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Concept Design and Optimization of MSW Management System

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THESIS

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THESIS

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OF A MSW MANAGEMENT SYSTEM

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List of Acronyms

AB – air base, a USAF facility overseas

DM – decision-maker

DM$ - Deutsch Mark, German currency

DOD – Department of Defense

DSD – Duale System Deutschland, the private German recycling system

ECS – eddy current separator, separates nonferrous metals with a rare earth magnet

EPA – Environmental Protection Agency

fpm – feet per minute

HDPE – high-density polyethylene, type 1 plastic, used in milk jugs

HHW – household hazardous waste

kW*hr/t – kilowatt hours per ton

LCL – lower confidence limit, a statistical measure

MCDM – multi-criteria decision-making

MRF – materials recovery facility

MSW – municipal solid waste

MWPF – mixed waste processing facility, "dirty MRF"

OIR – other inorganic residue

OR – other organic residue

pcy – pounds per cubic yard

PET – polyehtylene terephthalate, type 1 plastic, used in beverage containers

PSD – particle size distribution

psi – pounds per square inch, a measurement of pressure

PVC – polyvinyl chloride, type 3 plastic

RFTF – recovery factor transfer function

rpm – revolutions per minute

TA – *Technische Anleitung*, a German technical instruction

TOC – total organic carbon

tpd – tons per day

UCL - upper confidence limit, a statistical measure

USAF – United States Air Force

VIMDA – Visual Interactive Method for Discrete Alternatives, MCDM software

VS – volatile solids

Abstract

The maximum recovery of recyclables from municipal solid waste (MSW) using material recovery facility (MRF) technologies is determined. Two waste streams at Spangdahlem AB, Germany are analyzed; stationary container wastes and commingled recyclables. Three schemes are considered, one for each waste stream, and one for both.

Multi-criteria decision making is the methodology. The criteria are recovery and annual benefit minus cost (B-C). Recovery is determined using the recovery factor transfer function of Diaz et al. (1982). Each technology, or unit operation, in a sequence is independent because particle size distribution of each waste component is considered. B-C is based on revenue from sold recyclables, tipping fees saved by not landfilling separated waste, and manual labor and amortized equipment costs.

Six unit operations are considered: eddy current separator (ECS), magnet, air classifier, screen, manual sort, and shredder. Sequences one to six operations long are considered. Three heuristics eliminate 42,179 of 55,986 potential sequences as infeasible.

The result is domination by a MRF to process both wastes and a tradeoff between 35.7% recovery of the total at an annual B-C of $0.95 million and recovery of 35.6% at an annual B-C of $1.02 million. Hand sort recovers the most, and is cost effective.

CONCEPT DESIGN AND OPTIMIZATION OF

A MSW MATERIAL RECOVERY SYSTEM

I. Introduction

Background

Municipal solid waste (MSW) generation has been increasing steadily in the U.S. and Germany. Owing to the monetary and environmental costs incurred by burying all this waste in landfills, these countries are striving to reduce the amount of landfilled waste. Landfills are unsightly, attract vermin, release noxious odors, produce greenhouse gases such as methane, and can contaminate groundwater. As a result, it has become increasingly difficult to site new landfills due to public resistance.

Methods of diverting waste from the landfill include prevention, reduction at the source, reuse, recycling, composting, and incineration. The U.S. Air Force (USAF) is attempting to divert waste from landfills generated at its facilities in the U.S. and Germany. Spangdahlem Air Base, in the German State of Rheinland-Pfälz, is one such facility.

In 1989, the U.S. generated 244 million metric tonnes (269 million U.S. tons) of MSW, about 84% of which was landfilled. The tonnage increased to an unprecedented high of over 308 million tonnes (340 million tons) in 1997, yet the proportion of the total MSW stream landfilled has decreased annually to an all-time low of 61% in 1997 (BioCycle, 1998:36). Part of the reason for this decreased landfilling is that the U.S. Congress and many state legislatures have passed laws requiring diversion of MSW from landfills. The U.S. is following in the footsteps of Germany, whose laws have been even tougher. The average annual generation of MSW in the U.S. is 1,021 kg (2,250 pounds) per capita (Tchobanoglous et al., 1993:138). Germany on the other hand produces 50 million tonnes (55 million tons) of MSW per year, or 370 kg (814 pounds) per capita (Koller, 1998:1).

Regulatory Environment

In the U.S., the efforts to reduce waste and landfilling have come from the top down. Executive Order 13101, "Greening the Government," issued September 14, 1998 by President Clinton, mandated that all U.S. installations worldwide have recycling programs.

The Air Force introduced quantitative reduction goals in January 1993 with the AF Pollution Prevention Program. It mandated a 30% reduction from a 1992 baseline by 31 December 1996 and a 50% reduction by 31 December 1997. The newest Air Force goals are based on percent of total waste, and not on a baseline year (HQ USAF/ILEV, 26 Jan 1999). The total now includes construction debris (CD). The percentage diversion by fiscal year (FY) are 15% by 1999, 20% by 2000, 25% by 2001, 30% by 2002, 35% by 2003, and 40% by 2004 and 2005. This must be accomplished while achieving an economic benefit. Diversion efforts must break even by FY2004 and show economic benefit by FY2005. Air Force leaders and managers are struggling to meet these mandates.

