Design of a Materials Recovery Facility (MRF) For Processing the Recyclable Materials of New York City's Municipal Solid Waste

by

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EXECUTIVE SUMMARY

The closure of Freshkills Landfill in Staten Island at the end of 2001 has forced the City of New York to seek alternative methods of waste management. To begin its waste diversion, the city has resorted to exporting a portion of its waste to other states. The high costs associated with waste exportation along with dramatic increases in disposal tipping fees in recent years has compelled New York City to explore potential alternative waste management options. Increased recycling provides an attractive option since it eliminates some disposal requirements with the additional benefits of reducing pollution, conserving energy, creating jobs and building more competitive manufacturing industries. In addition, through the utilization of a well-designed materials recovery facility and collection system, recycling can be a very economical waste management opportunity.

A materials recovery facility (MRF) is a place where solid wastes are delivered to be separated, processed and stored for later use as raw materials for remanufacturing and reprocessing. In the summer of 1999, the Bureau of Waste Prevention, Reuse and Recycling of the Department of Sanitation (DOS) sponsored an investigation of the technical and economic aspects of a single, city-owned MRF. The study, described in this report, examined the design and operation of a 150 tons per hour (876,000 tons per year) facility that could handle all of New York City's recyclables. The operations within the MRF are designed to be as automated as possible to increase speed of operation, reduce costs and improve recovery. The proposed MRF would be a more cost-effective alternative compared to the currently utilized waste management system. The MRF would require approximately 16 acres of land and cost approximately \$127 per ton of diverted material. This would correspond to nearly \$46 million of savings for the city in waste management costs annually.

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1. Introduction

The scheduled closure of Freshkills Landfill in Staten Island at the end of 2001 is forcing the City of New York to explore alternative waste management options to begin overcoming its primary reliance on landfilling for waste disposal. The Department of Sanitation currently collects approximately 13,000 tons of municipal solid waste (MSW) each day from about 8 million residents and non-profit institutions. To begin the transition from solely disposing wastes at Freshkills Landfill, a considerable portion of the waste generated in the Bronx borough is being delivered to transfer stations for exportation to Virginia. The exportation of wastes is a very expensive waste management practice (costing about $80 per ton) and additional exportation appears to be inevitable unless changes are made in the current waste management system. The increased restrictions and costs on disposal options and the community opposition to the transport and landfilling of New York City's waste provides motivation to explore other potentially more cost-effective and environmentally acceptable waste management activities.

Today's MSW management systems are highly integrated and include various options in materials collection, materials recovery, composting, combustion and landfilling. A thorough examination of a waste management system should consider factors from the point of waste collection to final disposal. One waste management option involves increasing recycling within the city and thereby decreasing the city's overall disposal needs. By transforming waste materials into useable resources, recycling represents a method of managing solid waste while reducing pollution, conserving energy, creating jobs and building more competitive manufacturing industries. However, attempts to expand the New York City recycling program in the past have been plagued with opposition, participation and operation problems. In the early 1990's, the city had plans for a $125 million project to build five city-owned facilities in each of the five boroughs. The city-owned facilities would have benefited the city by eliminating the high costs associated with the need to ship materials at greater distances to obtain better prices from private contractors. In addition, the inclusion of modern separation technologies could lower operating costs and improve the quality of processed material, decreasing the overall waste management costs of the city. The first facility was planned to be built in Staten Island, but was challenged by the private recycling contractors who had additional capacity to process New York City's residential wastes. Due to the strong opposition from the industry, environmentalists and budget administrators, the plan was eventually abandoned.

With the ongoing increase in solid waste disposal and transportation costs, there is now a greater incentive than ever before to alter the current waste management systems in New York City and develop more cost effective systems. In the past, when landfill tipping fees were low, recycling was not economically feasible as a waste management practice. However, between 1985 and 1992, the national average landfill tipping fee increased by more than 500 percent in the northeastern region of the United States.[1] With tipping fees increasing dramatically and an increased reliance on expensive and contentious waste exportation, recycling has become a very economical and proven approach to waste management.

The objective of this document is to examine the issues associated with the design and operation of a materials recovery facility for the City of New York. This includes analyzing available separation and recovery technologies, designing the ideal system layout, and estimating the costs and siting requirements for the proposed facility.

2. Materials Recovery Facilities

A materials recovery facility (MRF) accepts materials, whether source separated or mixed, and separates, processes and stores them for later use as raw materials for remanufacturing and reprocessing. The main function of the MRF is to maximize the quantity of recyclables processed, while producing materials that will generate the highest possible revenues in the market. MRFs can also function to process wastes into a feedstock for biological conversion or into a fuel source for the production of energy. Although these waste management options of chemical transformation of wastes through combustion in conjunction with energy recovery and biological transformation in the form of aerobic and anaerobic composting are viable and proven technologies, they are not considered in this study. This paper focuses exclusively on designing the MRF for resource recovery by means of mechanical materials separation.

The stages involved in designing a MRF system to process commingled recyclables include:

1. Conceptual design
2. Evaluation of the markets and economics of operation
3. Development and gathering of data necessary for the design
4. Detailed engineering design of system
5. Siting design
6. Procurement of equipment
7. Construction
8. Processing of materials
9. Marketing

2.1. Collection

The collection system for the recyclables that are delivered to the MRF plays a significant role in determining the facility design. The building layout and equipment must be designed to accommodate the processing, movement and storage of the collected materials with safe external access and internal flow. The manner by which wastes are collected will have considerable effect on the costs and resource utilization of the MRF. Collection options for residential refuse and recyclables include:[2]

1. Mixed refuse collection: Collection of mixed refuse in a single compartment truck with no source separation of recyclables.
2. Recyclables collection: Collection of commingled recyclables in a vehicle with two compartments or separate vehicles (one compartment of vehicle is used for all paper materials and the other for non-paper materials).
3. Co-collection: Collection of mixed refuse and recyclables in different colored bags for transport in a single or separate compartment vehicles.
4. Wet/dry collection: Wet/dry collection with either recyclables included or collected separately. Wet materials, which include yard trimmings, food scraps, disposable diapers, soiled paper and animal waste, are composted.

The proposed New York City MRF will be designed to accommodate the current collection system and will therefore process source separated commingled recyclables that are collected either weekly or BI-weekly. Recyclable materials are divided into two co-collected streams with green bags containing paper recyclables and blue bags containing metal, glass and plastic (MGP) recyclables as shown in Table 1.

Table 1: Source Separated Materials for Recycling

Green Bags (Paper)	Blue Bags (MGP)
• Magazines and Catalogs • Kraft • Old Corrugated Cardboard (OCC) • Other Cardboard (boxes, tubes, smooth, egg cartons) • Office Paper • Computer Paper • Newspaper • Phone Books • Envelopes • Other Mixed Paper	• Beverage Cartons • Household Metals • HDPE • PET • Glass Jars and Bottles • Metal Cans • Aluminum Foil/Trays • Other Metal (hangers, empty aerosol)

Although, this study does not discuss altering the current collection system in New York City, the overall cost effectiveness of any waste management system predominantly depends on the optimization of collection. Collection costs represent the most expensive component (usually about half the costs) of a typical waste management system. One reason for the magnitude of collection costs is that the cost of collecting materials is volume-based while market prices are weight-based. It is therefore very difficult to collect materials with low bulk densities such as plastics in a cost-effective manner. Compaction increases the amount of material collected by each vehicle and therefore improves the economics of collection, but simultaneously increases the amount of broken glass that both contaminates other collected materials and complicates future separation at the MRF. Compaction is utilized in current collection vehicles in New York City.

