for separation and baling operations. This area consists of the sort room, the area required for equipment and the area for loading recyclables on the conveyer and the conveyer itself. The load area includes the area for debagging operations. The processing area is calculated in Equation 4-7.

Sort room
The sort room, where recyclables are recovered, is approximately 12 ft above the floor, elevated, enclosed, heated, and air-conditioned. The length of the sort room is equal to the sorting length of the conveyer. The sort room width accommodates 4 ft wide conveyer belts, and room for pickers working beside these belts. Sorting length of the conveyer is a function of the composition and quantity of recyclables that are recovered in the MRF, and is calculated in **Equation 4-8**. The width of the sort room is user input and the default value is derived below. For a given speed of a conveyer, width of conveyer, thickness, and density of recyclables on the conveyer, there is a maximum capacity that the conveyer can carry. If this maximum capacity is exceeded, then another conveyer is added in the sort room. In this MRF design, the speed of the sorting conveyer is 30 ft/min, the width of the conveyer is 4 ft, the average depth of recyclables on the conveyer is 6 inches, and their density on the conveyer is assumed to be 8 lb/cu ft. Using these data, and a 7 hr/day operation time, the carrying capacity of the conveyer is calculated as:

Equation 4-6

$$Conveyer\ capacity(TPD) = \frac{4^{ft} \times 30^{ft/\min} \times 0.5^{ft} \times 60^{\min/hr} \times 7^{hr/day} \times 8^{lb/cu\_ft}}{2000^{lb/ton}}$$
$$= 100.8\ TPD$$

To derive the sort room width, we assumed a waste generation rate of 3 lb/person-day, and that 20% of the waste generated in a week is non-ONP recyclables. We further assume that all 20% of the recyclables are to be processed in this MRF in 5 days per week. 100.8 TPD, the mass of non-ONP recyclables that can be transported on a 4 feet wide conveyer, corresponds to a city with a population of approximately 240,000. Thus, for populations of less than 500,000, the default sort room width of 20 ft (for 2 conveyers) is adequate. If the user expects that more than 200 TPD (= 2 conveyers x 100 TPD/conveyer) will be processed in the MRF, then the sort room width should be increased accordingly. It is suggested that for every extra conveyer added, the width of the sort room be increased by 8 ft.

The estimate for the processing floor area does not include floor area for the magnet and the eddy current separator. It is assumed that area for the magnet and the eddy current separator is small compared to the rest of the processing area, and can be neglected.

Equation 4-7

$$\begin{aligned} Processing\ area_i &= Sortroom\ area_i + Floor\ area\ for 2\ balers_i + Loading\ area_i \\ &= (n3 \times conveyer\_sort\_length_i) + (MF2 \times f1) + (f2) \end{aligned}$$

Processing $area_i$: Area required to process a ton of recyclable i, sq ft/TPD
f1: Factor for calculating floor area required for balers, default value 8 sq ft/TPD baled
f2: Factor for calculating area required for opening of bags, default values are 20 and 15 sq ft/TPD for mechanical and manual bag opening respectively
n3: Width of sort room, default value is 20 ft
MF2: Maneuverability factor for processing area, default value 2.5 [1]
$conveyer\_sort\_length_i$: Length of conveyer required for picking recyclable i, ft/TPD

Conveyer sort length

The conveyer sort length required in Equation 4-7 is obtained from Equation 4-8. Conveyer sort length is proportional to the number of pickers. Picker stations are 4 ft apart, on both sides of the belt in a staggered formation, thus, only 4 ft of conveyer length are required to accommodate 2 pickers. The sorting conveyer length is multiplied by a user input redundancy factor. This extra conveyer length is split between the conveyers equally. Extra conveyer length allows for cross belt connections and operational flexibility such as recovery of new recyclables.

Equation 4-8

$$Conveyer\_sort\_length_i = \frac{nP_i \times 4 \times Redundancy\ factor}{2}$$

$conveyer\_sort\_length_i$: Length of conveyer required for picking recyclable i, ft/TPD
nP_i: Number of pickers for recyclable i, pickers per TPD, from Equation 4-10
4: 4 feet of conveyer length are required per picker
2: conveyer length is divided by 2 since pickers are positioned on both sides of belt
Redundancy factor: Extra conveyer length required for conveyers, default value 2

Picking Rate for a recyclable

Picking Rate (PR) is defined as the weight of a recyclable (in tons) that is recovered by a picker in one hour. Very limited information is available about picking rates for various recyclables in different types of MRFs. The EPA handbook on MRFs [1] provides approximate ranges of recovery efficiencies and sorting rates. The data provided in this source cover a wide range, e.g. the sorting rate (PR) for plastic (PET, HDPE) is 300-600 lb/hr/sorter. The handbook does not differentiate between the MRF type. Intuitively, the picking rate for a recyclable in a mixed waste MRF will be less than that in a commingled recyclables MRF.

The rate of picking recyclables off the conveyer depends on the number of recyclables present on the conveyer. The PR for clear glass from a mixture of two types of plastics and metal cans would be less than the PR for clear glass from a mixture of only metal cans.

A formula for determination of more accurate estimate picking rates is presented below.

$$PR_A = \left(\frac{PR^*_A \times Volume_A}{\sum Volume} \right)_{at\ measured\ speed\ of\ conveyer}$$

PR_A: Corrected picking rate for recyclable A at specified speed of conveyer, tons/hour
PR^*_A : Measured "maximum" picking rate for recyclable A at specified speed of conveyer, tons/hour
$Volume_A$: Volume of recyclable A on the sorting belt, cu ft
ΣVolume: Total volume of all recyclables and waste on the sorting belt, cu ft

The formula presented above is based on the premise that the picking rate of a recyclable is a function of the relative "presence" of a recyclable on the sorting belt. This "presence" is proposed to be approximately equal to the relative volume of the recyclable among other recyclables or waste also present on the belt. The maximum picking rate for recyclable A is the rate at which a sorter can pick recyclable A off the conveyer (at a specified speed of conveyer) if only A were passing by. This maximum picking rate for recyclable A would decrease when the speed of the conveyer is increased.

The formula presented above can be used to calculate a picking rate for each recyclable during the sorting operation. The volume of the recyclable can be obtained by dividing the weight of a recyclable to be processed by its density. Similarly the total volume of all recyclables can be obtained once the composition of recyclables (in a commingled recyclables MRF) to be processed is known.

Research is needed to verify and provide data for the formula presented above and a table of values for picking rates at different conveyer speeds should be generated. This would be of great value to material recovery facility designers for estimation of the number of sorters required for a known quantity and mixture of recyclables to be recovered. In the waste management model being used in this document, the composition of the recyclables that are processed in the MRF is a model solution, and hence the formula presented above cannot be used to generate the picking rates needed in the model.

The nature of the optimization model used for the DST requires one PR for each recyclable to be specified in the separation process model. These data determine the recyclables that are to be recovered in a MRF. Thus, an approximate value for the picking rate is input to the model. These values are listed in Table 4-2. These rates are higher than the rates given in Table 2-2 because the rates given here are applied to commingled recyclables and not to mixed waste refuse.

Table 4-2 Picking Rate for Recyclables in a Commingled Recyclables MRF

Waste Component	Variable Name	Picking Rate (Tons per hour)
Old Newsprint	ONP	Negatively sorted
Old Corrugated Cardboard	OCC	0.100
Office Paper	OFF	0.750
Phone Books	PBK	0.750
Books	BOOK	0.750
Old Magazines	OMG	0.750
3rd Class Mail	MAIL	0.750
Paper Other #1	PAOT1	0.750
Paper Other #2	PAOT2	0.750
Paper Other #3	PAOT3	0.750
Paper Other #4	PAOT4	0.750
Paper Other #5	PAOT5	0.750
Mixed Paper	PMIX	Negatively sorted
HDPE - Translucent	HDT	0.060
HDPE - Pigmented	HDP	0.100
PET	PPET	0.060
Plastic - Other #1	PLOT1	0.060
Plastic - Other #2	PLOT2	0.060
Plastic - Other #3	PLOT3	0.060
Plastic - Other #4	PLOT4	0.060
Plastic - Other #5	PLOT5	0.060
Mixed Plastic	PLMIX	0.060
Ferrous Cans	FCAN	Magnet
Ferrous Metal - Other	FMOT	Magnet
Aluminum Cans	ACAN	0.025
Aluminum - Other #1	ALOT1	0.025
Aluminum - Other #2	ALOT2	0.025
Glass - Clear	GCLR	0.250
Glass - Brown	GBRN	0.150
Glass - Green	GGRN	0.050
Mixed Glass	GMIX	0.050

PR is used to calculate the number of pickers to sort the incoming commingled recyclables. In Equation 4-10, Sorting Efficiency (SE) of recyclable i, is defined as the weight of i recovered from the conveyer divided by the weight of i that enters the MRF. SE is assumed to be 0.94 for clear glass (GCLR), brown glass (GBRN) and green glass (GGRN) to allow for breakage. Glass recyclables not recovered due to breakage, are disposed off as residue. For the rest of the recyclables, SE is assumed to be 1.00.

The length of the effective work day is given by Equation 4-9. Recovery facilities are usually operated on a one shift basis, but the length of the single shift may vary. To allow the user to choose the length of a shift, the effective work day length is a user input. This effective work day length is used to calculate the number of pickers required to separate recyclables from the conveyer belt. If two shifts are desired, then the value of WD can be increased by the user.

Equation 4-9

$$WDe = WD - (break\_time) - (sec\_sort\_time)$$

WDe: Effective work day length, default value is 7 hr/day
WD: Work day length, default value is 8 hr/day
break_time: Time when the conveyer is temporarily stopped, usually to provide rest for pickers, default value is 0.5 hr/day
sec_sort_time: Time allocated, usually at the end of the day, for a negative sort for contaminants in sorted recyclables, default value is 0.5 hr/day

Number of Pickers
The number of pickers required for a recovering a ton of recyclable is calculated in Equation 4-10.

Equation 4-10

$$nP_i = \frac{SE_i}{PR_i \times WDe}$$

nP_i: Pickers required for the recyclable i, pickers per TPD
SE_i: Sorting efficiency for recyclable, fraction, default values are provided
PR_i: Picking rate for recyclable i, Tons/picker-hr, default values are provided
WDe: Effective work day length, default value is 7 hr/day

In calculating the total number of pickers required for the MRF, it is assumed that fractional pickers can be used. This is logical because during the course of a shift, picker assignment to recyclables is flexible, and pickers help each other when working at less than maximum capacity. It is also assumed that part-time services can be employed. According to the design process flow, pickers are not assigned for ONP and ferrous cans in the sort room. ONP is negatively sorted from paper recyclables. Pickers are not required for ferrous cans because they are recovered with a magnet at the end of the sorting conveyer. Depending on the option the user chooses, aluminum cans are recovered either manually or by using an eddy current separator. If manual aluminum sortation is specified by the user, then ‘nP’ will include the sorters required for picking aluminum cans in the aforementioned sort room. The default option for aluminum is mechanical recovery.

Area required for balers
The area required for balers is estimated by the second term of Equation 4-7. Factor ‘f1’ relates the capacity of the MRF to the floor area required for the balers.

Loading area
The area required for loading recyclables is estimated by the third term of Equation 4-7, by multiplying the sorting conveyer length (from Equation 4-8 by factor ‘f2’ and the maneuverability

factor MF2 (value 2.5). The default values for f2'for automated and manual bag opening are 15 and 20 sq ft/ TPD, respectively.

This concludes the processing area calculations.

Office area

The office area includes the front office, meeting rooms, employee rest areas, changing rooms, and rest-rooms. Office area required per ton of material is given by Equation 4-11.

Equation 4-11

$$Office\ area_i = n4$$

Office $area_i$: Office area required per ton of material i, sq ft/TPD
n4: office area factor, default value is 11 sq ft/ TPD, developed in Appendix 5

Storage area

Storage area is required for baled recyclables. Storage area for baled recyclables is the area required to store all the bales made in one day. The footprint of each bale is a user input and the default value is 20 sq ft. The bales are assumed to be stacked 3 high. The storage area for baled recyclables is given by Equation 4-12**.**

Equation 4-12

$$Storage\_area_{bi} = \frac{MF2 \times No.\ days \times footprint \times SE_i}{3 \times BW_i}$$

Storage_area $_{bi}$: Storage area required for bales of recyclable *i*, sq ft/TPD
MF2: Maneuverability factor for storage area, value 2.5
No. days: Number of days bales are stored, default value is 1 day,
footprint: Area occupied by a bale, default value 20 sq ft
SE_i: Sorting efficiency, tons of material recovered per ton of material processed
3: bales are assumed to be stacked 3 high
BW_i: Weight of a bale of non-glass recyclable, default values are provided, Tons

This concludes the section on the equations for calculating the floor area of a MRF.