The European Union is expected to pass the Landfill Directive in March of 1999. The "Common Position," adopted in 1998 as a final step before actual legislation requires a phased reduction of the total quantity of biodegradable waste allowed to be landfilled:

75% by 2006, 50% by 2009, and 35% by 2016. The Member States, including Germany, must incorporate these targets into their own national legislation within two years of their formal adoption (by March 2000). Initially, the proposal focused on banning the landfilling of wastes with a TOC greater than 10 percent. Germany has adopted its own regulation in line with this original intent (Evans, 1998:72).

In the area of reducing MSW, Germany has been the world leader, having successfully reduced MSW generation with its Green Dot program. In June 1993, the German federal government passed a Technical Instruction (known as a TA in German) titled *Technische Siedlungsabfall*. This law mandated that all consumer packaging either be returned to the point of sale for recycling, or that a system be set up for their collection at large. As a result of this extra cost, manufacturers decreased the amount of packaging significantly. For example, toothpaste is sold in the tubes, but the tube is not placed in a box as well, as is common in the U.S. Many companies banded together to exercise the second option. They created the *Duale System Deutschland* (DSD), called "dual" because it is separate from pre-existing, government-run waste collection systems. Manufacturers must pay into the system to have their packaging collected and processed. In return, they are allowed to place the Green Dot symbol on their packaging, which certifies that their packaging is recyclable.

The 1993 TA also mandated that by 2005, organics must be collected separately in all areas and be composted. Also by 2005, all MSW must be treated before disposal such that the volatile solids (VS) is less than 5%, or such that the Total Organic Carbon (TOC) is less than 3%. With the current state of the art, the *de facto* result is that this is only possible in thermal treatment plants, also known as incinerators (Spangdahlem AB and

AFCEE, 1998:2-3; Koller et al., 1998:1). Incineration is an alternative way from recycling to divert waste from landfills. Energy is typically recovered from this process and sold in the form of electricity to offset costs. Incineration reduces volume by about 90%, depending on the components. Glass and metal do not change when incinerated, but the other contents in MSW are reduced to ash.

Research Problem

The technically feasible optimum recovery of materials from MSW has not been addressed in the literature. Authors may refer to it conceptually, but no concrete work has been done to determine this upper threshold. Recyclables are typically recovered at a materials recovery facility (MRF), which can employ a number of technologies for separation and volume reduction. This research addresses the feasible optimum recovery of materials from MSW using MRF technologies.

Justification for the Research

Under current German waste law, by the year 2005 all MSW will have to be incinerated to meet VS and TOC minimums. If it is possible under current technology to remove enough of the organics, then separation may add another alternative method other than incineration to meet the mandates. In any event, Spangdahlem AB (and all other U.S. military installations in Germany) must determine whether to operate a MRF or continue to pay the local governments to collect, haul, and segregate MSW generated by these U.S. activities.

Research Objective

The objective of this research is to determine the maximum diversion of materials from the landfill using current separation technologies.

Research Questions

1. What is the maximum diversion of materials from the landfill that can be achieved on the MSW waste stream at Spangdahlem using MRF technologies?

2. Does this diversion provide compliance with German and USAF mandates?

3. How can the maximum or compliant diversion be achieved?

4. What is the tradeoff between recovery and benefit/cost?

Scope and Limitations

This research considers commercially available waste handling technologies. Values for the criteria of recovery, purity, and cost are taken from the literature and from manufacturers' statements. No attempt is made to extend or speculate on improvements to the existing state of the art in waste separation.

The data used from the Spangdahlem AB waste characterization make the results valid only for that base or a waste stream with the same characteristics. The methodology, however, can be applied to any waste stream.

Research Approach

The method used to answer these questions is multi-criteria decision making (MCDM). The criteria are of two types: the percentage of material recovered, R; and the annual benefit minus cost, B-C, of the system performing the recovery. The data set used is the 1996 characterization of the Spangdahlem AB waste stream performed by Parsons Engineering.

II. Literature Review

The field of MSW management is fairly low-tech and has adopted or adapted technology and techniques from older fields, such as mining. This chapter discusses the definition of MSW, metrics of MSW separation, the various types of separation equipment available, the applicable regulatory environment (including U.S. law, USAF policy, German law, and the DOD standards for U.S. forces in Germany), and multi-criteria decision making (MCDM) techniques.

Definition of MSW

MSW, commonly referred to as "trash" or "garbage," consists of residential, commercial, institutional, construction and demolition, municipal services, and treatment facility wastes. It does not include agricultural and industrial wastes. In the U.S., what is regulated as hazardous waste in industry is not regulated when found in residential MSW. In the latter case, the waste is referred to as household hazardous waste (HHW), and consists of common substances like unused paint and aerosols.