By collecting all wastes together, higher volumes of materials can be taken from the solid waste stream, collection vehicles can be simplified, and collection times and costs are reduced. A well-engineered MRF will still produce marketable materials from a mixed waste (refuse and recyclables) stream. For example, the city of Los Angeles has reported that citywide collection of recyclables has increased 140 percent with single-stream collection over the two-stream collection the city had previously utilized. In addition, the switch in collection scheme reduced collection costs for the city by about 25 percent.[3]

2.2. Market Specifications

Ultimately, for a recycling program to be successful, stable and reliable markets for the targeted recyclables must be identified and established since unsold materials will require temporary storage and may ultimately need to be landfilled. The market of a particular material depends on both the cost of recovering the raw materials and the quality of the recycled materials from the MRF in comparison to the costs and quality associated with extracting virgin raw materials from the natural environment. Collection and processing are both very expensive and without stable and dependable markets, materials should not be targeted for recycling. Once the targeted materials of a recycling program are selected, the market specifications for each of these materials must be identified to determine the properties of the unit separation operations. Some sample market specifications are shown in Table 2.[4]

A common problem in the quality of many recovered materials is contamination by broken glass. Broken glass mixes into cartons, plastic containers, cans and other targeted products, which lowers the product quality and therefore the product value. Due to the problematic effects of glass contamination, the proposed MRF will be designed to minimize glass breakage within each unit operation and during transport.

2.3. Mechanical Vs. Manual Operations

Another significant issue in the operation of the MRF is the choice between mechanical or manual separation techniques. Older, traditional MRFs rely heavily on manual sorting, which is both very expensive and time consuming when handling large volumes of materials. Labor represents one of the highest cost components of the MRF. The annual personnel cost for just five sorters is equivalent to roughly the amortized cost of a million dollars worth of capital equipment (over 20 years at 10 percent interest). There are trade-offs between operating and capital costs when considering whether to employ manual or mechanical separation processes. Despite these trade-offs, because of the high nature of labor costs, most long-term cost analyses will typically show that automated processing is more cost effective than manual processing.

Table 2: Sample Market Specifications

Material	Market Specification
Paper	• Separated by grade • Baled (size and weight specified) or loose • Dry or including some wet • Clean or some degree of contamination
Ferrous Containers	• Flattened, unflattened or shredded • Labels removed or not removed • Clean or with a degree of contamination • Including bimetal or no bimetal • Loose, baled or densified (weight and size specified)
Aluminum Containers	• Flattened, shredded, baled or densified • Free of moisture, dirt, foil, lead, glass, etc.
Plastic Containers	• Baled, granulated or loose • Separated by color or type or mixed • With or without caps
Glass	• Separated by color or mixed • Size of cullet (specified) • Degree of contamination

Manual sorting can potentially produce higher quality material recovery, but is inefficient because of relatively low processing rates (Table 3). Manual sorting also yields more rejected materials and misses a considerable portion of the HDPE and PET plastics in the New York City waste stream due to the inability to target certain container shapes. If a plastic resin cannot be distinguished with the naked eye, it cannot be efficiently manually sorted and will therefore not be targeted.[5] It is extremely difficult for a sorter to distinguish between PVC and PET plastics, but these resins can be separated quickly and accurately using automated systems.

Table 3: Manual Sorting Rates and Efficiencies[6]

Material	Unit Density (containers/ton)	Sorting Rate (containers/ hour/person)	Sorting Rate (tons/hour/ person)	Recovery Efficiency (%)
Newspaper	-	-	0.75 - 5	60 – 95
Corrugated	-	-	0.75 - 5	60 – 95
Glass (mixed)	3,000 - 6,000	1,800 - 3,600	0.45 - 0.9	70 – 95
Glass (by color)	3,000 - 6,000	900 - 1,800	0.45 - 0.9	80 – 95
Plastic (PET, HDPE)	9,000 - 18,000	1,800 - 3,600	0.15 - 0.3	80 – 95
Aluminum (from plastic)	45,000 - 54,000	1,800 - 3,600	0.05 - 0.06	80 – 95

In comparison to manual sorting, automated sorting has lower labor costs, greater material recovery and faster processing rates as shown in Table 4. Automation also has the advantages of reducing the health and safety risks that result from workers handling wastes directly. Furthermore, machines can usually be adjusted to target new materials by just adding new sensors, and can consequently take more from the waste stream as new markets develop.[7] This is important for accommodating expansions in the NYC recycling program that increase both the volume and range of recyclable material that need to be processed.

Table 4: Automated Sorting Rates and Efficiencies[8]

System	Targeted Materials	Sorting Rate (tons/hr)	Removal efficiency (%)
Glass Separation (MSS ColorSort)	3/8" to 2" Clear, Brown, Green, Blue, and Yellow glass	5	> 95
Plastic Separation (MSS BottleSort)	PVC, Clear PET, Colored PET, Natural HDPE, Mixed Color HDPE, PP, and PS (up to 7 colors)	2.5	99 - PVC 90 - other resins
Paper Separation (MSS PaperSort)	Mixed Office Paper	2.2	80

Carton Separation (MSS CartonSort)	Cartons	1.5 - 3	90

Most of the private MRFs that the city currently employs are extremely manually intensive, making the materials recovery very costly. New York City must therefore pay contractors to accept its wastes. The proposed MRF for New York City will be as automated as possible to increase speed of operation, reduce costs and improve quality. Currently, it is not feasible to have a fully automated MRF, since there are certain automated unit operations that are not well proven and may still be unreliable. For example, there are available automated paper sorting technologies, but manual sorting remains the most reliable way to ensure quality separation. It is important to provide flexibility within the MRF to eventually allow automated technologies to replace manual operations and be integrated into the operation system.

2.4. Tipping Floor

When materials are brought into the facility, they are deposited in a large recessed area called the tipping floor. The tipping floor will be designed to accommodate extra materials for the second operational shift and for at least two days of the expected volume of materials. The floor will be designed to handle heavy weight, withstand the wear of pushing materials and provide efficient drainage for liquids.

The unloading of the materials from the collection vehicles onto the tipping floor must be efficient yet protect the materials. Traditionally, tipping floors utilize front-end loaders to move the deposited material onto conveyors that rise up to the separation systems. This approach renders the tipping floor one of the most inefficient components of the MRF since dropping and moving the materials on the floor requires additional equipment and causes large amounts of glass breakage.[9] Because of glass breakage on the tipping floor, many facilities around the country can only recover mixed glass. In 1998, about 96 percent of the glass recovered by New York City vendors was mixed cullet, which currently has no market value and requires expensive disposal.[10]

One potential solution to this problem of glass contamination that will be utilized in the proposed MRF is to deposit materials directly onto a sunken belt conveyor. The sunken conveyor system benefits the MRF in a number of ways. The continuous movement of the discharged material by the conveyors eliminates the need for the vehicles to pull forward when unloading, lowering the facility's area requirements. In addition, front-end loaders will not be needed to constantly manipulate and route the materials on the floor, which will reduce both congestion and the contamination from broken glass.

Walls are situated on the sides of the conveyor to keep the materials from falling off. The materials will be delivered in trucks containing either green or blue bags. The vehicles will back into respective unloading areas, and deposit the contents of their trucks into chutes that will transport the materials to the conveyor system with minimal breakage. If the facility eventually decides to process mixed wastes in addition to the commingled recyclables, the conveyor system can be adjusted along with the system configuration.[11]

3. Waste Characterization

Before the unit operations and equipment to process the recyclables can be identified and selected, it is necessary to perform an analysis of the city's waste stream to determine the type, relative quantity and origin of each incoming material. A thorough mass and materials balance of the MSW will determine the amount of each material the facility must process and store as well as the amount of residue that will need to be managed. The appropriate equipment sizing and the relative size of the facility will also depend on the quantity and composition of materials brought to the facility. Table 5 shows the waste composition of New York City from 1990 as well as the composition of the collected recyclables in 1998.