4.4.2 Land Acquisition Cost

The floor area of a MRF is used to calculate the total area of the facility. The floor area is multiplied by a factor `n6' to give the total area of the recovery facility. The total area includes area for structure, access roads, fencing, weigh station, landscaping etc.

Equation 4-13

$$Land\ aquisition\ cost_i = \frac{Floor\ area\ of\ MRF \times n6 \times land\_acq}{43560}$$

Land acquisition cost: Cost of land for MRF per ton of material, \$/TPD
Floor area of MRF: Floor area of the MRF, from Equation 4-4, sq ft/TPD
n6: Multiplying factor for total area of MRF, default value is 3 sq ft total area/ sq ft floor area
land_acq: Cost of land, default value 500 \$/acre
43560 sq ft/acre

4.4.3 Engineering cost

The engineering cost consists of the consulting and technical services while the MRF design and construction. Engineering cost is estimated to be a fraction of the construction cost, and is expressed by Equation 4-14.

Equation 4-14

$$Engineering\,cost_i = eng\_cost \times Construction\ cost_i$$

Engineering $cost_i$: Cost of engineering services expressed per ton of material processed, \$/TPD
Construction cost: Cost of constructing MRF, given by Equation 4-3, \$/TPD
eng_cost: Engineering cost rate, % of construction cost, the default value is 30%, [1]

4.4.4 Equipment Cost

The equipment cost consists of the capital cost of equipment and installation. Equipment cost is calculated using Equation 4-15.

Equation 4-15

$$Total\ equipment\ cost_i = Equipment\,cost_i + Equipment\ installation\ cost_i$$

Equipment installation cost is a fraction (equip_inst) of equipment cost. Installation cost is given by Equation 4-16.

Equation 4-16

$$Equipment\ installation\ cost_i = equip\_inst \times Equipment\ cost_i$$

Equipment installation $cost_i$: Cost of installing equipment for a ton of material i, \$/TPD
Equipment cost: Capital cost of equipment, \$/TPD
equip_inst: Equipment installation cost, % of equipment cost, default value is 10%, [1, 4]

Equipment Capital Cost

The equipment capital cost is estimated using Equation 4-17. The glass crusher and magnet are included only if glass and ferrous cans are processed per management model solution. Similarly, the eddy current separator is included only if automated recovery of aluminum cans is selected by the user and aluminum recycling is specified by the management model solution. The magnet and eddy separator costs are inclusive of all other equipment required for their operation, e.g. bins, chutes, conveying equipment, etc. The equipment cost does not include the cost of trailers used for storage and transport of separated recyclables. It is assumed that the buyer of recyclables will provide trailers for the MRFs.

Equation 4-17

$$Equipment\ cost_i = Conveyer\ cost_i + bunkers\ cost_i + storage\ bins\ cost_i + chute\ cost_i + magnet\ cost_i + eddy\ current\ separator\ cost_i + rolling\ stock\ cost_i + baler\ cost_i + bag\ opener\ cost_i + trommel\ \cos t_i$$

Conveyers cost

The cost of conveyers is given by Equation 4-18. The unit cost of a conveyer (convey_cost), is an average for the loading conveyer, cross belts, and the sorting conveyer.

Equation 4-18

$$Conveyer\ cost_i = Conveyer\_sort\_length_i \times convey\_cost$$

Conveyer $cost_i$: Cost of conveyer for a ton of material I, $/TPD
convey_cost: Cost of conveyer, default value is 1200 $/ linear ft [1]
Conveyer_sort_length: Length of conveyer, from Equation 4-8, ft/TPD

Bunkers Cost

Bunkers are located under the elevated sorting room. Sorted recyclables are dropped into these bunkers. The number of bunkers is assumed to be proportional to the number of pickers. The cost of a bunker includes the cost of the moving floor required for its operation. The cost of bunkers for a ton of material processed is given by Equation 4-19**.**

Equation 4-19

$$Bunker\ \_cost_i = \frac{Bunker\_cost \times nP_i}{2}$$

Bunker_ $cost_i$: Cost of bunkers for material I, $/ TPD
Bunker _cost: Cost of a bunker, default value is $30000
nP_i: Pickers for material I, pickers/TPD
2: One bunker for every two pickers

Storage bins cost

Storage bins are required for glass recyclables until glass is emptied into trailers. The cost of storage bins for recyclables is estimated using Equation 4-20**.**

Equation 4-20

$$Storage\ bins\ cost_i = bin\_cost \times nP_{gi}$$

Storage bins $cost_i$: Cost of storage bins for material I, $/TPD
bin_cost: Cost of a bin, default value is $400, [2]
nP_{gi}: Number of pickers required for glass recyclables, pickers/TPD

Chutes cost

Chutes are required for guiding recyclables as they drop into bins placed under the sorting room. The number of chutes in the MRF will be equal to the number of pickers per shift. The cost of chutes for processing material 'i' is given by Equation 4-21.

Equation 4-21

$$Chute\ cost_i = nP_i \times chute\_cost$$

Chute $cost_i$: Cost of chute for recyclable 'i', $/TPD
nP_i: Number of pickers for a ton of material 'i', pickers/TPD
chute_cost: Cost of a chute, default value is $200

Magnet cost
If recycled, then ferrous cans are recovered by a magnet at the end of each sorting line. The cost of a magnet is given by Equation 4-22.

Equation 4-22

$$Magnet\ cost = magnet\_cost$$

Magnet $cost_i$: Cost of a magnet to recover ferrous recyclable 'i', $/TPD
magnet_cost: Cost of the magnet, default value is $3200/TPD, [2, 5]

Rolling stock cost
Three types of vehicles are likely to be used in the MRF: a front-end loader that pushes recyclables on the sorting conveyer, fork-lifts that move bales and a skidloader which performs the functions of both a front-end loader and a fork-lift. Usually the skidloader is the smallest and least expensive of the three types of vehicles used in a MRF. In smaller facilities, a skidloader can substitute for a fork-lift and a front-end loader. In larger facilities, dedicated equipment is required, and rolling stock may include floor scrubbers, etc. The cost of rolling stock is given by Equation 4-23.

Equation 4-23

$$Rolling\ stock\ cost_i = roll\_cost$$

Rolling stock $cost_i$: Cost of rolling stock for material 'i', $/TPD
roll_cost: Cost of rolling stock, default value is $700/TPD, developed in Appendix 5

For a MRF of capacity 50 TPD, Equation 4-23 gives the rolling stock capital cost as $35,000. A MRF of this size requires only one skidloader for handling the bales and loose recyclables. The cost of a skidloader is $30000-40000.

Baler cost
Two balers will be used in the facility, with two sorting lines and conveyers that lead into the hopper of the baler. The cost of balers is given by Equation 4-24. The two balers may be different. For example, a horizontal frictional baler may be dedicated to ONP, while a two ram baler is used to compact the rest of the recyclables.

Equation 4-24

$$Baler\ cost_i = baler\_cost \times SE_i$$

Baler $cost_i$: Cost of baler for material 'i' processed, $/TPD
baler_cost: Cost of balers, default value is $1500/TPD baled, developed in Appendix 5
SE_i: Sorting efficiency, tons of material recovered per ton of material processed

Eddy current separator cost
If recycled, then aluminum cans may be recovered manually or by using an eddy current separator. If the user selects automated separation, the cost of an eddy current separator is given by Equation 4-25.

Equation 4-25

$$Eddy\ current\ separator\ cost_i = eddy\_cost$$

Eddy current separator $cost_i$: Cost of an eddy current separator, $/TPD
eddy_cost: Cost of an eddy current separator, default value is 14290 $/TPDa, developed in Appendix 5

Bag opener cost
Commingled recyclables enter the MRF in bags. The bags can be opened manually or by using a mechanical bag opener. The choice of bag opening method used is a user option. The cost of a mechanical bag opener is given by Equation 4-26. The mechanical bag opener used as the default in the model consists of alternating rows of tines (pointed projecting part or spike) moving at different speeds to open bags moving on a conveyer. The spikes rip the bag open and the bags' contents are deposited on a conveyer.

Equation 4-26

$$Bag\ opener\ cost_i = bagopen\_cost$$

Bag opener $cost_i$: Cost of a bag opener for material 'i', $/TPD
bagopen_cost: Cost of a debagger, default value is 1500 $/TPD, [6], developed in Appendix 5

Trommel cost
Before commingled recyclables enter the sorting room, they pass through a trommel to remove grit, broken glass, etc. The cost of a trommel is given by

Equation 4-27

$$Trommel\ cost_i = trommel\_cost$$

Trommel $cost_i$: Cost of a trommel for material 'i', $/TPD
trommel_cost: Cost of a trommel, default value is 8000 $/TPD, [6], developed in Appendix 5

4.5 Operating Cost

The MRF operates on all days that recyclables are collected. Operating cost of the MRF include wages, overhead, equipment and building maintenance, utilities, and residue disposal. The annual operating cost for a MRF is given by Equation 4-28.

Equation 4-28

$$Operating\ cost_i = Labor\ cost_i + Overhead\ cost_i + Maintenance\ cost_i + Utilities\ cost_i$$

4.5.1 Labor Cost

The cost of labor is given by Equation 4-29. Labor required for the MRF consists of management, drivers and operators, and pickers. Small facilities may require only part-time managerial services, but bigger MRFs require full time managers, secretaries, and supervisors. In estimating the labor wages, it is assumed that part-time services can be hired.

Equation 4-29

$$Labor\ cost_i = Management\ wages_i + Picker\ wages_i + Driver\ and\ Operator\ wages_i + Bag opener\ wages_i$$

Management wages

Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to pickers, drivers and operators. This fraction is user input. Management wages are estimated in Equation 4-30.

Equation 4-30

$$Management\ wages_i = man\_wage \times (Picker\ wages_i + Driver\ and\ Operator\ wages_i + Bag opener\ wages_i)$$

Management wages$_i$: Management wages for recovering waste component i, $/Ton
man_wage: Management wage rate, default value is 25%
Picker wages$_i$: Picker wages for recovering waste component i, $/Ton
Driver and operator wages$_i$: Driver & Operator wages for recovering waste component i, $/Ton
Bag opener wages$_i$: Bag Opener wages for recovering waste component i, $/Ton

Picker wages

Wages for pickers are calculated using Equation 4-31. The picker wage rate is user input. The default value is 6 $/hr.

Equation 4-31

$$Picker\ wages_i = \frac{pick\_wage \times SE_i}{PR_i}$$

Picker wages$_i$: Wages paid to pickers for recovering recyclable I', $/Ton
SE$_i$: Sorting efficiency for recyclable, fraction, default values are provided
pick_wage: Picker wage rate, default value is 6 $/hr
PR$_i$: Picking rate of recyclable I', Tons/hr

Driver and operator wages

The number of drivers and operators is small for a small capacity commingled recyclable MRF. Large capacity MRFs require specialized labor. Operators are required for the operation of the two balers and for operation of the weighing station. The wages of operators and drivers are estimated by Equation 4-32. Factor f4 is used to obtain the number of working hours of drivers and operators based on weight of recyclables processed in a day in the MRF.

Example:

For a facility processing 100 tons a day, f4'estimates 32 hours/day of drivers and operators. Assuming an 8 hour working day, 4 drivers and operators are estimated for this facility, which can be justified as 2 baler operators, 1 driver, and 1 weigh station operator.

Equation 4-32

$$Driver\ and\ Operator\ wages_i = driv\_wage \times f4$$

Driver and operator $wages_i$: Wages paid to drivers and operators for waste component i, $/Ton
driv_wage: Wage rate for drivers and operators, default value is 10 $/hr
f4: Factor used to obtain the working hours of drivers and operators, default value is 0.32 hr/Ton, developed in Appendix 5

Bag opener wages

If bags of recyclables that are processed in the MRF are to be opened manually per user choice, then the cost of labor for bag opening is given by Equation 4-33.

Equation 4-33

$$Bag\ Opener\ wages_i = \frac{bag\_open\_wag}{n10}$$

Bag opener $wages_i$: Wages for bag openers, $/ton
bag_open_wag: Bag opener wages, default value is 6 $/hr
n10: Capacity of a bag opener, default value is 4 Tons/hr

4.5.2 Overhead cost

Overhead costs for labor are calculated as a fraction of labor wages. Overhead includes overtime, office supplies, insurance, social security, vacation, sick leave, and other services. Overhead costs are calculated using Equation 4-34.