MSW is typically measured by its mass, which is relatively constant except that the moisture content of MSW "as collected" varies from 15 to 40% of its mass depending on variables such as waste composition, geographic location, and season of the year (Tchobanoglous et al., 1993:599). MSW can also be measured by its volume, especially when designing landfills, but this parameter varies with the degree of compaction. It may take only 30 kg of dry and loose leaves to occupy 1 m^3 (50 lbs/yd^3), but well-compacted, landfilled MSW may be compressed up to 742 kg/m^3 (1,250 lbs/yd^3), 25 times as dense (Tchobanoglous et al., 1993:70)

The organic fraction of MSW, typically about 80% by weight in the U.S., includes paper, yard waste, food waste, cardboard, plastic, textiles, wood, rubber, and leather. The inorganic fraction includes glass, ferrous metal, nonferrous metal, dirt, and ash.

Parameters for Waste Separation

Solid waste separation processes have historically been evaluated by three parameters: the fraction of each material recovered by weight, R(X); the overall efficiency, E, calculated as the geometric mean of the recoveries; and the purity of a desired material in a certain separated stream, P(X). A diagram of a waste separation process is shown in Figure 1, and aids in understanding how the process is evaluated.

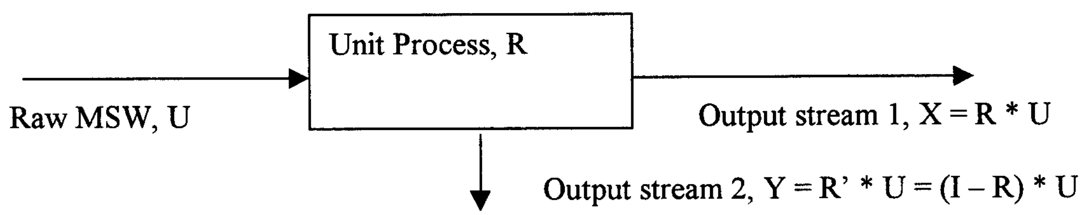


Figure 1. Diagram of a unit process (after Diaz et al., 1982:31)

Recovery is defined for any unit operation by the equation:

$$\text{Recovery}(X) = X_{out} / X_{in} \tag{1}$$

where

X_{in} = mass of material X in the inflow

X_{out} = mass of material X in the outflow

Factors affecting this parameter are listed and explained in Table 1. The interpretation of recovery for the table is broader than the one used here where the scope is limited to a unit process.

Table 1. Factors Affecting Material Recovery Rate

Factor	Explanation
Market Specifications	Tighter specs. potentially decrease recovery rates
Contamination of Incoming Materials	Product may be rejected by buyer
Glass breakage	Harder to sort, especially by color
Quantities per Sorter	As number of units per sorter increases, recovery rate decreases
Equipment Design	Proper design of conveyors and separation equipment for the types and quantities of materials handled directly affects recovery
Human Factors	A clean, well-lit, pleasant environment with emphasis on training, safety, health, and comfort tends to increase recovery
Fictitious Weights	Incoming trucks being weighed on scales should not have an inordinate amount of rain or snow on them

(USEPA/625/6-91/031, 1991:2-15)

Efficient design of a MRF requires a mass balance. Diaz et al. (1982:30) created a model where R(X) is known as the recovery factor transfer function (RFTF). The RFTF is a diagonal matrix, R, whose elements represent the fraction of each of the waste components. Since each unit operation considered has two output streams, the RFTF for the other stream is the complementary matrix, **R′**, defined as **R′** = **I** - **R**, where **I** is the identity matrix (Figure 2).

$$R = \begin{bmatrix} r_1 & 0 & \dots & \dots & 0 \\ 0 & r_2 & 0 & \dots & \dots \\ \dots & 0 & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & 0 \\ 0 & \dots & \dots & 0 & r_n \end{bmatrix} \qquad R' = \begin{bmatrix} 1-r_1 & 0 & \dots & \dots & 0 \\ 0 & 1-r_2 & 0 & \dots & \dots \\ \dots & 0 & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & 0 \\ 0 & \dots & \dots & 0 & 1-r_n \end{bmatrix}$$

Figure 2. Vectors **R** and **R′** for a unit operation.

The quantities of the waste components in the inflow to the system, and in output streams 1 and 2 are represented by the elements in vectors **U**, **X**, and **Y**, respectively as shown in Figure 3.

$$U = \begin{bmatrix} u_1 \\ \ldots \\ u_n \end{bmatrix} \qquad X = \begin{bmatrix} x_1 \\ \ldots \\ x_n \end{bmatrix} \qquad Y = \begin{bmatrix} y_1 \\ \ldots \\ y_n \end{bmatrix}$$

Figure 3. Vectors U, X, and Y for a unit operation.

The RFTF has a physical basis that can be established either through testing or from previously developed analytical expressions. Diaz explains that the strength of this model is the independence of the unit operations from each other:

> The models of each unit process is separate from the models of the other unit processes in a system, because the recovery factors are based upon size distributions of the refuse components ... In other words, each model is a separate entity and complete unto itself. Consequently, in the system model, the unit operations can be arranged to evaluate different processing trains. The RFTF modeling approach ... can be used to evaluate means for optimizing existing systems. Another advantage resulting from the versatility of the modeling technique is a capability for evaluating and optimizing various hypothetical processing trains ... Here the term 'hypothetical' refers to system models that have no actual plant to mimic (Diaz et al., 1992:33).