The most recent thorough waste characterization for New York City was completed in 1990. Although the waste composition has undoubtedly changed over the last decade, this waste characterization will be more useful than more recent characterizations from other cities since factors such as state bottle bills and local culture make the NYC waste composition unique.

4. Unit Processing Operations

The separation, processing and transformation of the commingled recyclables into useful materials is accomplished through various unit operations within the facility. The purpose of the unit operations is to use the physical or chemical characteristics of the recyclable materials to separate each targeted material. Once the targeted material is removed from the stream, it can be further processed depending on its subsequent use. The unit operations that comprise the system need to be selected based on:

1. The materials to recover and the quality desired
2. The inputs and outputs of each subsystem
3. The distinguishing characteristics of the desired products

Table 5: City-Wide Residential Waste and Recyclable Composition[12] [13]

Waste Component	Total 1990* (tons/day)	Percent of Total (%)	Average Monthly Collection 1998 (tons/day)	Materials Delivered to All Vendors 1998 (tons/day)	Materials Delivered to All Vendors 1998 (tons/year)
TOTAL PAPER	3,028	30.6	1,219.3	1,040.6	379,819
Corrugated Cardboard	454.7	4.6	265.7	226.4	82,636
Newspaper	890.0	9.0	797.0	682.2	249,003
Office/Computer Paper	77.4	0.8	-	-	
Magazines/Glossy Paper	261.2	2.6	-	-	
Books	77.4	0.8	-	-	
Non-Corrugated Cardboard	241.8	2.4	-	-	
Mixed Paper	1,035.1	10.4	79.9	68.6	25,039
Commercial Mixed Paper	1,344.7	13.6	-	-	
Unsold Paper	-	-	76.7	63.4	23,141
TOTAL PLASTICS	861.0	8.7	49.7	39.9	14,564
Clear HDPE containers	48.4	0.5	32.9	26.5	9,673
Colored HDPE	77.4	0.8	-	-	
LDPE	9.7	0.1	-	-	
Film	464.4	4.7	1.1	0.9	329
Green PET	9.7	0.1	-	-	
Clear PET	38.7	0.4	15.4	12.4	4,526
PVC	9.7	0.1	0.2	0.1	37
PP	9.7	0.1	0.1	0.05	18
PS	77.4	0.8	-		
Rigid Containers	193.5	2.0	-		
Misc.	125.8	1.3	-		

TOTAL ORGANICS	3,627.7	36.6	-		
Grass	328.9	3.3	-		
Brush	67.7	0.7	-		
Total Yard Waste	406.3	4.1	-		
Lumber	212.8	2.1	-		
Textiles	454.7	4.6	-		
Rubber	19.3	0.2	-		
Fines	222.5	2.2	-		
Diapers	328.9	3.3	-		
Food Wastes	1,228.6	12.4	-		
Misc.	754.6	7.6	-		
Commercial Grade Misc.	1,538.2	15.5	-		
TOTAL GLASS	483.6	4.9	323.5	256.9	93,769
Clear Glass	280.5	2.8	8.3	6.6	2,409
Green Glass	96.7	1.0	8.3	3.5	1,278
Brown Glass	87.1	0.9	1.5	1.3	475
Misc.	19.3	0.2	305.4	245.5	89,608
TOTAL ALUMINUM	87.1	0.9	5.6	4.6	1,679
TOTAL METAL	377.3	3.8	181.4	143.5	52,378
TOTAL INORGANICS (ceramics, BI-metals)	222.5	2.2	-	-	
TOTAL HAZARDOUS (paints, batteries, etc.)	38.7	0.4	-	-	
TOTAL BULK	957.7	9.7	-	-	
Residue and Unsold	-	-	320.9	260.5	95,083
OTHER WASTES	222.5	2.2	3.1	2.5	913
TOTAL MATERIALS	99,06.2	100	2,130.5	1,748.5	638,203

The unit operations will encompass as much proven equipment as possible that is both durable and has a validated and documented history. Common parts such as standardized belt widths, motor sizes, and other mechanical and electrical components will reduce the spare parts inventory required and simplify maintenance.[14]

4.1. The Conveyor System

Conveyor lines are used to transport materials to and from mechanical equipment within the MRF. In addition, flat belt conveyors will be used at the sorting stations since they permit easy access to the materials on the belts. Belt conveyors will be the most common types of conveyor utilized in the facility since they can effectively transport materials up steep inclines and are extremely versatile. Belt conveyors function through the continuous movement of a belt around two drums (Figure 1). The elevated drum rotor contains the motor, which serves to keep the motor as clean as possible. The belt moves along a supporting plate, and walls along the side of the conveyor are used to keep materials from falling off the belt. Screws will be used on the initial inclined conveyors to break the blue and green plastic bags that contain the recyclable materials. Flights will be necessary on other steeply inclined conveyors to prevent materials from sliding back.

The height of the flights and the angle, width and speed of the conveyor are all parameters that will be adjusted to provide the most efficient transport of the materials at various locations in the facility. The conveyors will be designed to handle the specific materials that they will encounter. Thus, the sunken conveyors that initially accept the waste will be designed differently than conveyors that are only transporting a specific material. Sensors and computers will automatically control the speed of each conveyor to adjust the depths of the feed and adapt to manual sorting rates. The conveyors will be durable, self-cleaning and designed to handle heavy loads so that the system will be able to process any type of waste composition.[15] Conveyors were the main problem encountered in a field study on processing mixed waste in New York City conducted in May of 1998.[16] The conveyors failed because they could not handle the heavy loads that are characteristic of mixed wastes.

4.2. Ferrous Metals Separation

Magnetic separation will be the first separation technology utilized in the MRF. Magnetic separation is a well-proven and established technology and is an obvious component of every MRF, whether manually or mechanically intensive. Magnetic separation removes the ferrous metals from the other commingled recyclables based on the attraction between ferrous metals and the magnet. This attraction exists due to the magnetic dipole properties of ferrous materials, which form a net magnetic field when exposed to an external magnetic field.

The ferrous separation employs an overhead self-cleaning electromagnet that uses an electric current that runs through a coiled wire to generate the magnetic field (Figure 2). The most important aspect of the technology is selecting the strength of the magnetic field so that the magnetic force can overcome the weight of the material and lift it from the stream. The necessary magnetic strength therefore depends on both the weight of the material and the distance of the material from the magnet. Gravity and the gap between the magnet and the conveyor keep other materials out of the product stream. The ferrous materials do not actually hit the magnet, rather they are directed to a bin by a conveyor with flights that runs along the magnet. In order to utilize the entire magnet, the feed conveyor is located directly under the magnet. The rate of extraction will be used to determine the optimal speed of the conveyor to achieve the highest efficiency possible.[17] Once the ferrous materials are separated, they can be either shredded or baled depending on market specifications.

4.3. Screening

Screening is employed to separate materials of different sizes into two or more size distributions. Screens will function to separate oversized and undersized materials as a pre-processing technique for other unit operations within the facility. The types of screens used in the MRF will be disc screens and trommels.