Equation 4-34

$$Overhead\ cost_i = lab\_overh \times Labor\ cost_i$$

Overhead $cost_i$: Annual cost of overhead, $/ton
lab_overh: Overhead rate, default value is 40%, [1], %
Labor $cost_i$: Total cost of labor, given by Equation 4-29, $/ton

4.5.3 Utility Cost

The cost of utilities (power, fuel, oil, etc.) is proportional to the capacity of the MRF. The cost of utilities is estimated by Equation 4-35.

Equation 4-35

$$Utility\ cost_i = util\_cost$$

Utility $cost_i$: Cost of utilities per ton of recyclable i, $/ton
util_cost: Utility cost rate, default value 1.2 $/ton processed, [1]

4.5.4 Maintenance cost

The cost of maintenance of equipment and structure is assumed to be proportional to the capacity of the MRF. Maintenance cost is given by Equation 4-36.

Equation 4-36

$$Maintenance\ cost_i = main\_cost$$

Maintenance $cost_i$: Cost of maintenance for recyclable i, $/ton
main_cost: Maintenance cost rate, default value is 4 $/ton processed, [1]

This concludes the description of the process flow diagram, the design considerations, and the equations that describe the design of a commingled recyclables facility. The following chapters will describe the designs of the other types of MRFs.

4.6 References

1. Handbook Materials Recovery Facilities for Municipal Solid Waste, US EPA, 1991.

2. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H., Vigil, S., A., McGraw Hill Inc., 1993, p 933.

3. Personal communication with Mr. Keith Hannah of McDonalds Services, Charlotte, North Carolina.

4. Personal communication with Mr. Jim Harding, Solid Waste Equipment, Omaha, Nebraska.

5. Personal communication with sales personnel, Eirez Magnetics, Erie, Pennsylvania.

6. Personal communication with sales representatives, Debagit, Memphis, Tennessee.

5 Design of a MRF for Co-collection in a Single Compartment

5.1 *Introduction*

The objective of this chapter is to present a design of a MRF which receives co-collected waste, i.e. both commingled recyclables and mixed refuse in a single compartment truck. Based on this design, a cost function is derived to relate the cost of a MRF to the quantity and composition of the waste to be processed therein.

The cost function of this MRF is similar to that of a commingled recyclables MRF [3], and only the differences between the two MRFs will be discussed in this chapter. The apparent advantage that this MRF has over the commingled recyclables MRF is that both mixed waste and recyclables can be collected by the same truck. Since both the bags from the curbside are loaded into the same compartment, there is no significant increase in the loading time at a stop. A disadvantage with this collection system is that mixed waste is also unloaded at the MRF and has to be handled again for transport to the disposal facility. Whether there is an overall benefit in collecting and recovery by using this system is dependent on site specific conditions.

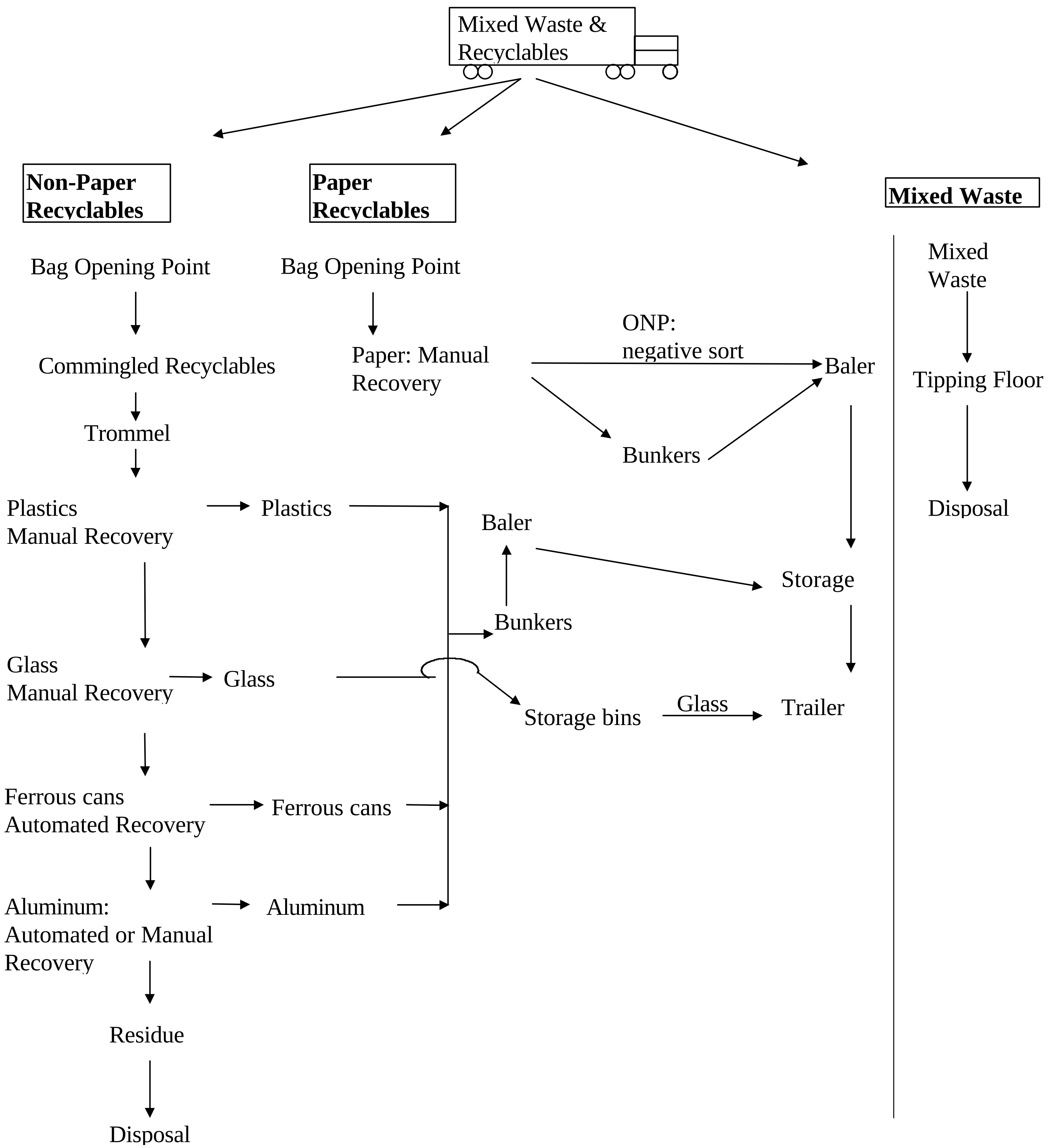
5.2 *Description of process flow*

The design is applicable to all possible combinations of incoming recyclables. The waste components that can be recycled, and their picking rate are shown in Table 5-1. The process flow diagram is shown in Figure 5-1.

Table 5-1 Components of Waste that can be Recovered and their Picking Rate in Co-collection MRF

Waste Component	Variable Name	Picking rate (Tons per hour)
Old Newsprint	ONP	Negatively sorted
Old Corrugated Cardboard	OCC	0.100
Office Paper	OFF	0.750
Phone Books	PBK	0.750
Books	BOOK	0.750
Old Magazines	OMG	0.750
3rd Class Mail	MAIL	0.750
Paper Other #1	PAOT1	0.750
Paper Other #2	PAOT2	0.750
Paper Other #3	PAOT3	0.750
Paper Other #4	PAOT4	0.750
Paper Other #5	PAOT5	0.750
Mixed Paper	PMIX	Negatively sorted
HDPE – Translucent	HDT	0.060
HDPE – Pigmented	HDP	0.100
PET	PPET	0.060
Plastic – Other #1	PLOT1	0.060
Plastic – Other #2	PLOT2	0.060
Plastic – Other #3	PLOT3	0.060
Plastic – Other #4	PLOT4	0.060
Plastic – Other #5	PLOT5	0.060
Mixed Plastic	PLMIX	0.060
Ferrous Cans	FCAN	Magnet
Ferrous Metal - Other	FMOT	Magnet
Aluminum Cans	ACAN	0.025
Aluminum - Other #1	ALOT1	0.025
Aluminum - Other #2	ALOT2	0.025
Glass – Clear (unbroken)	GCLR	0.250
Glass – Brown (unbroken)	GBRN	0.150
Glass – Green (unbroken)	GGRN	0.050
Mixed Glass (unbroken)	GMIX	0.050

Figure 5-1 Process Flow in a MRF for Co-collection in a Single Compartment



Commingled recyclables and paper recyclables are placed in blue bags, and mixed refuse is placed in a black bag at the curbside. These bags are collected in a single compartment truck in which black bags and blue bags are collected in the same compartment. Recyclables mixed with other refuse in a black bag are not recovered. All the recyclables that are released due to breakage of blue bags in the truck are not recovered.

Blue and black bags are emptied onto the tipping floor and then pushed onto a conveyer. Blue bags containing paper recyclables are manually separated from those containing non-paper recyclables at a picking station and routed to separate debagging stations. Black bags are pushed directly into trailers for disposal. Blue bags are opened in the debagging station of the MRF. Debagging may be manual or automated as specified by the user. Loose recyclables from opened blue bags are then conveyed to a sort room.

The processing for paper recyclables, glass, plastic, ferrous cans, and aluminum remains the same as in the commingled recyclables MRF.

Mixed refuse in the black bags from the tipping floor is pushed into trailers and transported to another location, either a landfill, waste-to-energy facility, refuse derived fuel plant, mixed waste composting facility, or anaerobic digestor as specified by the management model. The transport cost of residue from this facility to a disposal site is included in the transportation process model.

5.3 Determination of cost function

The cost function for this MRF differs from that of the commingled recyclables MRF [3] in the following way.

Tipping floor area

Recyclables and mixed waste in bags are unloaded from collection vehicles onto the tipping floor. The maneuverability factor for the tipping floor (MF1) is 4 (instead of the value of 2.5 used in other MRFs). The extra area allows for unloading of and separation of mixed waste and recyclables from the same compartment on the collection vehicle. The tipping floor allows for downtime of equipment by including a storage requirement.

This concludes the description of the process flow diagram, the design considerations, and the equations that describe the design of a commingled recyclables facility accepting waste from a co-collection system from a single compartment truck. The following chapters will describe the designs of other types of MRFs.

5.4 References

1. Handbook Materials Recovery Facilities for Municipal Solid Waste, US EPA, 1991.

2. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H., Vigil, S., A., McGraw Hill Inc., 1993, p 933.