The parameter of efficiency is defined as the geometric mean of the recoveries as shown in Equation (2) below:

$$\text{Efficiency} = (\text{Recovery}(X) * \text{Recovery}(Y) * \ldots * \text{Recovery}(m))^{1/n} \qquad (2)$$

where

m = the number of recovered materials

n = the number of output streams.

The parameter of purity is defined mathematically as:

$$Purity(X) = X_{out} / (X_{out} + nonX_{out}) \qquad (3)$$

where $nonX_{out}$ = mass of materials other than X

In this analysis, purity is assumed to be small. The only quantitative information on purity available in the literature is from Diaz et al.(1982:39) regarding a magnet, as shown in Table 2. They estimate that a magnet recovers 80% of ferrous metals, but that the impurities consist of 2% of the paper and plastics and 5% of the other organics.

Table 2. Magnet Recovery Factors

Material	Fe	Al	Glass	Paper	Plastic	OIR	OR
Removed	0.80	0.00	0.00	0.02	0.02	0.00	0.05
Remaining	0.20	1.00	1.00	0.98	0.98	1.00	0.95

OIR = Other Inorganic Residue; OR = Other Organic Residue (Diaz et al., 1992:39)

The purity of recovered ferrous metals could be easily determined from field data once the system is operating. Before that, however, the parameter must be estimated through estimates from the literature or claims from equipment manufacturers. This information is sparse and not recent, or is considered "proprietary" by the equipment manufacturer.

Materials Recovery Facilities

One way to divert waste from landfills is by separating out recyclables and reselling them. This is commonly done at a materials recovery facility (MRF). A MRF is a building that usually has a dumping area, conveyor belts, separation stations, a baler, and storage space. Separation may be manual, mechanical, or both.

A 1995-96 study (Berenyi, 1995:121-3) by Governmental Advisory Associates (GAA) found 337 MRFs in planning or operation, and its 1997 follow-up survey found

43 more (Berenyi, 1997:27). The definition of MRF for inclusion in the GAA study was that the facility must:

1. process a multi-material or multi-grade stream of source separated material for marketing to end users, brokers, or value-added resellers.
2. receive some fraction of this stream as commingled recyclables requiring further sorting. Sorting can be done manually or by any combinations of manual and mechanized approaches.
3. participate directly or indirectly in municipally structured solid waste programs.

MRFs receiving presorted wastes only are commonly called "clean MRFs" in the industry. Facilities were excluded from the studies if functioning solely as:

1. commercial/industrial scrap processing operations
2. drop-off centers
3. buy-back (purchasing only) or container redemption centers
4. transfer stations which receive and transfer recyclables without processing.

These studies further classify MRFs into 3 subgroups:

1. low tech MRF – relies primarily on manual sorting, and may use conveyors and magnetic separation
2. high tech MRF – relies on a combination of manual and mechanical processing beyond magnetic separation, including trommels, screens, eddy current separators, and air classifiers.
3. paper MRF – handles paper only (Berenyi, 1997:2).

Facilities that receive raw waste without any presorting by generators are commonly called "dirty MRFs." The GAA studies refer to them as Mixed Waste

Processing Facilities (MWPFs). A MWPF is distinct from transfer facilities, where waste is transferred from garbage trucks into 18-wheelers, and disposal facilities, such as landfills, in that it:

1. processes waste from a mixed MSW stream coming from residential, commercial and industrial sources.
2. directs MSW to a system designed to achieve maximum recovery of multiple types of recyclables from the waste flow though positive manual or mechanized sorting.
3. transfers the unrecovered MSW to a landfill or other facility for final disposal or additional processing for energy or material recovery, such as waste-to-energy or composting (Berenyi, 1997:3).

Each mechanized separation device in a MRF is referred to as a unit operation. MSW managers have been borrowing technology from older fields to separate waste, but MSW is much more complex and variable than most other materials.

Because of this complexity, variability, and emerging technology, it is more productive to remove one type of item at a time, rather than to use a single, more complex operation, which Stessel (1990:430) calls the "food processor" approach. Stessel outlines the principles that should be followed for successful unit operations:

> Complexity is thus reduced by increasing the number of unit operations while decreasing the complexity of the task assigned to each. The 'food processor' approach to unit operations design will seldom achieve the theoretical optimum of a collection of separate steps. It is much easier to address specific problems during shakedown with distinct unit operations. In shakedown, modification, and ultimate performance, long-term economy will be demonstrated. (Stessel, 1990:430)

The maximum achievable recovery referred to above has not been addressed specifically in the literature. To achieve this maximum recovery, a MRF must be well designed.

Proper design of a MRF requires a mass balance. If this is not done, processing equipment may be under- or oversized, or predicted splits of material are not reached causing overburden of some downstream unit operations and underburdening of others. According to Diaz et al. (1982:24), faulty mass balances can be due to four factors:

1. incomplete knowledge of MSW components and characteristics
2. inadequate understanding of unit processes' operation and performance
3. unavailability of performance data for equipment items
4. focus only on quantity, neglecting quality.