Disc screens are flat screens that consist of an array of disks that spin on shafts (Figure 3). Disc screens move the materials across the screen by means of the disc rotation, which allows materials to be fed directly onto the screen. This feature makes the disc screen less likely to cause glass breakage compared to other screens. The disc screen also offers adjustability in opening size and can be self-cleaning. Disc screens are most effective when the fine material to be removed is denser than the larger materials; the larger materials are relatively rounded and will not prevent passage of the fines to the screen; and when breakage could be a problem.

Trommels are rotating cylindrical screens that are inclined at a downward angle with the horizontal (Figure 4). Material is fed into the trommel at the elevated end and the separation occurs while the material moves down the drum. The tumbling action of the trommel effectively separates materials that may be attached to each other. Length, angle and diameter of the drum, depth of the material and the speed of rotation are important specifications in configuring the trommel to accomplish the desired goals. If necessary, the trommel can have flights that function to carry the materials to a higher location within the drum at lower rotational velocity.

The facility will use the longest possible trommel operating at the greatest possible angle to increase the amount of material the screen can process. Two-stage trommels will be used to first remove small items along the initial length of the cylinder and then separate larger items over the remaining length of the cylinder.[18]

4.4. Air Classification

Air classification is utilized to separate light materials from heavier materials through the use of an air stream of sufficient velocity to carry away the lighter materials. A vertical zig zag air classifier with a rotating drum feeder will be used in the proposed MRF to separate aluminum, cartons and plastics from glass (Figure 5). The feeder system uses a stationary drum with rotating blades that act as airlock valves and a vertical feed hopper to deposit material into the drum. The airlock valves allow the feeding system to take place in a confined space, providing good energy efficiency. The vertical zig zag configuration has been shown to enhance separation as a result of the pulsing of materials in and out of the air stream that flows up the throat of the classifier, but at the expense of increased jamming. A cyclone separator is used in conjunction with the air classifier to remove the lighter separated fraction from the air stream after it exits the classifier throat. The cyclone separator uses a centrifugal action that results from the airflow through the cyclone to move the materials to the walls of the separator. The materials then slide down the walls to the exit.

A potential theoretical replacement for the zig zag air classifier in the future is the active pulse-flow air classifier (APFAC; Figure 6). The APFAC has a straight throat to reduce the possibility of jamming and has the advantages of pulsed airflow. Pulsing air is blown into the throat from below the feeder, which prevents bridging of materials that could constrict the throat of the classifier. A rotary airlock valve is installed near the bottom of the throat to minimize the pressure drop that may occur at the exit where the heavier materials are directed. Laboratory evaluations have shown the APFAC producing peak efficiencies of 95 percent. However, the APFAC has not been used in industry and will need initial research and development to ensure that it functions according to theory.[19]

Another air classification system that will be used in the proposed MRF is the air knife. The air knife will be used to extract aluminum cans from mixed aluminum feed after an eddy current separates the non-ferrous materials. The air knife separates materials by passing the feed through an air blower that pushes the light materials farther than the heavier materials.

4.5. Non-ferrous Metal Separation

Eddy current separation removes non-ferrous metals based on conductivity, and is a well-proven and established technology for resource recovery. Although there are a number of different configurations, a design type known as the Rotating Disk Separator will be used in the proposed facility. The Rotating Disk Separator involves the materials “free falling” between parallel rotating magnetic disks, which are composed of permanent magnetic plates (Figure 7). The opposing magnetic fields create high magnetic fluxes that generate electrical currents within the non-ferrous metals. The electrical (eddy) currents in the non-ferrous materials cause them to be deflected when faced by an opposing magnetic field. The conductivity of the metal determines the strength of the eddy current that can be produced. Since aluminum has a low density relative to its conductivity, it is easily extracted using eddy current separation.[20]

This technology can potentially be used to separate a wide range of additional metals that have value such as lead, copper, silver, gold and titanium. However, the only non-ferrous metal that is targeted by the New York City recycling program is aluminum. Aluminum is the most common non-ferrous metal in municipal solid waste, accounting for about 90 percent of all non-ferrous metals. If other non-ferrous metals are targeted in the future, the system could be adjusted with additional separation processes such as flotation to further separate among these metals. The removal of lead for example would be environmentally beneficial before disposal.

4.6. “Detect and Route” Systems

Detect and route (DAR) systems will be used to separate glass, plastic and cartons within the proposed MRF. In a DAR system, the properties of the material are first identified with detectors. The information from the sensors concerning the identification and location of the material is stored. Using the identification of the object, the location of the object and the speed of the conveyor, the system removes the object when it reaches an appropriate diversion point. The object is diverted to a specific bin by air jets that are aligned along one wall of the conveyor. If heavier objects need to be sorted in the future, a positive action device such as a ram or tilt plate can be used rather than air jets to remove the object.[21]

The type of detection system and detectors to be used will depend on the targeted materials. A computer is needed for the system to receive and analyze the information from all the sensors. The computer can compare the information from the sensors against tables of values to identify the material. The system will operate at the maximum speed that does not compromise performance. The computer should be as fast as possible and should be upgradable. The system's software should also be flexible enough to allow it to be reconfigured for changes in system operation.

Since DAR systems depend on sensors focusing on each object from the material stream, it is important that the objects pass the detectors individually. Thus, the conveyor system needs to spread out the feed so that materials enter the DAR system one by one. Material clusters cannot be sorted accurately by automated systems. A properly sized steeply inclined flight conveyor will cause the feed to be one object thick by allowing all but one object to slide over the flight. Bars above the belt conveyors can also help to spread out the feed, but may cause jamming problems.

Contaminants will greatly reduce the capacity and effectiveness of a DAR system. For example, before glass is sent to the glass sorting system, screens and air classifiers will be utilized to remove labels and caps. This was a significant problem with the performance failure of the automated optical glass sorting system used by NECRINC in Rhode Island.[22] Likewise, glass and other contaminants need to be removed from the plastic stream before the automated sorting begins.

One major concern of DAR systems is what to do about objects composed of multiple materials since they may contain multiple attributes that are being identified by the detectors. These materials may initially need to be rejected completely. Another concern is the high capital cost associated with the various automated systems. These capital costs are offset by the reduction in labor costs. The systems become very cost-effective when large amounts of recyclables are processed, as is the case with the waste stream of New York City.

There are a number of companies that have developed and manufactured automated separation systems for the recycling industry. One such company, Magnetic Separation Systems (MSS) based in Nashville, TN, will be highlighted in this paper. MSS has worked with automated sorting systems for over 22 years and is responsible for installing the first eddy current system in operation. Systems from MSS have been installed in the U.S., Australia, Canada, Germany, France, Japan, Korea, Switzerland and Taiwan.[23] Options for automated separation systems are not limited to those discussed in this paper.

4.6.1. Glass Separation

Glass poses a major disposal problem in New York City. Once glass is crushed it is essentially impossible to sort manually by color. Crushed glass also contaminates other recycled materials such as cartons and plastics, lowering their quality and market value. Although markets for recovered glass are stable for brown and clear glass, these markets specify very low contamination. The domestic demand for green glass is low due to its infrequent use domestically. Most MRFs manually sort glass with clear flint being negatively sorted. These MRFs often lose money on the processing of glass because the market value does not justify the collection, labor, transportation and disposal costs.

The proposed MRF will utilize a MSS DAR system to sort glass by color. The glass feed will be pre-processed with a trommel and an air classifier to remove non-glass materials. Light spectrophotometry will be used to distinguish among the different colors of glass so that they can be identified and separated. Specifically, the detection system will be based on the transmission of visible light at certain wavelengths to distinguish between clear, brown and green glass. If a mixed waste stream is eventually processed at the MRF, a method to distinguish ceramics and other opaque materials will be necessary. The removal of ceramics is important since the glass market is extremely sensitive to ceramic contamination. It is important to maximize integrity retention of the glass to both reduce contamination of other materials and to aid the DAR system. The system will also allow mixed glass recycling in addition to recycling by individual color if a good market is eventually available to avoid the expensive disposal costs of the rejected mixed cullet.