3. Design of a Commingled Recyclables MRF.

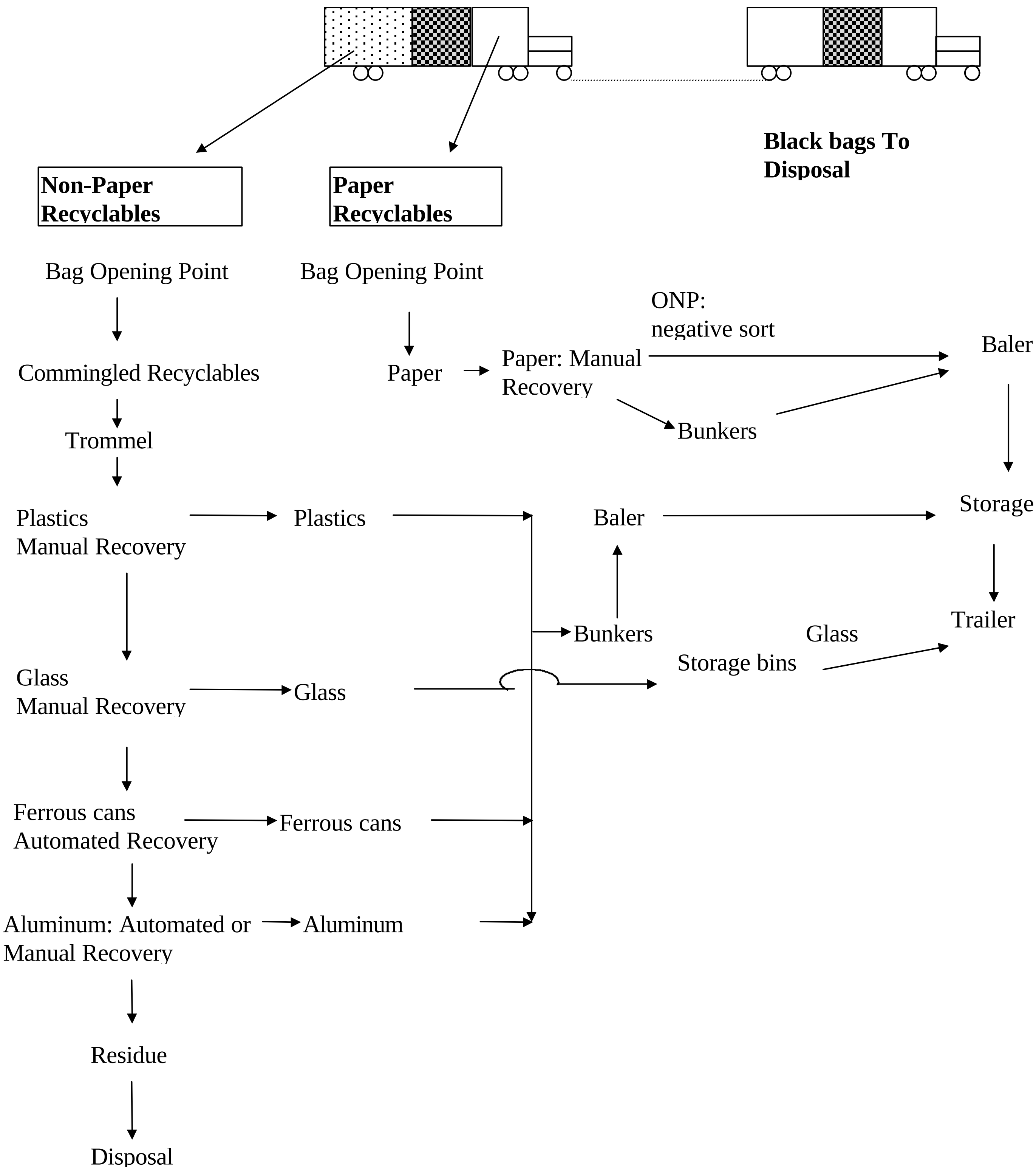
6 Design of a MRF for Co-collection in Separate Compartments

6.1 Introduction

The objective of this chapter is to present a design of a MRF which receives co-collected waste, i.e. both commingled recyclables and mixed refuse in a three compartment truck. Based on this design, a cost function is derived to relate the cost of a MRF to the quantity and composition of the waste components to be processed therein.

The design of this MRF is similar to that of a commingled recyclables MRF [3]. The process flow diagram for the MRF is shown in Figure 6-1. Paper and non-paper recyclables in separate blue bags (or loose as specified by the user) are unloaded onto the tipping floor and the separation and handling processes are the same as that of a commingled recyclables MRF. Mixed refuse is in a separate compartment of the collection vehicle and is transported to another location, either a landfill, waste-to-energy facility, refuse derived fuel plant, mixed waste composting facility, or anaerobic digestor. The cost to transport residue from this MRF to a disposal site is calculated in the transportation process model.

Figure 6-1 Process Flow Diagram Co-collection in Separate Compartments MRF



6.2 Description of process flow

The description of the process flow remains exactly the same as that of a commingled recyclables MRF. Refer to Chapter 4 for the detailed design of a commingled recyclables MRF.

This concludes the description of the process flow diagram, design considerations, and equations that describe the design of a facility accepting commingled recyclables from a double compartment co-collection truck.

This chapter also concludes the description and designs of the five types of MRFs that are discussed in this document

6.3 References

1. Handbook Materials Recovery Facilities for Municipal Solid Waste, US EPA, 1991.

2. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H., Vigil, S., A., McGraw Hill Inc., 1993, p 933.

3. Design of a commingled recyclables MRF, Chapter 6.

7 Life-cycle Inventory (LCI) for MRF Processes

The objective of this chapter is to present the equations used to develop a life-cycle inventory for a MRF. Equations are presented to address energy consumption, and air, water, and solid waste releases associated with both energy use and other MRF operations.

7.1 Energy Consumption Equations

The MRF process model accounts for two types of energy associated with both fuel and electricity. The fuel energy calculations include:

- Combustion energy: the energy used in rolling stock, lighting and heating, and equipment, and
- Precombustion energy: the energy required to manufacture the fuel or electricity from feed stock.

The LCI for electric energy is calculated in the Electric Energy process model. The LCI for fuel consumed by rolling stock is calculated based on factors for emissions associated with diesel production (precombustion) and diesel consumption in specific types of equipment.

For all MRFs in the integrated solid waste management system, the total energy consumption is expressed by Equation 7-1**.**

Equation 7-1

$$E\_total = E\_rolling\ stock + E\_building + E\_equipment$$

E_total: Total energy consumption for operating a MRF, Btu/ton
E_rolling stock: Energy consumed to operate rolling stock, Btu/ton
E_building: Energy consumed to heat and light MRF building, Btu/ton
E_equipment: Energy consumed to operate equipment in MRF, Btu/ton

7.1.1 Energy Consumed by Rolling Stock

Three types of vehicles are likely to be used in a MRF: a front-end loader that pushes recyclables on the sorting conveyer, fork-lifts that move bales, and a skidloader which performs the functions of both a front-end loader and a fork-lift. Usually the skidloader is the smallest and least expensive of the three types of vehicles used in a MRF. In smaller facilities, a skidloader can substitute for a fork-lift and a front-end loader. In larger facilities, dedicated equipment is required, and rolling stock may include floor scrubbers, and other specialized equipment. The energy required for operating rolling stock in a MRF is given by Equation 7-2.

Equation 7-2

$$E\_rolling\ stock = E\_rolling\_comb + E\_rolling\_precomb$$

E_rolling stock: Energy consumed to operate rolling stock, Btu/ton
E_rolling_comb: Combustion energy required to operate rolling stock, Btu/ton
E_rolling_precomb: Energy required to produce rolling stock fuel, Btu/ton

The combustion energy required to operate rolling stock in a MRF is given by Equation 7-3, and the precombustion energy required to produce the fuel energy for the rolling stock is given by Equation 7-4**.** Fuel used for rolling stock is diesel.

Equation 7-3

$$E\_rolling\_comb = gall\_Ton \times Btu\_gall$$

Equation 7-4

$$E\_rolling\_precomb = gall\_Ton \times E\_precomb\_gall$$

E_rolling_precomb: Energy required to produce rolling stock fuel, Btu/ton
gall_Ton: Quantity of fuel required in MRF, gallons/Ton, derived in Appendix 5
Btu_gall: Btu per gallon of fuel, Btu/gallon
E_precomb_gall: Energy required to produce a gallon of fuel, Btu/gallon

7.1.2 Energy Consumed for Heating and Lighting the MRF Building

Energy is used for heating and lighting the MRF building and its enclosed office area. The energy required for this purpose is estimated on a square foot basis. Energy consumption factors are derived in Appendix 5. These factors are based on national averages for warehouse type buildings, and general office areas. The MRF building consists of the tipping floor area, processing floor area, storage area, and the office area. The same energy consumption factor is used for the tipping floor, processing floor, and storage area, while a different factor is used for office area. The energy required for heating and lighting the MRF building for recyclable 'i'is given by Equation 7-5. The energy calculated by this equation includes the energy for producing the electricity for heating and lighting the MRF building. For electricity, the precombustion energy requirement is included in the factor R in Equation 7-5. R'is the aggregate of combustion and precombustion energy for a user defined regional electricity grid, i.e. R'is the energy in Btu it takes to produce a kWh of electricity for a user specified regional grid.

Equation 7-5

$$E\_building_i = C \times R \times \frac{1}{days\ per\ year} \times \left(\begin{array}{l} (E1\_sqft \times Tipping\_floor\_area_i + Processing\_floor\_area_i + \\ Storage\_area_i) + (E2\_sqft \times Office\_area_i) \end{array} \right)$$

C: Factor for converting Btu to kWh, 2.93 x 10^{-4} kWh/Btu
R: Regional aggregate (combustion + precombustion) energy factor, Btu per kWh, from Electric Energy Process model.
Days per year: Number of operating days per year
E_building: Energy consumed to heat and light the MRF building for recyclable 'i', Btu/ton
i: Item of waste
E1_sqft: Energy consumption factor for warehouse type areas, Btu/year-sq ft, see Appendix 5,
E2_sqft: Energy consumption factor for office type areas, Btu/year-sq ft, see Appendix 5,
$Tipping\_floor\_area_i$: Tipping floor area in MRF for item *i*, sq ft/TPD
$Processing\_area_i$: Processing floor area in MRF for item *i*, sq ft/TPD
$Storage\_area_i$: Storage area in MRF for item *i*, sq ft/TPD
$Office\_area_i$: Office area in MRF for item i, sq ft/TPD

7.1.3 Energy Consumed by Equipment

Electric energy is consumed by equipment used in the MRF to process and recover recyclables. Energy consumed by the equipment is proportional to the weight of materials processed by the equipment. The energy required to operate the equipment for a waste item I'in a MRF is the sum of energy required to run the equipment (combustion energy), and the energy required to produce this energy (precombustion energy), and is given by Equation 7-6. Note that some of the equipment in Equation 7-6 is not used in some MRF designs, e.g., a magnet is not used in a presorted MRF. The energy consumption rate for individual pieces of equipment in a MRF are derived in Appendix 5.

Equation 7-6

$$E\_equipment_i = R \times C \times \begin{pmatrix} E\_conveyer_i + E\_trommel_i + E\_magnet_i + E\_eddy\_current\_separator_i \\ + E\_baler_i + E\_bag\_opener_i \end{pmatrix}$$

$E\_equipment_i$: Electric energy consumed by equipment in MRF, Btu/ton
R: Regional aggregate (combustion + precombustion) energy factor, Btu per kWh, from Electric Energy Process model
C: Factor for converting Btu to kWh, 2.93×10^{-4} kWh/Btu
$E\_conveyer_i$: Energy consumption rate of conveyer, Btu/ton, see Appendix 5
$E\_trommel_i$: Energy consumption rate of trommel, Btu/ton
E_magnet_i: Energy consumption rate of magnet, Btu/ton, see Appendix 5
$E\_eddy\_current\_separator_i$: Energy consumption rate of eddy current separator, Btu/ton, see Appendix 5
E_baler_i: Energy consumption rate of balers, Btu/ton, see Appendix 5
$E\_bag\_opener_i$: Energy consumption rate of mechanical bag opener, Btu/ton, see Appendix 5

7.2 Airborne Release Equations

The MRF Process model calculates the quantities (by weight) of airborne pollutants emitted per ton of material processed in a MRF. Airborne releases for a MRF include combustion (emissions from diesel powered rolling stock) and precombustion emissions from fuel and energy production.

Release rates are calculated for the following airborne pollutants:

Carbon monoxide
Nitrogen oxides
Total Particulates
Carbon dioxide emissions from fossil fuel sources
Carbon dioxide emissions from biomass fuel sources
Sulfur oxides
Hydrocarbons, excluding methane
Methane
Lead
Ammonia
Hydrochloric acid

The total airborne releases for a pollutant *p* from a MRF are given by Equation 7-7.

Equation 7-7

$$A\_total_p = A\_rolling\_comb_p + A\_rolling\_precomb_p + A\_electric\_precomb_p$$

A_total_p: Total airborne release *p* due to MRF operation, pounds of pollutant/ton
p: Airborne pollutant
$A\_rolling\_comb_p$: Emission *p* from combustion of rolling stock fuel, pounds of pollutant/ton
$A\_rolling\_precomb_p$: Emission of pollutant *p* from rolling stock fuel production, pounds of pollutant/ton
$A\_electric\_precomb_p$: Emission of pollutant *p* from electricity production, pounds of pollutant/ton

For example, for NO_x emissions, Equation 7-7 would be written as:

$$A\_total_{NO_x} = A\_rolling\_comb_{NO_x} + A\_rolling\_precomb_{NO_x} + A\_electric\_precomb_{NO_x}$$

7.2.1 Airborne Releases from Rolling Stock Fuel

Air releases from combustion of fuel are calculated using Equation 7-8, and precombustion releases are calculated by Equation 7-9. The quantity of fuel used by rolling stock to process a ton of materials is represented by gall_Ton, and is derived in Appendix 5.