Equipment selection will determine the recovery, purity, and profitability of materials. Several considerations are relevant when selecting equipment. Diaz et al. (1982:24) suggest five equipment criteria:

1. the properties of materials to be processed
2. the required throughput
3. desired product specifications
4. available space
5. desired level of maintenance cost and downtime.

Decision Tools

Spreadsheet. A spreadsheet can be programmed to solve for the optimum alternative based on a single criterion. It can also be programmed to rank alternatives based on their score or values under that criterion. Although a spreadsheet can be programmed to remove dominated solutions in multi-criteria scenarios, no convenient function exists to perform this task. Where the DM's utility function is explicit, a spreadsheet can be programmed to solve for the optimum for all criteria. If, however, the utility function of the decision-maker (DM) is *implicit* and there are multiple criteria, a spreadsheet cannot find the optimum. This must be done by the DM, or with MCDM methods.

MCDM. There are many and varied multi-stage separation processes, each with its own method for evaluating the efficiency of separation. These processes include wastewater treatment, cracking of crude oil, treatment of mined ores, and environmental remediation. Multi-stage separation processes are crucial in the petroleum, petrochemical, and chemical industries. Khoury (1995:ix) presents various methods of quantifying the performance of multi-stage separations in these industries. Klee (1980:80) applies MCDM techniques to MSW separation, including such criteria as Process Cost/Ton, System Reliability, Market Reliability, and Nuisance Potential. He compares three alternatives methods of processing waste based on their performance in these criteria.

MCDM works across three spaces. The X space, or decision space, is the list of alternatives and how they rate within the criteria of interest. The Y space, or outcome space, consists of the utilities or values associated with the attributes in the X space. Decisions are made based on information in the Y space. The Z space is the preference structure of the DM, or the method the DM uses to decide which alternative is best. The DM could have any of several preference structures, such as maximizing all criteria or trying to meet a goal. In the latter, the DM measures each alternative by its distance from the goal. This distance itself can be measured in several ways such as totally compensatory between criteria (Manhattan metric), totally non-compensatory (Chebychev metric), or somewhere in between (Euclidean metric, etc).

One preference structure that is simple for most DMs to understand is the additive value function, v(f). In this function, each criteria is assigned a weight. The weights typically sum to 1. For the criteria of interest in this work, the value function would be $v(f) = w_R*R + w_{(B-C)}*(B-C)$

Decision Analysis. Another tool for modeling alternative process trains is Decision Analysis (DA). DA uses decision trees consisting of nodes and branches to show the alternatives and resulting values. One software package that can be used to create these trees is Decision Programming Language (DPL). In DPL, there are three types of nodes: a decision node, symbolized by a rectangle; an uncertainty or chance node (oval); and a value node (rectangle with rounded corners). The branches stemming from a chance node can be used to represent recovery expressed as a number between 0 and 1. A decision node can be used to represent the various equipment items that can be placed at a given stage, or the various components of the waste stream going through any single unit operation. The limitation is that DPL can not handle all these dimensions at the same time. DPL does, however, have the capability to analyze sensitivity of a model to any of its variables.

System Dynamics Modeling. System dynamics modeling is appropriate when the model includes feedback loops. For example, when residents who participate in their community recycling program might be required to separate their recyclables. If, however, they see the person who picks them up dumping them together into the same bin, they may be likely to reduce their participation or stop it completely. Since the

MSW situation modeled in this work has no feedback loops, system dynamics modeling is not an appropriate modeling technique.

III. Unit Operations

Mechanical Separation

Several types of equipment are used to separate and process the components of MSW. These unit operations are designed to modify the waste to facilitate removal and to remove components and/or contaminants from the waste stream. Processing options are categorized by Rhyner et al. (1995:159-77) as hand sorting, size separation (screening), density separation, magnetic field separation, size reduction (shredding), optical-type separation, densification (baling), and materials handling (conveying). These operations are presented in Table 3, with information about their functions and preprocessing requirements.

Hand Sorting

Hand sorting is the original method of waste separation. It is usually done on the conveyor belt that leads to the first mechanical process. The sorters remove items that could damage equipment or that are of value. According to Vesilind and Rimer (1981:141), pickers can salvage about 0.45 tonnes/hr/person (0.5 tons/hr/person). The belt should be no more than 1.52 m (60 inches) wide for picking from only one side, 3.05 m (120 inches) for two-sided. The belt should move no faster than 12.2 m/min (40 ft/min). Daylight is better than artificial light. Hand sorting is somewhat dangerous, as there may be sharps, diseases, explosives, or other harmful materials in the waste stream.