4.6.2. Plastic Separation

The city targets plastics by container type rather than code since it is inefficient to manually inspect every container for its code. Furthermore, it is unrealistic to instruct residents to manually inspect every container they use and recycle according to the coding system. Only blow-molded plastic containers, which are containers with necks that are thinner than the container bodies, are collected. Although blow-molded plastic containers account for about 99 percent of PET and 86 percent of HDPE containers, all other container shapes are missed, so separation by dimensions is inefficient.

PVC has been a particularly significant impediment to PET recycling. PET and PVC can sometimes be impossible to separate with the human eye and their separation is critical. When PET contaminated with PVC is melted, hydrochloric acid is formed, which corrodes the metal parts of the processing machines. As little as 50 ppm of PVC can contaminate an entire load of PET and result in the load being unmarketable. Furthermore, the increasing number of plastic resins that can potentially be marketed at high value have made DAR systems for plastics very cost-effective.

The proposed MRF will use an automated DAR system for plastics, which will greatly improve recovery and allow all plastics to be put into the system in the future. The detection system will use infrared spectrum transmission from a combination of four wavelengths to distinguish among unpigmented plastics. Pigmented plastics can also be separated using special cameras in conjunction with the infrared sensors. The color sorting system uses cross checking between the resin sensor and the color sensor. For example, if the resin identification sensor classifies a container as opaque HDPE, and the color identification system classifies the container as blue, the identification would be compared to a logic table, which would determine that the container was blue HDPE.[24] In this way, color separation of pigmented HDPE and PET can occur for any possible color. The MRF will use a system from MSS called BottleSort that is used in 30 operations worldwide and uses infrared transmitters and sensors that take thousands of surface measurements per bottle. The machine then identifies the material and activates an air ejection system to direct the materials to the appropriate conveyors. Once the system is fine tuned, identification accuracies close to 100 percent are obtainable.[25]

4.6.3. Paper and Carton Separation

An automated DAR carton sorting system will be used in the proposed MRF to separate cartons from the mixed plastics. However, the technology for automated paper separation is not well proven or established currently in the industry. Consequently, a trommel and manual paper separation will be used in the proposed MRF.

There are a number of DAR systems for paper that are currently being developed. MSS has developed a DAR system called PaperSort, which is the first high-speed automated optical sorting system for recycled paper. Compared to manual paper sorting, the system is much faster and increases the quality of recovered material. The system first uses mechanical techniques to reduce the depth of the feed to a uniform single layer. The stream of paper is then sent to reflective sensors that identify the optical properties of the paper. The information about the type, size and position of the paper are used to activate appropriate air nozzles to automatically remove the paper from the conveyor. The PaperSort system is designed to handle mixed office paper and is still under testing by MSS for mixed household paper streams. A full-scale system is in use at Weyerhaeuser's recycling plant in Baltimore and has proven successful in initial tests. [26] [27]

Another experimental paper sorting system is the General Kinematics Corporation's Finger Screen. The system allows the mixed paper to flow over a series of tapered, slotted finger elements that successfully screen the paper without jamming. This system has the advantage over the traditionally used trommel in that it does not "fluff" the paper. The volume of the paper stream is thereby reduced so that the system can handle a greater amount of material.[28]

4.7. Size Reduction

Size reduction is the unit operation for mechanically reducing the size of materials. Size reduction is carried out through shredding, grinding and milling. Since the effectiveness of many unit operations within the facility depends on keeping the materials as large as possible, size reduction will only be utilized after all separation is accomplished.

The main size reduction equipment that will be used in the proposed MRF will be shredders and glass crushers. The shredders will be used for large items that are initially removed from the waste stream and for organic material that is brought to the facility if the MRF were to accept mixed waste. The size-reduced product is reasonably uniform and has greater surface area to volume ratios, which increases decomposition. The increased surface area also increases air exposure, reducing odors and promoting dryness. The choice of shredder will depend on the material to be shredded, the amount of energy required, the size changes needed and the benefits of those size changes.[29] Glass crushers in the form of hammer mills will be used to reduce storage space and shipping costs for the separated glass.

4.8. Compactors and Balers

Compaction will be utilized to increase the density of the recovered materials so that the materials can be stored and transported with the highest cost efficiency through the maximization of volume in each load. The level and method of compaction will be determined by market specifications since different markets want to receive materials baled, shredded or loose. The balers are automated in that they sense when a certain pressure is reached from the material compaction and stop compacting accordingly. The degree of compaction will depend on a number of cost factors and will be adjusted to the most cost-effective level. The cost factors include the incremental compaction per additional energy cost, the transportation costs, the fate of the compacted material and the availability of storage space. Since the facility will handle high-volumes of material, automatic tying devices will be installed on each baler to wrap and tie the materials with wire or steel strap, keeping the materials compacted. There will be a baler for each material to improve efficiency by not having to either stop processing or clean the balers.[30]

5. MRF Equipment and Layout

Once the unit operations to process the materials are selected, the equipment needed to carry out the operations must be chosen and installed. The capabilities, reliability, maintenance requirements, flexibility, safety, efficiency, environmental effects, market specifications, and costs of the various alternatives will govern the selection of equipment for the facility.

Although there are many possible combinations for grouping the separation processes within the facility, the operations should follow certain guidelines:

1. Pathways should be as straight as possible
2. The system should be designed to encounter changes in the feed stream
3. Conveyance and free fall to move material should be maximized
4. The adjustability of the system should be maximized
5. The independence of devices should be maximized

These guidelines allow the entire operation to continue functioning if there are any equipment failures or unexpected materials in the stream. Equipment redundancy and easy maintenance are other factors that will help prevent the need to ever shut down operations, but will add to the overall costs of the facility.

5.1. MRF Operations

Trucks filled with the collected recyclable materials from New York City will travel to the MRF, weigh in at the scale house, and dump green (paper) and blue (MGP) bags onto sunken conveyors in separate locations. Front loaders will be required in case the material must be deposited on the tipping floor.

5.1.1. Paper Stream

The green bags (paper) are deposited on an inclined conveyor that is lined with screws.

The screws serve the dual purpose of carrying the material up the incline and breaking the bags. At the first sorting station, non-recyclable materials are removed from the paper stream. Once the contaminants that can interfere with the subsequent unit operations are removed, the paper stream is directed along the conveyor to a trommel. The trommel will allow large materials (overs) such as newspaper and corrugated paper to pass through, while smaller mixed paper (unders) fall through the screen openings. The trommel can be adjusted to remove contaminants that are even smaller than the mixed paper if necessary. The trommel must be monitored so that very large sections of corrugated paper do not jam the cylinder. The two streams of material from the trommel are then conveyed to manual sorters.

The "overs" stream from the trommel (large paper items) are directed to a sorting conveyor where old corrugated cardboard (OCC), mixed paper, magazines and kraft are manually removed and placed into appropriate containers. Since newspaper is generally the largest quantity item, it is negatively sorted. The exact method and extent of separation will depend on the requirements of the paper vendors. The "unders" from the trommel (smaller paper items) are conveyed to a different group of manual sorters who will sort mail, ledger, and other grades of paper depending on available markets. Once the storage bunkers for the different paper materials are filled, they are emptied through a door at the bottom of the bins. Conveyors then move each paper material to a baler, which compresses and ties the paper with wire into cubes. Forklifts will be used to load the bales of paper onto tractor-trailers for shipment.