Equation 7-8

$$A\_rolling\_comb_p = A\_comb\_gall_p \times gall\_Ton$$

Equation 7-9

$$A\_rolling\_precomb_p = A\_precomb\_gall_p \times gall\_Ton$$

$A\_rolling\_precomb_p$: Air emission of pollutant *p* from rolling stock fuel production, pounds of pollutant/ton
$A\_comb\_gall_p$: Air emission factor for pollutant *p* in combustion of rolling stock fuel, pounds per gallon
gall_Ton: Quantity of fuel required, gallons/Ton, derived in Appendix 5
$A\_precomb\_gall_p$: Air emission of pollutant *p* during fuel production, pounds per gallon

7.2.2 Airborne Releases from Electricity used by Equipment and by Building

Airborne releases from production of electricity used in the MRF and by equipment are given by Equation 7-10.

Equation 7-10

$$A\_electric\_precomb_p = A\_precomb\_kWh_p \times (E\_building + E\_equipment)$$

$A\_electric\_precomb_p$: Emission of pollutant *p* from electricity production, pounds of pollutant/ton

$A\_precomb\_kWh_p$: Emission rate of pollutant *p* during electricity production, pounds per Btu
E_building: Energy consumed to heat and light the MRF building, Equation 7-5, Btu/ton
E_equipment: Energy consumed to operate equipment, from Equation 7-6, Btu/ton

7.3 Waterborne Release Equations

The MRF Process model uses the previously described consumption parameters gall_Ton (gallons of fuel consumed per ton processed), and E_equipment and E_building (energy consumed by equipment, and for heating and lighting building) to calculate the quantities of waterborne pollutants emitted per ton of material processed.

Release rates are calculated for the following waterborne pollutants:

- Suspended Solids
- Biochemical Oxygen Demand
- Chemical Oxygen Demand
- Ammonia
- Barium
- Silver
- Cadmium
- Arsenic
- Mercury
- Phosphate
- Selenium
- Chromium
- Lead

The MRF process model accounts for waterborne pollutant emissions associated with production of energy (electricity and fuel) consumed at the MRF. Default values for water releases from energy production are provided..

The waterborne releases for a pollutant *p* due to MRF operation are given by Equation 7-11.

Equation 7-11

$$W\_total_p = W\_fuel\_precomb_p + W\_electric\_precomb_p$$

W_total_p: Total waterborne release *p* released due to operation of a MRF, pounds of pollutant/ton
$W\_fuel\_precomb_p$: Release of pollutant *p* during production of rolling stock fuel, pounds of pollutant/ton
$W\_electric\_precomb_p$: Release of pollutant *p* during electricity production, pounds of pollutant/ton

7.3.1 Waterborne Releases from Rolling Stock Fuel Production

Waterborne releases from production of fuel are calculated using Equation 7-12. The quantity of fuel used by rolling stock to process a ton of materials in a MRF is represented by gall_ton, and is derived in Appendix 5.

Equation 7-12

$$W\_fuel\_precomb_p = W\_precomb\_gall_p \times gall\_ton$$

$W\_fuel\_precomb_p$: Release of pollutant *p* during production of rolling stock fuel, pounds of pollutant/ton
gall_ton: gallons of fuel required per ton, gallons/ton, derived in Appendix 5
$W\_precomb\_gall_p$: Precombustion release during production of fuel, pounds per gallon

7.3.2 Waterborne Releases from Electricity Production

Waterborne releases from production of electricity that is used in buildings and equipment are given by Equation 7-13.

Equation 7-13

$$W\_electric\_precomb_p = W\_precomb\_kWh_p \times (E\_building + E\_equipment)$$

$W\_electric\_precomb_p$: Water releases from production of electricity used in MRF, pounds/ton
$W\_precomb\_kWh_p$: Precombustion emission for pollutant *p* for electricity production, pounds per Btu
E_building: Energy consumed to heat and light the MRF building, Equation 7-5, Btu/ton
E_equipment: Energy consumed by equipment in MRF, Equation 7-6, Btu/ton

7.4 Solid Waste Generation Equations

The MRF Process model uses the previously described consumption parameters gall_ton (gallons of fuel consumed per ton of material processed), and E_equipment and E_building (energy consumed by equipment and for heating and lighting the MRF building) to calculate the quantities of solid waste generated per ton of material processed. Solid waste generation is expressed in terms of pounds of pollutant per ton of material processed. Note that the solid waste referred to in this section pertains to the waste generated when energy is produced. Default values for solid waste generated due to energy production are provided. Solid waste remaining after recyclables are removed (residue) is routed to a treatment or disposal facility. The LCI of residue is accounted for in these treatment and disposal facilities.

The total solid waste generated due to energy usage in a MRF is given by Equation 7-14.

Equation 7-14

$$S\_total_s = S\_fuel\_precomb_s + S\_electric\_precomb_s$$

S_total_s: Total solid waste *s* generated, due to a MRF, pounds of waste/ton
s: Type of solid waste
$S\_fuel\_precomb_s$: Solid waste *s* generated during production of rolling stock fuel, pounds of waste/ton
$S\_electric\_precomb_s$: Solid waste *s* generated during production of electricity, pounds of waste/ton

7.4.1 Solid Waste from Rolling Stock Fuel Production

Solid waste generation from production of fuel is calculated using
Equation 7-15. The quantity of fuel used by rolling stock to process a ton of material in the MRF is gall_ton, and derived in Appendix 5.

Equation 7-15

$$S\_fuel\_precomb_s = S\_precomb\_gall_s \times gall\_ton$$

$S\_fuel\_precomb_s$: Solid waste *s* generated, from production of rolling stock fuel, pounds of waste/ton
gall_ton: gallons of fuel required per ton, gallons/ton, derived in Appendix 5
$S\_precomb\_gall_s$: Precombustion generation of waste, for fuel production, pounds of waste per gallon

7.4.2 Solid Waste Generated from Production of Electricity used in MRF

Solid waste generated from production of electricity used in a MRF building and by equipment is given by Equation 7-16.

Equation 7-16

$$S\_electric\_precomb_s = S\_precomb\_kWh_s \times (E\_equipment + E\_building)$$

$S\_electric\_precomb_s$: Solid waste *s* generated during production of electricity, pounds of waste/ton
$S\_precomb\_kWh_s$: Solid waste *s* generated during production of energy, pounds per Btu
E_equipment: Energy consumed by equipment, Btu/ton
E_building: Energy consumed to heat and light the MRF building, Btu/ton

Appendix 3

Default Values for Input Data and Output Coefficient Table

Part A:User Input Data

A.1. Economic input data

Parameter description	Units	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
1. Design Options						
1.1. Bag Opening: Manual =1, Mechanical = 0, Bins = N		0		0	0	0
1.2. Aluminum Sorting: Manual =1, I		1		0	0	0
1.3. Front End MRF Sorting Option: Clean Design = 1, Dirty Design = 0						
2. Working Time						
Working Day length	hr	8.5	8.5	8.5	8.5	8.5
Breaks and stoppages time	hr/day	0.5		0.5	0.5	0.5
Second sort time	hr/day	0.5		0.5	0.5	0.5
Effective Working Day length	hr/day	7.5		7.5	7.5	7.5
Tipping floor storage	day	0.5	1	1	1	1
Number of workdays per year	day	260	260	260	260	260
3. Bag Miscellaneous data						
Bag breakage factor	%				10%	
Weight per bag	lb	8		5	5	5
4.Economic Parameters						
Life of MRF structure	year	20	20	20	20	20
Annual Interest Rate	%	5.00%	5.00%	5.00%	5.00%	5.00%
Construction rate cost	$/sq ft	55.00	55.00	55.00	55.00	55.00
Engineering rate	% of structure cost	30%	30%	30%	30%	30%
Land acquisition cost	$/acre	550.00	550.00	550.00	550.00	550.00
Equipment Installation rate	% of equipment cost	10%	10%	10%	10%	10%
5. Data for area calculation						
Land requirement	multiple of MRF floor area	5	3	3	4.5	4
Height of refuse on tipping flo	ft	10	10	10	10	10
Sort room width	ft	28		20	20	20
Area required for balers	sq ft/TPD	8	8	8	8	8
Bag opener machine loading	sq ft/TPD bag	20		20	20	20
Manual bag opening area	sq ft/TPD bag	15		15	15	15
Office area rate	sq ft/TPD	11	11	11	11	11
6. Operating and Maintenance Cost data						
Labor requirement/ capacities						
Driver and operator requireme	hr/Ton	0.32	0.24	0.32	0.32	0.32
Capacity of manual bag open	Ton/hr	4		4	4	4

Parameter description	Units	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
7. Labor wages and rates						
Labor Overhead rate	% of labor cost	40%	40%	40%	40%	40%
Management wages	% of labor wages	25%	25%	25%	25%	25%
Bag opener wage rate	$/hr	7.00		7.00	7.00	7.00
Picker wage rate	$/hr	7.00		7.00	7.00	7.00
Driver and Operator wage rat	$/hr	11.00	11.00	11.00	11.00	11.00
8. Utilities and Maintenance Cost data						
Utility cost rate	$/ ton recovered	1.50	1.50	1.50	1.50	1.50
Maintenance cost rate	$/ ton recovered	5.00	5.00	5.00	5.00	5.00
9. Equipment Cost data						
Bunker cost rate	$/bunker	30000.00	30000.00	30000.00	30000.00	30000.00
Conveyer cost rate	$/ft	1306.30		1306.30	1306.30	1306.30
Bins cost rate	$/bin	435.43	435.43	435.43	435.43	435.43
Chutes cost rate	$/chute	217.72		217.72	217.72	217.72
Rolling stock cost rate	$/TPD	925.30	762.01	762.01	762.01	762.01
Baler cost rate	$/TPD baled	1632.88	1632.88	1632.88	1632.88	1632.88
Magnet cost rate	$/TPD f	3483.47		3483.47	3483.47	3483.47
Cost of bag opener	$/TPD	1632.88		1632.88	1632.88	1632.88
Cost of eddy current separatc	$/TPD a	15555.87		15555.87	15555.87	15555.87
Trommel cost	$/TPD of recyclables			8708.68	8708.68	8708.68
10. Equipment lifetime						
Bunker life	year	15		5	5	5
Conveyer life	year	5		5	5	5
Bins life	year	5	5	5	5	5
Chutes life	year	5		5	5	5
Rolling stock life	year	10	5	5	5	5
Baler life	year	10	5	5	5	5
Magnet life	year	5		5	5	5
Bag opener life	year	5		5	5	5
Eddy current separator life	year	5		5	5	5
Trommel life	year			5	5	5
11. Data for equipment requirement						
Volume of bins used	cu ft	90	90	90	90	90
Height of bin	ft	5	5	5	5	5

12. Waste Item Specific Input Data
12.1. Sorting Efficiency (%)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value	Dirty Front End Model Value	Clean Front End Model Value
RTYL, MTYL	Yard Trimmings, Leaves							0.70
RTYO, MTYO	Yard Trimmings, Grass							0.70
	Yard Trimmings, Branches							0.70
RCCR, MCCR, CCCR	Old News Print	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Old Corr. Cardboard	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Office Paper	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Phone Books	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Books	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Old Magazines	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	3rd Class Mail	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Paper Other #1	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Paper Other #2	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Paper Other #3	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Paper Other #4	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Paper Other #5	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	CCCR Other	0.70	1.00				0.70	0.70
	Mixed Paper	0.70	1.00	0.99	0.90	0.99	0.70	0.70
RCNR, MCNR, CCNR	HDPE - Translucent	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	HDPE - Pigmented	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	PET	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Plastic - Other #1	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Plastic - Other #2	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Plastic - Other #3	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Plastic - Other #4	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Plastic - Other #5	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Mixed Plastic	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	CCNR Other	0.70	1.00				0.70	0.70
RNNR, MNNR, CNNR	Ferrous Cans	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Ferrous Metal - Other	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Aluminum Cans	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Aluminum - Other #1	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Aluminum - Other #2	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Glass - Clear	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Glass - Brown	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Glass - Green	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	Mixed Glass	0.70	1.00	0.99	0.90	0.99	0.70	0.70
	CNNR Other	0.70	1.00				0.70	0.70
RCCN, MCCN, CCCN	Paper - Non-recyclable							0.70
	Food Waste							0.70
	CCCN Other							0.70
RCNN, MCNN, CCNN	Plastic - Non-Recyclable							0.70
	Miscellaneous							0.70
	CCNN Other							0.70
RNNN, MNNN, CNNN	Ferrous - Non-recyclable							0.70
	Al - Non-recyclable							0.70
	Glass - Non-recyclable							0.70
	Miscellaneous							0.70
	CNNN Other							0.70