Table 3. Unit Operations Used for Separating and Processing MSW

Item	Function	Preprocessing
Size Reduction/Shredding		
Hammer mill	Size reduction of all wastes	Remove large bulky items, contaminants
Flail mill	Size reduction of all wastes, bag breaking	Remove large bulky items, contaminants
Shear shredder	Size reduction of all wastes, bag breaking	Remove large bulky items, contaminants
Glass crusher	Size reduction of all glass	Remove all nonglass materials
Wood grinder	Size reduction of yard trimmings, all wood wastes	Remove large bulky items, contaminants
Size Separation/Screening	Separation of over- or under-sized material by vibrating or disc screen or trommel (often used as bag breaker), all wastes	Remove large bulky items, large cardboard pieces
Density Separation		
Air classifier	Separation of light materials by air stream	Remove large cardboard and bulky items, shredding
Cyclone	Separation of light materials from air stream	
Magnetic Separation		
Magnet	Separation of ferrous metal	Remove large bulky items, large cardboard pieces
Eddy current separator	Separation of nonferrous metal; ferrous metals also separated	Remove large bulky items, large cardboard pieces
Densification		
Baler	Compaction into bales; paper, cardboard, plastics, textiles, Al	Separate components
Can crusher	Compaction and flattening; Al and tin cans	Remove large bulky items
Handling, Moving		
Scales	Operational records; drive-ons for trucks, roll-ons for bales, etc	
Conveyor belt	Materials transport and manual separation, all wastes	Remove large bulky items

(Tchobanoglous et al., 1993:256)

Removing desirable material from MSW is called “positively sorting.” Removing undesirable material and allowing desired material to pass for later processing is called "negatively sorting." For mixed materials, positively sorting generally achieves higher recovery (USEPA, 1991:2-57). Tables 4, 5, and 6 below show manual sorting rates and efficiencies according to three different sources. The second table does not specify how long a work day is, but it is assumed to be 8 hours.

Notice that the values generally agree on how many tons of paper, glass, or plastics an employee can pick in a day, although the categories do not exactly match. For example, paper products in Table 4, listed specifically as cardboard and newspaper, range from 6.6 to 44 tonnes/sorter/day (6 to 40 tons/sorter/day). Table 5 lists paper from 5.3 to 14.3 tonnes/sorter/day (4.8 to 13.0 tons/sorter/day), with an average of 7.9 (7.2). The minimums are similar, but the maximum is lower. This may be due to inexact matching of categories. Table 6 lists "mixed paper" from 4.4 to 35.3 tonnes/sorter/day (4.0 to 32.0 tons/sorter/day), with an average of 22.1 (20.0). Again, the minimum is similar to the other two, but the maximum lies between the other two maximums. A conservative average estimate, then, would be 7.9 (7.2) because it falls within all ranges, although it may be low.

Picking lines are often elevated so that separated material can be dropped into bins below. Factors in designing picking lines include belt width, belt speed (4.6 to 27 m/min, or 15 to 90 ft/min), and the average thickness of waste on the belt (burden depth). Effective picking is possible at burden depths up to 15 cm (6 inches) (Tchobanoglous et al., 1993:267). Belts should have variable speed devices. The higher speeds are possible when negatively sorting. A speed of 9.1 m/min (30 ft/min) is appropriate for average sorting conditions for paper sorting and commingled container sorting. The working surface of the belt should be 91 to 107 cm (36 to 42 inches) from platform level (USEPA, 1991:2-59). To improve separation, plastic bags should be broken open and the contents spread out.

Table 4. Manual Sorting Rates and Efficiencies

Material	Container /lb	Container /minute /sorter	Lb/hr/ sorter	Tons/ 8hr-day/ sorter[a]	Tonnes/ 8hr-day/ sorter	% Recovery
Newspaper	---	---	1,500-10,000	6-40	5.4-36	60-95
Cardboard	---	---	1,500-10,000	6-40	5.4-36	60-95
Glass mixed/whole	1.5-3.0	30-60	900-1,800	3.6-7.2	3.3-6.5	70-95
Glass by color	1.5-3.0	15-30	450-900	1.84-3.6	1.67-3.3	80-95
Plastic PET,HDPE	4.5-9.0	30-60	300-600	1.2-2.4	1.1-2.4	80-95
Aluminum from plastic	22.5-27	30-60	100-120	0.4-0.48	0.4-0.44	80-95

[a] Based on average sorting rates (Containers/minute/sorter). (USEPA, 1991:2-58)

Table 5. MRF Employee Productivity tonnes (tons) per employee per 8-hr day

Material	Low	Average	High
Paper	4.4 (4.8)	6.5 (7.2)	11.8 (13.0)
Metals	1.6 (1.8)	5.41 (5.96)	15.9 (17.5)
Glass	1.8 (2.0)	3.82 (4.21)	9.1 (10.0)
Plastics	0.91 (1.0)	1.42 (1.57)	2.3 (2.5)
Total	2.40 (2.65)	4.57 (5.04)	7.54 (8.31)

(Miller, 1995:94)

Table 6. MRF Employee Productivity tonnes (tons) per employee per 8-hr day

Material	Range	Typical	Remarks
Commingled MSW			
Res'l & Comm'l	2.2-29.0 (2.4-32.0)	18.1 (20.0)	
Commercial	2.9-43.5 (3.2-48.0)	21.8 (24.0)	
Source-separated			
Mixed paper	3.6-29.0 (4.0-32.0)	18.1 (20.0)	
Paper & OCC	3.6-21.8 (4.0-24.0)	10.9 (12.0)	2 products
Mixed plastics	0.732.9 (0.8-3.2)	1.5 (1.6)	PETE & HDPE
Mixed glass/plastics	1.5-4.4 (1.6-4.8)	3.6 (4.0)	2 products: mixed glass & mixed plastic
Glass	1.5-5.8 (1.6-6.4)	2.9 (3.2)	by color
Al/glass/plast/tin cans	0.7-3.6 (0.8-4.0)	2.2 (2.4)	4 products