5.1.2. Metals, Glass, and Plastics (MGP) Stream

The blue bags (MGP) system is much more complicated than the paper separation system. The delivered blue bags are loaded onto a sunken conveyor that is lined with screws which breaks the bags and carries the material up to an elevated sorting station. Non-recyclable materials such as wood and white goods are removed manually from the conveyor and sent directly to shredders and compactors for disposal. The remaining recyclables continue on the conveyor until they reach a powerful electromagnet for ferrous separation. Steel cans and other ferrous metal are removed and dropped into a container, where depending on the market specifications, they can be flattened or shredded before they are baled. The remaining material travels to a disc screen with 2-inch holes, which removes dirt, broken glass, and other small materials from the feed stream. The material that passes through the screen can be sent for disposal or sent to a trommel to separate a mixed glass product. The materials that pass over the screen are sent to an air classifier that separates the heavy materials (glass) from the lighter materials (aluminum, plastic, and cartons).

The glass stream is sent to a smaller trommel that is used in conjunction with an air stream to remove caps and labels from the mixed glass. The glass is then sent to an optical sorting machine that will separate it into green, brown and clear categories. The separated glass is crushed into cullet and directed to containers. Once the containers holding the cullet are full, they are emptied onto conveyors that lead directly to trucks.

The lighter materials from the air classifier are sent to an eddy current separator, which propels the aluminum away from the non-metal containers and directs them to a conveyor that leads to an air knife. The air knife separates the aluminum cans from the aluminum foil and directs each stream to a corresponding bin for compaction. Cartons are separated from the plastics using automated sorting technology. Finally, plastic bottles are separated by resin type using automated sorting technology. The sorted PET, HDPE, and colored HDPE are sent to different containers for storage before they are shredded, granulated or perforated before compaction and baling.

Forklifts will be used to move the baled materials to storage or transport areas, and front-end loaders will be used to move loose material. Residue will be left over after processing from contaminants that were mixed in with the recyclables and from some non-recoverable material such as broken glass. The residue will be prepared for landfilling, combustion or composting. The system layout is illustrated in Figure 8.

6. Facility Characteristics

The costs, capacity, siting and design of the facility will depend on the amount of material processed, location of the facility from the collection routes and markets and the availability of transportation. Table 6 shows characteristics of some existing U.S. MRFs that accept source-separated materials.

Table 6: U.S. Facilities Receiving Source Separated Paper and MGP (1994)[31]

Facility Builder, Location	Total Project Cost (M$)	Landfill Tipping Fee ($/ton)	Operating Hours (shifts)	Workers per Shift (skilled / unskilled)	Facility Area (ft^2)	Materials Processed (TPD)	Additional Capacity (TPD)	Total Annual Cost/Ton ($/ton)
Resource Recycling Technologies Cape May, NJ	8	75	12 (1.5)	23 (8/15)	37,000	250	83	65.8
Stratford County Recycling Center Stratford, CT	9.6	-	12 (1.5)	42 (12/30)	59,000	250	250	52.6
Resource Recycling Technologies Palm Beach, FL	7	47	-	23 (8/15)	37,000	350	116	41.2
BFI Cincinnati, OH	2	7.5/yd.	10 (1)	18 (2/16)	47,000	215	40	21.5
Edco Disposal Corp. San Diego, CA	3	55	9 (1)	18 (6/12)	52,000	265	155	19.6
Rumpke Cincinnati, OH	2.5	22.5	18 (2)	35 (10/25)	75,000	170	20	36.0
Rumpke Colombus, OH	3	49	8 (1)	25 (9/16)	88,000	112	210	25.5
City Fibers Inc. Los Angeles, CA	2	36	24 (3)	45 (10/35)	80,000	150	50	27.4
BFI Indianapolis, IN	2	-	24 (3)	14 (5/9)	35,000	200	-	27.4
Best Ways Recycling Los Angeles, CA	3	15	12 (1.5)	15 (6/9)	100,000	325	230	14.8

Karta Container and Recycling Peekskill, NY	3	55	12 (1.5)	45 (9/36)	28,000	400	75	17.3

6.1. Facility Design

The facility layout will include the unloading area for the delivered materials, the presorting area and tipping floor, the area requirements for the unit separation operations, the storage and transporting areas, the sizing for the parking and traffic flow patterns for the facility, and additional buffer space. Scales will be utilized to weigh both incoming and outgoing materials, and there will be a queuing area for trucks at both the entrances of the scale and the facility. The unloading area will be large enough to accommodate a few days worth of material in case problems occur within the facility. Large volumes of materials may need to be stored to gain better leverage in the market or during periods when the markets are poor.

The interior of the facility will be large enough to allow changes in interior layout and the addition of new equipment to accommodate increases in population and the possibility for program expansion. There should be a minimum number of interior columns to allow maximum flexibility for equipment placement and the possibility to rearrange the layout in the future. The ceiling should be high enough to accommodate equipment specification. Conveyor lines, air classifiers, shredders and other processing equipment can be as tall as forty feet in larger MRFs.[32] The design of the facility will also include space for employee facilities and possible touring and meeting areas.

The facility will be enclosed to control noise. Since shredding, baling and screening are dust-producing operations, dust collection systems and fans will be incorporated into the facility design. To combat the odors that result within the enclosed facility, a filtered ventilation system will be installed. Air emissions controls will be installed to prevent any pollution that could negatively impact the environment. Automatic sprinklers and control devices will be installed throughout the facility to suppress and prevent fires from spreading within the facility. Facility workers will be required to use hearing protection, hard hats, and dust masks for their protection.

6.2 Facility Capacity

Since the city currently delivers over 2000 TPD (tons per day) of materials to its vendors, the proposed MRF will be designed to handle 150 TPH (tons per hour) and will function on two 8-hour shifts per day and 7 days per week. The facility will therefore have a maximum capacity of 2,400 TPD and 876,000 TPY (tons per year). The shifts can be lengthened to 10-hour shifts, giving the facility 3000 TPD and 1,095,000 TPY capacity if there is an increase in delivered materials.

6.3. Facility Siting

Ideally the MRF will be located close to both the source of the MSW generation and the companies that will use the recycled materials since the minimization of travel distances is important for reducing costs. In order to be located near the residential areas, the facility must be both environmentally and aesthetically acceptable. A buffer space with trees and shrubs will help improve aesthetics and decrease noise. Access to transportation sources is another important consideration in siting the MRF. Industrial areas represent ideal locations since they normally have access to utility services and different modes of transportation including rail, barge and highway. Furthermore, neighbors of industrial areas are accustomed to high volumes of truck traffic. Table 7 estimates the siting requirements for the proposed 150 TPH facility.

Table 7: Siting Requirements for the 150 TPH Facility[33]

Facility Component	Area (ft^2)
Processing Facility (including tipping floor, processing equipment, residue transfer area, and storage)	160,000
Scales, Truck Queuing and Outdoor Vehicle Maneuvering Space	97,000
Parking for Rolling Stock	248,000
Employee Parking	32,000
Site Buffer Allowance	147,000
Total Site Requirement	684,000 (~16 acres)
Siting Requirement per Capacity (ft^2 /TPD)	285

The siting requirements for other existing facilities with similar operations vary greatly, ranging from 59 to 400 square feet/TPD capacity.[34]

6.4. Facility Economics

Capital, operation and maintenance, collection, and disposal costs comprise the total costs of the MRF. Capital costs will include the construction, equipment and equipment installation costs. The construction costs include the costs associated with site work, structure and contingency costs of the building, roads, landscaping, and weigh stations. The operating costs will include management, labor and utility costs. Maintenance costs will exist for the building and equipment.