12.2. Picker Rate (Ton/picker-hr)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value	Dirty Front End Model Value	Clean Front End Model Value
RTYL, MTYL	Yard Trimmings, Leaves							0.250
RTYO, MTYO	Yard Trimmings, Grass							0.250
	Yard Trimmings, Branches							0.250
RCCR, MCCR, CCCR	Old News Print	0.250		No sorting	No sorting	No sorting	0.250	0.250
	Old Corr. Cardboard	0.250		0.750	0.100	0.100	0.250	0.250
	Office Paper	0.250		0.750	0.750	0.750	0.250	0.250
	Phone Books	0.250		0.750	0.750	0.750	0.250	0.250
	Books	0.250		0.750	0.750	0.750	0.250	0.250
	Old Magazines	0.250		0.750	0.750	0.750	0.250	0.250
	3rd Class Mail	0.250		0.750	0.750	0.750	0.250	0.250
	Paper Other #1	0.250		0.750	0.750	0.750	0.250	0.250
	Paper Other #2	0.250		0.750	0.750	0.750	0.250	0.250
	Paper Other #3	0.250		0.750	0.750	0.750	0.250	0.250
	Paper Other #4	0.250		0.750	0.750	0.750	0.250	0.250
	Paper Other #5	0.250		0.750	0.750	0.750	0.250	0.250
	CCCR Other	0.025					0.025	0.025
	Mixed Paper	0.500		0.750	0.750	0.750	0.500	0.500
RCNR, MCNR, CCNR	HDPE - Translucent	0.025		0.060	0.060	0.060	0.025	0.025
	HDPE - Pigmented	0.040		0.100	0.100	0.100	0.040	0.040
	PET	0.025		0.060	0.060	0.060	0.025	0.025
	Plastic - Other #1	0.025		0.060	0.060	0.060	0.025	0.025
	Plastic - Other #2	0.025		0.060	0.060	0.060	0.025	0.025
	Plastic - Other #3	0.025		0.060	0.060	0.060	0.025	0.025
	Plastic - Other #4	0.025		0.060	0.060	0.060	0.025	0.025
	Plastic - Other #5	0.025		0.060	0.060	0.060	0.025	0.025
	Mixed Plastic	0.025		0.060	0.060	0.060	0.025	0.025
	CCNR Other	0.025					0.025	0.025
RNNR, MNNR, CNNR	Ferrous Cans	Magnet		Magnet	Magnet	Magnet	Magnet	Magnet
	Ferrous Metal - Other	Magnet		Magnet	Magnet	Magnet	Magnet	Magnet
	Aluminum Cans	0.010		0.025	0.025	0.025	0.010	0.010
	Aluminum - Other #1	0.010		0.025	0.025	0.025	0.010	0.010
	Aluminum - Other #2	0.010		0.025	0.025	0.025	0.010	0.010
	Glass - Clear	0.150		0.250	0.250	0.250	0.150	0.150
	Glass - Brown	0.100		0.150	0.150	0.150	0.100	0.100
	Glass - Green	0.025		0.050	0.050	0.050	0.025	0.025
	Mixed Glass	0.025		0.050	0.050	0.050	0.025	0.025
	CNNR Other	0.025					0.025	0.025
RCCN, MCCN, CCCN	Paper - Non-recyclable							0.250
	Food Waste							0.250
	CCCN Other							0.250
RCNN, MCNN, CCNN	Plastic - Non-Recyclable							0.250
	Miscellaneous							0.250
	CCNN Other							0.250
RNNN, MNNN, CNNN	Ferrous - Non-recyclable							0.250
	Al - Non-recyclable							0.250
	Glass - Non-recyclable							0.250
	Miscellaneous							0.250
	CNNN Other							0.250

12.3. Density in a Bin (lb/cu ft)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value	Dirty Front End Model Value	Clean Front End Model Value
RTYL, MTYL	Yard Trimmings, Leaves							5.00
RTYO, MTYO	Yard Trimmings, Grass							5.00
	Yard Trimmings, Branches							5.00
RCCR, MCCR, CCCR	Old News Print	5.00		6.19	6.19	6.19	5.00	5.00
	Old Corr. Cardboard	5.00		1.87	1.87	1.87	5.00	5.00
	Office Paper	5.00		3.50	3.50	3.50	5.00	5.00
	Phone Books	5.00		3.50	3.50	3.50	5.00	5.00
	Books	5.00		3.50	3.50	3.50	5.00	5.00
	Old Magazines	5.00		3.50	3.50	3.50	5.00	5.00
	3rd Class Mail	5.00		3.50	3.50	3.50	5.00	5.00
	Paper Other #1	5.00		3.50	3.50	3.50	5.00	5.00
	Paper Other #2	5.00		3.50	3.50	3.50	5.00	5.00
	Paper Other #3	5.00		3.50	3.50	3.50	5.00	5.00
	Paper Other #4	5.00		3.50	3.50	3.50	5.00	5.00
	Paper Other #5	5.00		3.50	3.50	3.50	5.00	5.00
	CCCR Other	2.37					2.37	2.37
	Mixed Paper	5.00		2.37	2.37	2.37	5.00	5.00
RCNR, MCNR, CCNR	HDPE - Translucent	2.37		2.37	2.37	2.37	2.37	2.37
	HDPE - Pigmented	2.37		2.37	2.37	2.37	2.37	2.37
	PET	2.37		2.37	2.37	2.37	2.37	2.37
	Plastic - Other #1	2.37		2.37	2.37	2.37	2.37	2.37
	Plastic - Other #2	2.37		2.37	2.37	2.37	2.37	2.37
	Plastic - Other #3	2.37		2.37	2.37	2.37	2.37	2.37
	Plastic - Other #4	2.37		2.37	2.37	2.37	2.37	2.37
	Plastic - Other #5	2.37		2.37	2.37	2.37	2.37	2.37
	Mixed Plastic	2.37		2.37	2.37	2.37	2.37	2.37
	CCNR Other	2.37					2.37	2.37
RNNR, MNNR, CNNR	Ferrous Cans	4.90		4.90	4.90	4.90	4.90	4.90
	Ferrous Metal - Other	4.90		4.90	4.90	4.90	4.90	4.90
	Aluminum Cans	2.36		2.36	2.36	2.36	2.36	2.36
	Aluminum - Other #1	2.36		2.36	2.36	2.36	2.36	2.36
	Aluminum - Other #2	2.36		2.36	2.36	2.36	2.36	2.36
	Glass - Clear	14.00	14.00	14.00	14.00	14.00	14.00	14.00
	Glass - Brown	14.00	14.00	14.00	14.00	14.00	14.00	14.00
	Glass - Green	14.00	14.00	14.00	14.00	14.00	14.00	14.00
	Mixed Glass	14.00	14.00	14.00	14.00	14.00	14.00	14.00
	CNNR Other	2.37					2.37	2.37
RCCN, MCCN, CCCN	Paper - Non-recyclable							5.00
	Food Waste							5.00
	CCCN Other							5.00
RCNN, MCNN, CCNN	Plastic - Non-Recyclable							5.00
	Miscellaneous							5.00
	CCNN Other							5.00
RNNN, MNNN, CNNN	Ferrous - Non-recyclable							5.00
	Al - Non-recyclable							5.00
	Glass - Non-recyclable							5.00
	Miscellaneous							5.00
	CNNN Other							5.00

12.4. Weight of a Bale (Ton)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
RTYL, MTYL	Yard Trimmings, Leaves					
RTYO, MTYO	Yard Trimmings, Grass					
	Yard Trimmings, Branches					
RCCR, MCCR, CCCR	Old News Print	0.60	0.68	0.68	0.68	0.68
	Old Corr. Cardboard	0.60	0.88	0.88	0.88	0.88
	Office Paper	0.60	0.73	0.73	0.73	0.73
	Phone Books	0.60	0.73	0.73	0.73	0.73
	Books	0.60	0.60	0.73	0.73	0.73
	Old Magazines	0.60	0.73	0.73	0.73	0.73
	3rd Class Mail	0.60	0.73	0.73	0.73	0.73
	Paper Other #1	0.60	0.73	0.73	0.73	0.73
	Paper Other #2	0.60	0.60	0.73	0.73	0.73
	Paper Other #3	0.60	0.60	0.73	0.73	0.73
	Paper Other #4	0.60	0.73	0.73	0.73	0.73
	Paper Other #5	0.60	0.73	0.73	0.73	0.73
	CCCR Other	0.59	0.59			
	Mixed Paper	0.60	0.60	0.60	0.60	0.60
RCNR, MCNR, CCNR	HDPE - Translucent	0.59	0.59	0.59	0.59	0.59
	HDPE - Pigmented	0.59	0.59	0.59	0.59	0.59
	PET	0.59	0.59	0.59	0.59	0.59
	Plastic - Other #1	0.59	0.59	0.59	0.59	0.59
	Plastic - Other #2	0.59	0.59	0.59	0.59	0.59
	Plastic - Other #3	0.59	0.59	0.59	0.59	0.59
	Plastic - Other #4	0.59	0.59	0.59	0.59	0.59
	Plastic - Other #5	0.59	0.59	0.59	0.59	0.59
	Mixed Plastic	0.59	0.59	0.59	0.59	0.59
	CCNR Other	0.59	0.59			
RNNR, MNNR, CNNR	Ferrous Cans	0.95	0.95	0.95	0.95	0.95
	Ferrous Metal - Other	0.95	0.95	0.95	0.95	0.95
	Aluminum Cans	0.95	0.95	0.95	0.95	0.95
	Aluminum - Other #1	0.95	0.95	0.95	0.95	0.95
	Aluminum - Other #2	0.95	0.95	0.95	0.95	0.95
	Glass - Clear	0.50	0.50	0.50	0.50	0.50
	Glass - Brown	0.50	0.50	0.50	0.50	0.50
	Glass - Green	0.50	0.50	0.50	0.50	0.50
	Mixed Glass	0.50	0.50	0.50	0.50	0.50
	CNNR Other	0.59	0.95			
RCCN, MCCN, CCCN	Paper - Non-recyclable					
	Food Waste					
	CCCN Other					
RCNN, MCNN, CCNN	Plastic - Non-Recyclable					
	Miscellaneous					
	CCNN Other					
RNNN, MNNN, CNNN	Ferrous - Non-recyclable					
	Al - Non-recyclable					
	Glass - Non-recyclable					
	Miscellaneous					
	CNNN Other					

12.5. Market prices of recyclable material ($/Ton)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
RTYL, MTYL	Yard Trimmings, Leaves					
RTYO, MTYO	Yard Trimmings, Grass					
	Yard Trimmings, Branches					
RCCR, MCCR, CCCR	Old News Print	23.00	23.00	23.00	23.00	23.00
	Old Corr. Cardboard	66.00	66.00	66.00	66.00	66.00
	Office Paper	76.00	76.00	76.00	76.00	76.00
	Phone Books	79.00	79.00	79.00	79.00	79.00
	Books	79.00	79.00	79.00	79.00	79.00
	Old Magazines	79.00	79.00	79.00	79.00	79.00
	3rd Class Mail	79.00	79.00	79.00	79.00	79.00
	Paper Other #1	79.00	79.00	79.00	79.00	79.00
	Paper Other #2	79.00	79.00	79.00	79.00	79.00
	Paper Other #3	79.00	79.00	79.00	79.00	79.00
	Paper Other #4	79.00	79.00	79.00	79.00	79.00
	Paper Other #5	79.00	79.00	79.00	79.00	79.00
	CCCR Other	79.00	79.00			
	Mixed Paper	79.00	79.00	79.00	79.00	79.00
RCNR, MCNR, CCNR	HDPE - Translucent	21.00	21.00	21.00	21.00	21.00
	HDPE - Pigmented	14.00	14.00	14.00	14.00	14.00
	PET	6.00	6.00	6.00	6.00	6.00
	Plastic - Other #1	6.00	6.00	6.00	6.00	6.00
	Plastic - Other #2	6.00	6.00	6.00	6.00	6.00
	Plastic - Other #3	6.00	6.00	6.00	6.00	6.00
	Plastic - Other #4	6.00	6.00	6.00	6.00	6.00
	Plastic - Other #5	6.00	6.00	6.00	6.00	6.00
	Mixed Plastic	2.00	2.00	2.00	2.00	2.00
	CCNR Other	2.00	2.00			
RNNR, MNNR, CNNR	Ferrous Cans	91.00	91.00	91.00	91.00	91.00
	Ferrous Metal - Other	91.00	91.00	91.00	91.00	91.00
	Aluminum Cans	1180.00	1180.00	1180.00	1180.00	1180.00
	Aluminum - Other #1	1180.00	1180.00	1180.00	1180.00	1180.00
	Aluminum - Other #2	1180.00	1180.00	1180.00	1180.00	1180.00
	Glass - Clear	42.00	42.00	42.00	42.00	42.00
	Glass - Brown	22.00	22.00	22.00	22.00	22.00
	Glass - Green	15.00	15.00	15.00	15.00	15.00
	Mixed Glass	15.00	15.00	15.00	15.00	15.00
	CNNR Other	15.00	15.00			
RCCN, MCCN, CCCN	Paper - Non-recyclable					
	Food Waste					
	CCCN Other					
RCNN, MCNN, CCNN	Plastic - Non-Recyclable					
	Miscellaneous					
	CCNN Other					
RNNN, MNNN, CNNN	Ferrous - Non-recyclable					
	Al - Non-recyclable					
	Glass - Non-recyclable					
	Miscellaneous					
	CNNN Other					