(Tchobanoglous et al., 1993:268)

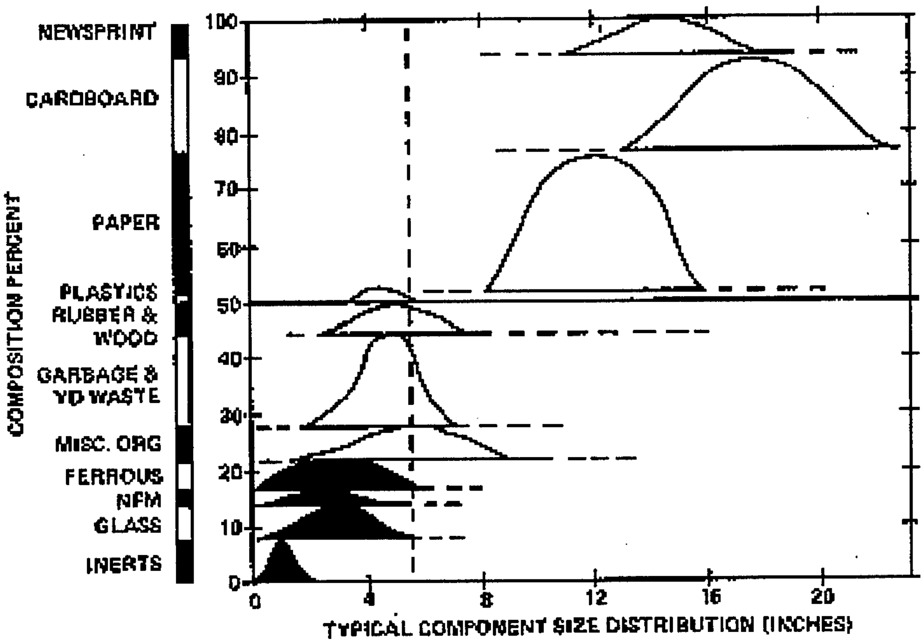
Size Separation/Screening

Screens separate refuse by size and not necessarily by component. Screens are commonly used toward the end of a series of unit operations to remove broken glass. They can also be used as initial rough sorters, or to remove the organic fraction of shredded waste (Vesilind and Rimer, 1981:141-2).

A particle can pass a screen of uniformly sized holes if the particle is smaller than the hole in two or more dimensions. Theoretically, screens can recover 100% of undersized material ("unders"), but at very low throughput. No oversized material ("overs") can pass through the holes by definition, but overs can be expected to contain some unders that were blocked from passing through the holes.

To know what fraction of a waste stream will be overs or unders, it is necessary to know about the particle size distribution (PSD) of the components. The design aperture size of any screen will depend on the PSD of the waste passing over it and the desired separation effect. Hasselriis (1984:19) and Diaz (1982:52) have analyzed the PSD of

MSW in inches as shown in Figures 4 and 5, respectively. The breakout of components and the results are similar. They agree that Cardboard is the largest, followed by paper products (Hasselriis breaks it into paper and newsprint), and that rock and debris (inerts) are the smallest. Hasselriis estimates the overall mean size at about 13 cm (5 inches), while Diaz shows the median or 50th percentile (an estimator of the mean) at about 12 cm (4.7 inches). This is determined by locating the size at which the 50% finer horizontal line crosses the curve titled Composite.



NFM = Non-ferrous metals, Garbage = Food Waste/Putrescibles

Figure 4. PSD of MSW by component (used with permission, Hasselriis, 1984:19)