The revenue from the sale of recyclable materials will also be considered in determining the overall costs. Table 8 shows the market prices for various recyclables and illustrates the instability of the market.

Table 8: Market Prices for Selected Recycled Materials (dollars/ton)[35]

Material	Sept. 1992	Nov. 1994	July 1996	July 1998
Pulp				
Newspaper	20	80-100	15-20	50
OCC (Cardboard)	21	110	50	70
Plastics				
PET	107	220	90	250
HDPE (natural)	50	540	280	300
HDPE (mixed)	50	270	190	230
Glass				
Clear	21	27	25	25
Amber	20	22	25	25
Green	1	0	1	3.50
Metals				
Ferrous	45	72	93	85
Aluminum	830	1440	970	950
Aluminum Foil	not marketed	700	485	475

In order to determine the total revenue from the sales of the recyclable materials, the total tonnage of recycled material delivered to vendors in 1998 was valued using 1998 market prices. The revenue from recycled cartons is not factored into the analysis because cartons were a newly targeted material and the quantity of cartons recovered was unavailable. Materials such as kraft, office and computer paper, phone books, and magazines were targeted for collection, but were not targeted in the resource recovery systems of the private MRFs. The proposed MRF will be designed to separate and recover many of these additional materials as well as increase the recovery of previously targeted materials. These factors are not considered in this economic analysis, but will improve the economics of the facility since many of these materials have significant market value. (Table 9) Due to the volatility of the recyclable material markets, it is difficult to obtain a very accurate estimate of the revenues from the sale of recyclables.

Table 9: Market Prices for Various Non-Targeted Recyclables (May 2000)[36]

Material	Market Price ($/ton)
Kraft	90
White Ledger	160
Colored Ledger	120
Mixed LDPE	200
PP	360
PS	320
Lead	380
Copper	980

By far the greatest portion of the waste management costs for recycling is the cost of collecting the materials. These high collection costs indicate the advantages of mixed waste collection over separate collection. Although alternative collection scenarios are not considered in this analysis, the significance of the employed collection scenario is profound. Besides changing collection scenario, recycling collection systems can become more cost effective by changing truck designs, collection schedules and truck routes. For example, trucks can potentially be designed to pick up refuse and recyclable materials simultaneously while keeping them in separate compartments. The collection costs were assumed to be $114/ton and the amount of material collected was based on the 777,633 tons collected by New York City in 1998.[37]

The amount of material that is processed by the facility will also affect the overall processing costs. It is therefore important to use the most cost-effective balance between processing a greater amount of material and minimizing transportation costs. According to estimates on the processing costs to operate a proposed Staten Island facility in 1992, the cost to process a ton of recyclables would have decreased by over 75 percent, if the facility increased processing from 50 to 600 TPD.[38]

Table 10 shows the total annual costs for the proposed 150 TPH facility. Appendix A contains detailed estimates of the capital costs, operation and maintenance costs, revenue from recyclables as well as assumptions used to calculate them. All costs are based on the conceptual design of the facility presented in this paper. Costs are given in 1998 dollars and were amortized over 20 years at a 10 percent interest rate. A longer or shorter amortization period will significantly affect the economics of the facility.[39] The costs from this economic analysis should only be used as a guide for the costs of a MRF.

Table 10: Annual Collection/Processing Costs for the 150 TPH (876,000 TPY) MRF

Cost Component	Annual Cost ($)
Site Lease Costs (@ $3/sq. ft.)	2,052,000
Capital Costs	6,545,000
O and M Costs	4,975,000
Collection Costs (@ $114/ton)	88,650,000
Tipping Fee for Residues (@ $50/ton)	5,957,000
Revenue from Recyclables	-27,403,000
Total Costs	81,776,000
Cost per Ton Diverted	**$127/ton**

Table 11 shows the costs associated with the current waste management system in New York City.

Table 11: Current Collection and Disposal Costs for 777,633 TPY of Recyclables

Cost Component	Annual Cost ($)
Collection Costs (@ $114/ton)	88,650,000
Disposal Costs to Private Contractors (@ $50/ton)	38,882,000
Total Costs	127,532,000
Cost per Ton Diverted	**$200/ton**

In addition to the monetary economic benefits associated with the MRF, there are additional benefits due to the avoidance of other external costs. Particularly, the MRF will benefit the environment, human health, and promote the conservation of nature by preventing noise, smell, health impacts, traffic congestion, and pollution associated with other disposal methods. The health risk and release of greenhouse gases from landfill emissions as well as the pollution from incineration will be avoided. These environmental external costs are difficult to quantify, but the benefits are nonetheless gained by society.

7. Conclusions

There are many advantages to be gained by New York City in operating a largely automated MRF. One major consequence of relying on private contractors is the costs associated with geographic distribution. Relying on distant contractors results in much higher transportation costs for the city. Furthermore, since certain contractors only process certain types of recyclables such as paper, the city must route its collection vehicles accordingly to different plants and consequently pay additional transportation costs. The proposed facility would save the city an estimated $46 million annually by reducing the city's disposal costs from $200/ton to $127/ton. Although the economics of the MRF will vary depending on markets, location and transportation, these economic results illustrate the potential savings the city can accrue through the operation of a well-engineered MRF.

Processing all the materials within the city's limits would have the advantage of keeping jobs, tax dollars and other economic activity in the city. The proposed New York City MRF will also be able to process all of New York City's targeted recyclables, and will be adaptable to sort and process additional materials in the future, which can not be guaranteed by the existing contractors. Eventually, textiles, PP, LDPE, and even the recycling bags may be targeted by the city for recycling.

Many other cities around the United States have used MRFs in very cost effective waste management systems and typically make revenue from delivered materials (Table 12). The New York City waste management system can also be cost effective through a well-designed MRF, efficient collection and reliable markets.

Other processing scenarios that can be explored for the New York City MRF in the future include:

1. Accepting mixed municipal solid waste in addition to source separated recyclables
2. Accepting only mixed municipal solid waste
3. Accepting commercial and/or institutional waste in addition to the residential wastes
4. Producing refuse derived fuel in addition to recovering recyclables
5. Producing a compostable feedstock in addition to recovering recyclables
6. Receiving additional non-targeted source separated materials

Table 12: Revenues (Costs) Derived from the Delivery of MGP in Various Cities[40]

City	Revenue (Costs) [$/ton]
Oyster Bay, L. I.	25
Mercer County, NJ	9.50
Middlesex County, NJ	20
Los Angeles, CA	35
Boston, MA	0
Chicago, IL	(19)
New York City	(40) to (50)

A MRF can be a vital part of a successful waste management system in New York City. The continuation of this project at Columbia University would benefit from additional knowledgeable man-power, guidance from the experienced Columbia faculty, and the additional resources that Columbia can offer including solid separation laboratory facilities and a broad range of diverse expertise. Ideally, this paper would serve as a foundation for additional research on the concept of designing a MRF for the New York City waste management system.

APPENDIX

Assumptions Used in Economic Analysis

Assumptions for the economic analysis include:

Capital Costs

- Construction costs include a 20% contingency allowance on the building structure and a 5% contingency allowance on equipment.
- Allowances for design, permitting and management are based on a percentage of construction costs.
- Capital costs are amortized over a 20-year period at an interest rate of 10 %.