12.6. Constants

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
Number of days of storage for bales	day	1	1	1	1	1
Distance between pickers	foot	4				
Pickers on both sides of conveyer belt? (Yes = 2)	pickers	2				
Redundancy factor for conveyer	(dimensionless)	2				
Maneuverability Factors	(dimensionless)	2.5	2.5	2.5	4	4
Footprint of bales	sq ft	20	20	20	20	20
Stacked bales (one on top of the other)	(dimensionless)	3	3	3	3	3

A.2. Life Cycle Inventory input data						
SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value
1. Energy consumption						
Rolling Stock	gallons/Ton	0.347	0.347	0.347	0.347	0.347
Warehouse type areas	kWH/year-sq ft	14.03	14.03	14.03	14.03	14.03
Office type areas	kWH/year-sq ft	34	34	34	34	34
Conveyer	kWH/Ton	0.8		0.8	0.8	0.8
Magnet	kWH/Ton ferrous	5	5	5	5	5
Eddy current separator	kWH/Ton aluminum	8	8	8	8	8
Balers	kWH/Ton	12	12	12	12	12
Mechanical bag opener	kWH/Ton	8	8	8	8	8
Trommel	kWH/Ton	1.03	1.03	1.03	1.03	1.03
2. Airborne releases						
From Rolling Stock fuel usage						
Carbon monoxide	lbs/gallon	0.0986	0.0986	0.0986	0.0986	0.0986
Nitrogen oxides	lbs/gallon	0.1545	0.1545	0.1545	0.1545	0.1545
Particulates (PM10)	lbs/gallon	0	0	0	0	0
Total particulates	lbs/gallon	0.0164	0.0164	0.0164	0.0164	0.0164
Carbon dioxide (biomass	lbs/gallon	23.005	23.005	23.005	23.005	0
Carbon dioxide (non-biom	lbs/gallon	0	0	0	0	0
Sulfur oxides	lbs/gallon	0.0122	0.0122	0.0122	0.0122	0.0122
Hydrocarbons (except me	lbs/gallon	0.0245	0.0245	0.0245	0.0245	0.0245
Methane	lbs/gallon	0	0	0	0	0
Lead	lbs/gallon	0	0	0	0	0
Ammonia	lbs/gallon	0	0	0	0	0
Hydrochloric acid	lbs/gallon	0	0	0	0	0

33. Final Cost Coefficients ($ per year/Ton per year)

SET NAME	DESCRIPTION	Mixed Waste S1 Model Value	Presorted Recyclables S2 Model Value	Commingled Recyclables S3 Model Value	Bags in 1 compartment S4 Model Value	Bags in 2 compartments S5 Model Value	Dirty Front End Model Value	Clean Front End Model Value
RTYL, MTYL	Yard Trimmings, Leaves	13.51			14.60	14.60	13.51	48.73
RTYO, MTYO	Yard Trimmings, Grass	13.51			14.60	14.60	13.51	48.73
	Yard Trimmings, Branches	13.51			14.60	14.60	13.51	48.73
RCCR, MCCR, CCCR	Old News Print	56.60	15.28	18.73	19.45	19.67	56.60	49.55
	Old Corr. Cardboard	56.60	16.55	39.99	157.84	171.68	56.60	49.46
	Office Paper	56.34	15.24	38.69	37.58	39.61	56.60	49.52
	Phone Books	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	Books	56.60	15.35	38.69	37.58	39.61	56.60	49.60
	Old Magazines	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	3rd Class Mail	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	Paper Other #1	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	Paper Other #2	56.60	15.35	38.69	37.58	39.61	56.60	49.60
	Paper Other #3	56.60	15.35	38.69	37.58	39.61	56.60	49.60
	Paper Other #4	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	Paper Other #5	56.60	15.24	38.69	37.58	39.61	56.60	49.52
	CCCR Other	412.03	15.36		=		412.03	366.62
	Mixed Paper	36.85	15.35	38.80	37.73	39.78	36.85	31.99
RCNR, MCNR, CCNR	HDPE - Translucent	412.03	27.19	280.59	265.73	288.68	412.03	366.62
	HDPE - Pigmented	263.94	27.19	180.61	174.83	188.70	263.94	234.53
	PET	412.03	22.22	275.62	257.78	280.73	412.03	366.62
	Plastic - Other #1	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	Plastic - Other #2	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	Plastic - Other #3	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	Plastic - Other #4	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	Plastic - Other #5	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	Mixed Plastic	412.03	20.73	274.13	255.39	278.35	412.03	366.62
	CCNR Other	412.03	20.73				412.03	366.62
RNNR, MNNR, CNNR	Ferrous Cans	32.58	16.52	61.20	59.28	62.88	32.58	14.22
	Ferrous Metal - Other	32.58	14.93	59.61	56.74	60.34	32.58	14.22
	Aluminum Cans	909.76	18.51	548.28	503.46	551.16	909.76	894.81
	Aluminum - Other #1	1004.24	15.28	554.38	506.77	555.32	1004.24	894.81
	Aluminum - Other #2	1004.24	15.28	554.38	506.77	555.32	1004.24	894.81
	Glass - Clear	78.10	14.43	108.57	100.98	109.02	78.10	72.21
	Glass - Brown	109.10	14.43	141.53	130.94	141.98	109.10	101.56
	Glass - Green	388.17	14.43	306.34	280.77	306.79	388.17	365.74
	Mixed Glass	388.17	14.43	306.34	280.77	306.79	388.17	365.74
	CNNR Other	412.03	16.52				411.59	366.18
RCCN, MCCN, CCCN	Paper - Non-recyclable	15.61			24.71	12.90	15.61	48.73
	Food Waste	13.51			24.35	12.90	13.51	48.73
	CCCN Other	13.51					13.51	48.73
RCNN, MCNN, CCNN	Plastic - Non-Recyclable	13.51			33.29	12.90	13.51	48.73
	Miscellaneous	13.51			28.09	12.90	13.51	48.73
	CCNN Other	13.51					13.51	48.73
RNNN, MNNN, CNNN	Ferrous - Non-recyclable	13.51			24.39	12.66	13.51	48.73
	Al - Non-recyclable	13.51			24.95	12.90	13.51	48.73
	Glass - Non-recyclable	13.51			24.95	12.90	13.51	48.73
	Miscellaneous	13.51			25.34	12.90	13.51	48.73
	CNNN Other	13.51					13.51	48.73

Appendix 4

Derivation of Construction Cost for MRF Structure

DERIVATION OF AN APPROXIMATE ENGINEERING COST ESTIMATE FOR CONSTRUCTION OF A 200 TPD MRF

An approximate engineering cost estimate was done to calculate the 'per sq ft' cost of a 200 Ton per Day Materials Recovery Facility.
The '$/sq ft' estimate will be used to calculate the capital cost of constructing a MRF with known area required for processing and storing recyclable

Construction cost of a 200 TPD MRF

ITEM	$/unit		# units	Cost	Remarks
1. Sitework	4.5	per sq. ft	45000	202,500	based on floor area of MRF
2. Fencing	12	per ft	3000	36,000	assuming 200' long sides and 50' wide roads
3. Landscaping		LS		25,000	
4. Formwork & r/f					
..expansion joints	2.5	per ft	1500	3,750	
..braces	8.7	each	50	435	
..barchairs	285	per 1000 ft	43000	12,255	
r/f for footings	1200	per ton	2	1,800	
5. Concrete					
..slab	50	per cu. yd	1593	79,630	floor area of MRF x 1 yd. thick slab
..footings	190	per cu. yd	50	9,500	
..floor hardner	0.8	per sq. ft	43000	34,400	equal to floor area
..loading docks	100	per cu. yd	75	7,500	
..curing	15	per 100 cu. y	1718	258	
6. Roof & siding including framew	11	per sq. ft floo	43000	473,000	based on floor area
7. Metal fabrications					
..stairs	200	per riser	40	8,000	two flights of 20 steps each
..railing	25	per ft.	300	7,500	sort room 70' long, 30 ' wide
..steel deck	5	per sq. ft	800	4,000	along sort room, and walkway to sort room
..doors	5000	each	6	30,000	two unloading and four loading doors
8. Electrical	5	per sq. ft	43000	215,000	
9. Offices & sorting room	25	per sq. ft	4000	100,000	
10. Pavement	10	per sq. yd	13333	133,333	about 30' wide, and all along sides of MRF
11. Storage area netting	2	per sq. yd	167	333	
12. Scale house	20000	LS	1	20,000	
13. Painting	0.5	per sq. ft	64000	32,000	40' high walls, 200' long, both sides, four walls, etc.,
14. Fire protection		LS		8,000	
15. Security gates	2500	LS	2	5,000	
			TOTAL	***$1,449,194***	
			Cost ($/sq ft)	**$34**	

DERIVATION OF AN APPROXIMATE ENGINEERING COST ESTIMATE FOR CONSTRUCTION OF A 600 TPD MRF

An approximate engineering cost estimate was done to calculate the 'per sq ft' cost of a 600 Ton per Day Materials Recovery Facility.
The '$/sq ft' estimate will be used to calculate the capital cost of constructing a MRF with known area required for processing and storing recyclables

Construction Cost of a 600 TPD MRF

ITEM	$/unit			# units	Cost	Remarks
1. Sitework	4.5	per	sq. ft	72000	324,000	based on floor area of MRF
2. Fencing	12	per	ft	5000	60,000	assuming 50' wide roads
3. Landscaping			LS		50,000	
4. Formwork & r/f						
..expansion joints	2.5	per	ft	2000	5,000	
..braces	8.7		each	70	609	
..barchairs	285	per	1000 ft	72000	20,520	
r/f for footings	1200	per	ton	3	3,600	
5. Concrete						
..slab	50	per	cu. yd	2667	133,333	floor area of MRF x 1 yd. thick slab
..footings	190	per	cu. yd	70	13,300	
..floor hardner	0.8	per	sq. ft	72000	57,600	equal to floor area
..loading docks	100	per	cu. yd	120	12,000	
..curing	15	per	100 cu. y	2857	429	
6. Roof & siding	10	per	sq. ft floo	75000	750,000	based on floor area
7. Metal fabrications						
..stairs	200	per	riser	25	5,000	two flights of 20 steps each
..railing	25	per	ft.	650	16,250	sort room 160' long, 30 ' wide
..steel deck	5	per	sq. ft	450	2,250	along sort room, and walkway to sort room
..doors	5000		each	10	50,000	two unloading and four loading doors
9. Electrical	5	per	sq. ft	72000	360,000	
10. Offices & sortin	25	per	sq. ft	10000	250,000	
11. Pavement	10	per	sq. yd	38889	388,889	about 30' wide, and all along sides of MRF
12. Storage area nett	1.2	per	sq. yd	1000	1,200	
13. Scale house		LS		15000	15,000	
14. Painting	0.5	per	sq. ft	100000	50,000	40' high walls, both sides, four walls, etc.,
15. Fire protection		LS			20,000	
16. Security gates			each	2	5000	
				TOTAL	2,593,980	
				Cost ($/sq ft) =	**36**	

Appendix 5

Derivation of Cost, Energy, and Area Requirement for MRF Structure, and Equipment

The MRF process model equations calculate the cost, energy, environmental emissions, and area occupied by equipment used in MRFs. These equations use default input data that a user can override. The spreadsheets and assumptions used to derive the default values for the area requirement, cost, energy, and environmental factors are included in Appendix 5.