Operation and Maintenance Costs

- Labor costs were based on the need of 35 sorters, equipment operators, janitors and other personnel for each of two 8-hour shifts per day.
- The facility will operate 7 days a week.
- Each laborer receives $30,000/year in salary, and employee benefits are 30 % of labor costs.
- A 20 % allowance was applied to O and M costs for general and administrative expense and contingency.
- The additional O and M costs associated with the 3 DAR systems are not reflected in the economics, but should not affect the overall costs significantly.
- The cost of unutilized capacity is not reflected in the economics.

Leasing, Collection, and Residue Disposal Costs

- The site lease cost is $3 per square foot.

- Collection costs were based on the amount of recyclable materials collected in 1998 (777,633 tons).
- Collection costs are estimated as $114 per ton collected (based on the 1994 national average collection cost).
- Residue to calculate disposal costs for MRF includes all residues, unsold and other wastes in 1998 (119,136 tons).
- A tipping fee for waste disposal was estimated as $50/ton.
- Cost per ton diverted is based on the total tons of material delivered to all vendors in 1998 (638,203 tons).

Revenue from Recyclables

- Revenue from the sale of recyclables was calculated based on the tonnage of material delivered to all vendors in 1998 (638,203 tons) and 1998 market prices.

Table A1: Capital Costs for 150 TPH MRF [41] [42]

Cost Component	Total Cost ($)
Site Work	2,340,100
MRF/Area	16,533,800
Scale House/Scales	372,980
Construction Capital Costs	14,470,780
Contingency (20% of construction)	3,849,376
Total Construction Costs	**37,567,036**
Front End Loader	540,000
Fork Lift	280,000
Conveyors	3,864,540
Balers	1,865,000
Bag Splitters	375,000
Screens	380,000
Magnets	180,000
Separators	150,000
Picking Platforms	252,000

Chutes and Sheet Metal	500,000
Electrical	1,745,000
MSS ColorSort	100,000
MSS BottleSort	120,000
MSS CartonSort	75,000
Subtotal Equipment Costs	10,426,540
Installation (20% of non-mobile Equipment)	1,921,300
Contingency (5% of Equipment + Installation)	617,390
Total Equipment Costs	**12,965,190**
Design/Engineering (8% of construction)	1,847,700
Design/Engineering (2% of Equipment)	259,304
Permitting (5% of Construction)	1,154,813
Surveying and Soil Report	80,000
Construction Management (8% of Construction)	1,847,700
Total Design and Management	**5,189,517**
TOTAL CAPITAL COSTS	**55,721,743**
ANNUAL CAPITAL CHARGE (20-year period, 10 % interest)	**6,545,055**

Table A2: Annual Operation and Maintenance Costs for 150 TPH MRF[43]

Cost Component	Annual Cost ($)
Facility Labor	2,100,000
Employee Benefits (30% of labor costs)	630,000
Equipment Maintenance	454,600
Building and Site Maintenance	461,900
Utilities	663,000
Administration and Profit (20%)	665,900
Total Operation and Maintenance Cost	4,975,400

Table A3: Annual Collection and Disposal Costs for 150 TPH MRF

Cost Component	Annual Tonnage	Cost ($/ton)	Annual Cost
Collection	777,633	114	88,650,162
Disposal of Residues	119,136	50	5,956,800

Table A4: Annual Revenue from the Sale of Recyclables for 150 TPH MRF[44] [45]

Material	Tons Recycled	Market Price ($/ton)	Total revenue ($)
Newspaper	249,003	50	12,450,150
OCC	82,636	70	5,784,520
Mixed Paper	25,039	5	125,195
Amber Glass	475	25	11,863
Green Glass	1,278	3.50	4,471
Clear Glass	2,409	25	60,225
Mixed Glass	89,608	0	0
Steel/BI	20,819	85	1,769,615
Scrap Metal	31,576	85	2,683,960
Aluminum Cans	766	950	727,700
Aluminum Foil	904	475	429,400
HDPE	9,673	230	2,224,675
PET	4,526	250	1,131,500
Total			27,403,274

Table A5: Total Annual Costs for 150 TPH MRF

Cost Component	Annual Cost ($)
Site Lease Costs (@ $3/sq. ft.)	2,052,000
Capital Costs	6,545,000
O and M Costs	4,975,000
Collection Costs (@ $114/ton)	88,650,000
Tipping Fee for Residues (@ $50/ton)	5,957,000
Revenue from Recyclables	-27,403,000

Total Costs	81,776,000
Cost per Ton Diverted	**$127/ton**

FIGURES[46]

Please note that only Figure 8 (MRF Schematic) is included in this pdf file. The other figures can be found in hard copy of Dubanowitz MS thesis, Columbia University, 2000

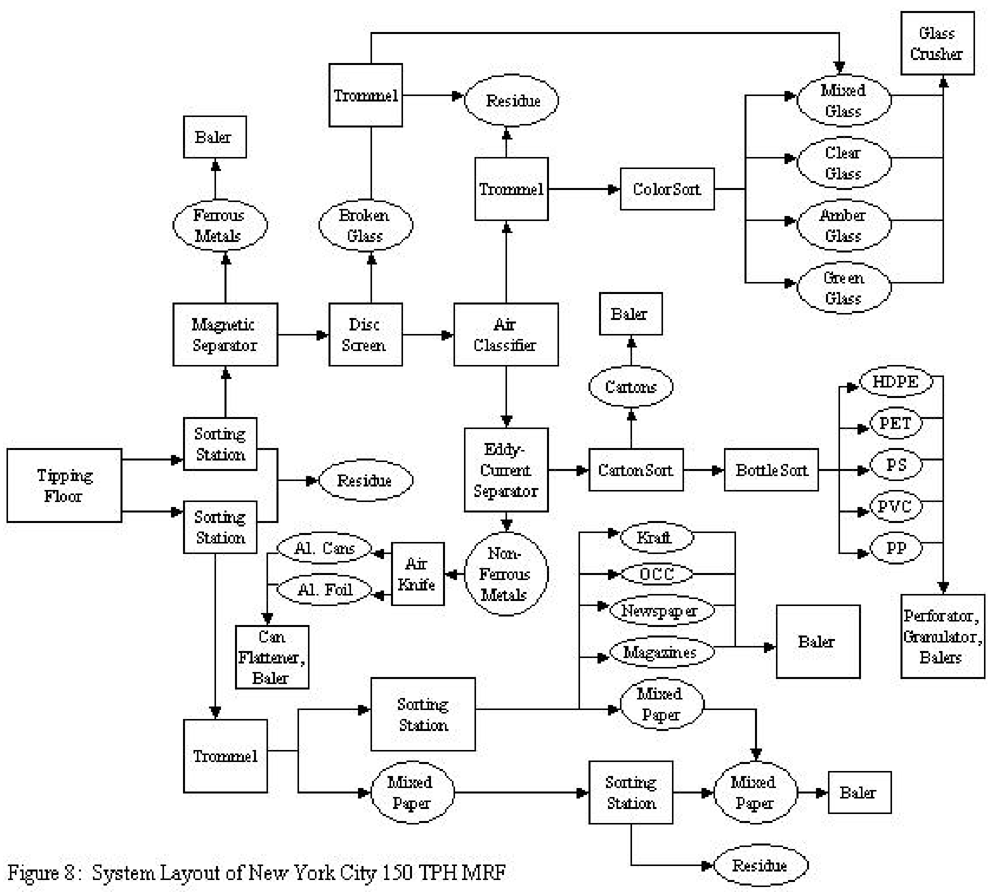

Figure 8: System Layout of New York City 150 TPH MRF

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