Note: Since capital cost is amortized over the lifetime of the equipment or structure, an equipment's "capital cost contribution" to the annual cost of a MRF (Annualized capital cost + Operating cost) is not significant. Thus, small errors in estimation of capital cost factors are not anticipated to have a major impact on the overall cost of the MRF.

TROMMEL COST AND ENERGY REQUIREMENT

A trommel is used to remove grit and broken glass from recyclables before they enter the sorting room. A factor that is developed in the following calculations for the cost, area, and energy requirement for trommels. The factor is derived from a linear regression of data for 3 MRF sizes.

TROMMEL AREA, COST, AND ENERGY REQUIREMENT

Assuming one shift per day.

TPD of commingled recyclables	Cost of Trommel ($)	Cost ($/TPD)	kW	kW/Ton	
8	31000	3875	2	0.25	
40	41000	1025	3	0.075	
80	46000	575	5	0.0625	
			Average =	0.129	kW/Ton

TPD: Tons Per Day of commingled recyclables processed

Default Values for Trommel Area, Cost, and Energy Requirement

The default value for cost of a trommel is: **3000 $/TPD**

The default value for power rating of a trommel at 8 hr/day **0.129 kWh/Ton**

References:

1. Communication with Michael McLemore, Central Manufacturing, Inc. Peoria, IL 61656

AREA REQUIRED FOR OFFICE IN A MRF

An estimate of the office area required a MRF is calculated from the following tables. These estimates are used in the linear optimization model to calc
the area for a MRF of known size. To estimate the factors, MRFs of sizes 50, 100, and 200 TPD are used that process a typical recyclables compositi

OFFICE AREA FACTOR

Office area in a MRF is the area required for the front office, the employee rest area, and the management rest area.
Assume one 8 hour shift

Office area = Front office area (A1) + Employee rest area (A2) + Management area (A3)

		A1		A2		A3			
TPD	Tons Processed	Front office (sq ft)		Employee rest area (sq ft)		Management rest area (sq ft)		Total area (sq ft)	Sq ft/TPD
50	50	15 x 10 =	150	20 x 20 =	400	10 x 10 =	100	650	13
100	100	15 x 15 =	225	25 x 25 =	625	15 x 15 =	225	1075	10.75
200	200	20 x 25 =	500	25 x 30 =	750	20 x 15 =	300	1550	7.75

Default Value

The default value for office area requirement in a MRF is: **11 sq ft/TPD**

BALER COST, AREA, AND ENERGY REQUIREMENT

Estimates of the cost, area, and energy requirement of balers used in a MRF are calculated in the following tables.
These estimates are used in the linear optimization model to calculate the cost, area, and energy required for balers in a MRF of known size.
To estimate the factors, 3 commingled recyclables MRFs, processing a typical mix of recyclables, of sizes 50, 100, and 200 TPD are used.
The estimate is a linear regression of the 3 values.

Recyclables Composition Assumed

Item	Weight %
ONP	50
FCAN	8
ACAN	7
GCLR	18
GBRN	10
PET	4
HDPE	3
	100

All costs are in $1993

Assuming an 8 hour shift, 1 shift per day

Baler Cost and Baler Area

Facility Size (TPD)	Tons baled	Cost of Balers ($)	Area for Baler (sq ft)		$/TPD baled	sq ft/TPD baled	HP of Baler	HP/Ton baled
50								
ONP: dedicated horizontal ba	25	30000	10 x 15 =	150			50	
Other recyclables	11	20000	10 x 15 =	150			50	
	36	50000		300	1388.9	8.3		2.8
100								
ONP: dedicated horizontal ba	50	50000	20 x 20 =	400			75	
Other recyclables	22	30000	10 x 15 =	150			50	
	72	80000		550	1111.1	7.6		1.7
200								
ONP: dedicated horizontal ba	100	165000	30 x 30=	900			150	
Other recyclables	44	50000	20 x 20=	400			100	
	144	215000		1300	1493.1	9.0		1.7

TPD   Tons per day
HP   Horsepower

Note:
1. The area for baler includes the floor area occupied by the baler. It does not include area for access by machinery and employees.
Access area is estimated by a maneuverability factor.
2. Cost of the baler includes the hopper, and attachments to connect the baler to the conveyer system.
3. A commingled recylables MRF is used to derive these default values, and it is assumed that the same balers and their cost functions will apply to other types of MRFs.

Default Values

The default value for the cost of a baler in a MRF is:	**$ 1500/TPD baled**
The default value for baler area is:	**8 sq ft/TPD baled**
The default value for power requirement of a baler is:	**2 HP/Ton baled**
Using 8 hours/day as operating time,	**i.e., 12 kWh/Ton baled**

References:

1. Product literature and communication with Service Representatives at Harris Waste Management Group, Inc.
2. Communication with Darrel Thompson, Plant Superintendent of Material Recovery, City of Highpoint, NC
3. Handbook for Materials Recovery Facilities for Municipal Solid Waste, Handbook, 9/1991, USEPA, EPA/625/6-91/031

COST AND ENERGY REQUIREMENT OF A FERROUS METAL MAGNET AND AN EDDY CURRENT SEPARATOR

Estimates of the cost and energy requirement of magnets and eddy current separators used in a MRF are obtained from the following calculations. These estimates are used in the linear optimization model to calculate the cost and energy required for operating these equipment in a MRF of known size. To calcula these factors, a commingled recyclables MRFs of sizes 50, 100, and 200 TPD are used that process a typical recyclables composition.

FERROUS MAGNET

A magnet is used to recover Ferrous cans from recyclables and mixed waste in a MRF.
Assuming 1 shift of 8 hours per day

TPD	Hours/day	Tons ferrous*	Cost of Magnet ($)	Cost Rate ($/TPD ferrous)	kW rating	kWh/Ton ferrous metal
50	8	4	15000	3750	3	6.00
100	8	8	25000	3125	5	5.00
200	8	16	35000	2188	10	5.00

TPD Tons per day of recyclables processed

* Note: It is assumed that ferrous cans are 8% by weight of the commingled recyclables.

Default Value for Cost of a Magnet

The default value for the cost of a magnet used in a MRF to recover ferrous cans is: **3200 $/TPD ferrous metal**
The default value for the power rating of a magnet used in a MRF to recover ferrous cans is: **5 kWh/Ton ferrous metal**

References:

1. Product literature and communication with Service Representatives, EIREZ Magnetic, Erie, PA 16154

EDDY CURRENT SEPARATOR

An eddy current separator is used to recover aluminum from mixed recyclables or mixed waste.

TPD	Hours/day	Ton aluminum*	Cost of Separator ($)	Cost Rate ($/TPD aluminum	kW rating	kWh/Ton aluminum
50	8	3.5	50000	14286	3	6.9
100	8	7	100000	14286	7	8.0
200	8	14	200000	14286	15	8.6

TPD Tons per day of recyclables processed

* Note: It is assumed that aluminum cans are 7% by weight of the commingled recyclables.

Default Value for Cost of an Eddy Current Separator

The default value for the cost of a separator used in a MRF to recover aluminum cans is: **14290 $/TPD aluminum metal**
The default value for the power rating of a separator used to recover aluminum cans is: **8 kWh/Ton aluminum metal**

References:

1. Product literature and communication with Service Representatives, EIREZ Magnetic, Erie, PA 16154

ROLLING STOCK - COST, AND FUEL REQUIREMENT

Estimates of the rolling stock cost, fuel consumption, and emission factors are calculated from the following tables.
These estimates are used in calculating cost, fuel consumed, and air emissions from rolling stock in a MRF of known size.

ROLLING STOCK - COST

The cost of rolling stock used to transport and move recyclables in a MRF.

TPD	Tons processed	Equipment	Cost ($)	Cost Rate ($/TPD)
50	50	1 FEL	35000	700
100	100	2 FEL	60000	600
200	200	1 FEL, 1 FL	100000	500

TPD Tons per day of recyclables processed
FEL Front End Loader
FL Fork Lift

Default Value for Cost of Rolling Stock
The default value for the cost of rolling stock used in a MRF is: **700 $/TPD**

References:

1. Integrated Solid Waste Management, Engineering Principles and Management Issues, Tchobanoglous, G., Theisen, H, Vigil, S., McGraw Hill Inc., 1993

FUEL AND POWER REQUIREMENT FOR ROLLING STOCK IN A MRF

		FUEL			POWER (kW)			
TPD	**Tons processed**	**FEL**	**FL**	**gall/ hr-TPD**	**FEL**	**FL**	**kW/ Ton**	**Vehicle Type**
50	50	2.5		0.05	58		1.16	910F
100	100	2.5	2.5	0.05	58	60	1.18	910F & IT12F
200	200	3.5	2.5	0.03	65	65	0.65	928F & IT12F

Average gall/ hr-TPD = 0.043 **kW/ Ton = 0.997**
Assuming an operating time of 8 hours per day, Fuel Requireme **0.347** **gall/Ton**

References

1. Caterpillar Performance Handbook, 25th Anniversary Edition
2. 1993 BobCatalog, Special Buyers Guide to Bobcat Compact Equipment

EMISSIONS FROM ROLLING STOCK IN A MRF

Units: lb/kW-hr

Vehicle	**HC**			**Total HC**	**CO**	**NOx**	**PM -Ave**	**Aldehyde**	**SOx**
	Exhaust	Crankcase	Refueling						
Forklift	0.0026	0.00005	0.000005	0.0026	0.010	0.023	0.002159	0.0003	0.0015
Skid Steer Loade	0.0034	0.00007	0.000005	0.0035	0.015	0.016	0.001962	0.0003	0.0015
			Average Values (lb/kW-hr) =	**0.0031**	**0.0124**	**0.0194**	**0.0021**	**0.0003**	**0.0015**

Rolling Stock Emissions

Pollutant	**lb/kW-hr**	**Hours of operation**	**requirement (kW/ton)**	**Emission (lb/Ton)**
HC	0.0031	8	0.997	**0.0245**
CO	0.0124	8	0.997	**0.0986**
NOx	0.0194	8	0.997	**0.1545**
PM	0.0021	8	0.997	**0.0164**
Aldehyde	0.0003	8	0.997	**0.0027**
SOx	0.0015	8	0.997	**0.0122**

References

1. Nonroad Engine and Vehicle Emission Study - Appendixes, Office of Air and Radiation, (ANR-443), 21A-2001, November 1991, USEPA.

COST AND AREA REQUIRED FOR MECHANICAL BAG OPENERS

Estimates of the area required for the loading area in a MRF, the cost and energy consumption of a mechanical bag opener are developed in the following calc
MRFs processing 25, 50, and 100 TPD are used to calculate these factors. The factors are used in a linear optimization program.
The mechanical bag opener used as the default in the model consists of alternating rows of tines (pointed projecting part or spike) moving at different speeds t
bags moving on a conveyer, [6]. The spikes rip the bag open and the bag's contents are deposited on a conveyer.

MECHANICAL BAG OPENING

Area required for Loading

Area

Total loading area = Conveyer area from tipping floor to bag opener (A1) + Bag Opener area (A2) + Conveyer from Bag opening area into sorting room (A3)

TPD of bags	Area A1 (sq ft)		Area A2 (sq ft)		Area A3 (sq ft)		Total area (sq ft)	Sq ft/TPD
25	10 x 5 =	50	20 x 4 =	80	27 x 20 =	540	670	26.8
50	15 x 5 =	75	20 x 4 =	80	30 x 20 =	600	755	15.1
100	25 x 5 =	125	20 x 4 =	80	35 x 20 =	700	905	9.05

TPD Tons per day

Cost of Mechanical Bag Openers

Tons of bags	Cost of Bag Opener ($)	Cost per TPD_bag ($/Ton)
25	95000	3800
50	110000	2200
100	150000	1500

Default Values:

The default value for bag opening area in a MRF is: **20 sq ft/TPD of bags**

The default value for cost of bag opener is: **1500 $/TPD of bags**

References:

1. Communication with Jud Crowe, Business Development, Resource Recovery Group, RADER Companies, Memphis, TN 38181

Energy requirement

'ons of bag	HP	HP/Ton	kW/Ton	
25	40	1.6	1.19	Rader Companies
50	75	1.5	1.12	Rader Companies
100	100	1.0	0.75	Rader Companies
160	8	0.1	0.04	Earth Force

Default Value:

The default value for the power rating of a bag opener for 8 hr/day **8 kW/Ton of bags**

References:

1. Product Information and Communication with Business Development Department, Resource Recovery Group, RADER Companies, Memphis, TN 38181