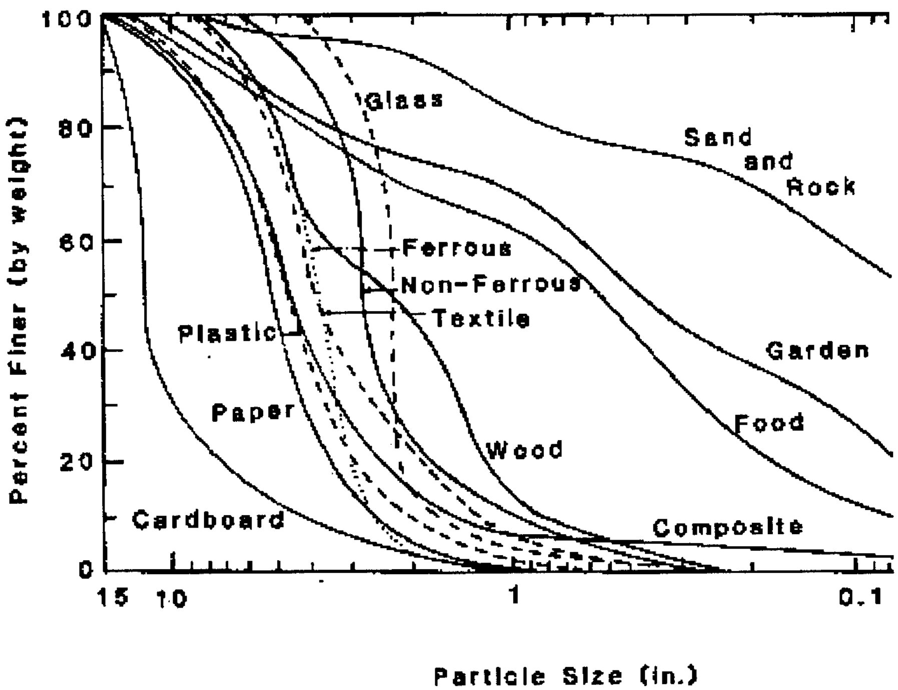


Figure 5. PSD of MSW by component (used with permission, Diaz et al., 1982:52)

Given that the two sources generally agree, the data from Diaz et al. are used from this point forward because it is possible to determine approximately what percent of mass passes for any given material and aperture size. For purposes of calculating the recovery from a screen, the RFTF for trommel overs is provided by Diaz et al. in Table 6. Notice that the measurement by percent finer (unders) from Figure 5 has been reversed to percent coarser (overs) in Table 6. The RFTF for overs in Table 6 is equal to 100 percent minus the pecent finer by weight from Figure 5.

The values in Table 7 all correspond to the aperture size of 2 inches in Figure 5. The RFTF for any aperture size can be determined from Figure 5, given that the size is shown on the figure.

The moisture content of all separated components remains the same as that of the in-feed. This assumption is extended to all aperture sizes for simplicity and due to lack of information that it may be otherwise.

Table 7. Trommel Overs Recovery Factors

Material	**Fe**	**Al**	**Glass**	**Paper**	**Plastic**	**OIR**	**OR**
Overs	0.80	0.80	0.20	0.85	0.90	0.25	0.25
H_2O	0.80	0.80	0.20	0.85	0.90	0.25	0.25

OIR = Other Inorganic Residue; OR = Other Organic Residue (Diaz et al., 1992:35)

Shaking screens. Shaking screens are often inclined to control direction of flow and increase throughput. They are readily plugged by material, and should be used for concentrated feeds of fine particle size, such as for removing impurities from composted materials (Rhyner et al., 1995:165).

Disk screens. Disk screens consist of lobed or star-shaped disks on parallel rotating shafts. The feed moves perpendicular to the shafts and the unders fall between the shafts. Electronic controllers can handle blockages by reversing the rotational direction of a shaft (Rhyner et al., 1995:167).

Trommels. Trommel screens are cylindrical screens that allow refuse to tumble around until the pieces smaller than the holes find themselves next to the holes and fall through. The recovery is highest when the screen is moving quickly enough to fling the material into the air, known as cataracting. If the screen moves slower than this, the particles slip back down (cascading) and the efficiency is lower. If the screen speed is higher than the "critical speed", f_c, then the particles adhere to the drum and never drop off (centrifuging), and the recovery is at its lowest. These three conditions are depicted in Figure 6. Most trommels operate at a fraction of critical speed (in rpm), which varies with the radius, r (meters), by the equation $f_c = 29.9*\sqrt{r}$. Hence, a trommel of diameter 3.5m (11.5 ft) would have $f_c = 16.0$rpm.

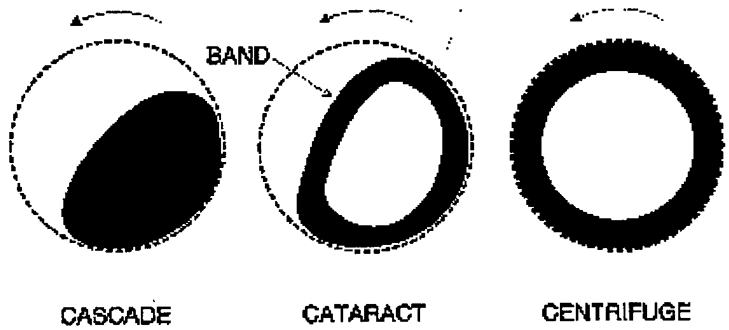


Figure 6. Trommel; velocity increases to right (used with permission, Stessel, 1996:190)

Trommels are resistant to clogging and use very little power, rotating at only 10 to 15 rpm (Vesilind and Rimer, 1981:142-3). Operating characteristics of a typical trommel are shown in Table 8. Recovery decreases as the depth of material or loading rate increase. Recovery also varies with rotational speed and aperture size. Stessel's 1991 computer model of trommels indicates intuitive results. Designers should choose the longest affordable trommel to increase recovery, and the greatest practical inclination angle for maximum throughput. The average residence time of raw waste in real trommels is 25 to 60 seconds, and 10 seconds for air-classified light materials (Rhyner et al., 1995:167).

Table 8. Operating Characteristics of a Typical Trommel

Parameter	Value	Units
Diameter	3.5 (11.5)	m (ft)
Screen length	4.0 (13.1)	m (ft)
Screen size	5.0 (2.0)	cm (in)
Screen open area	53	%
Inclination angle (variable)	3-7	°
Rotational speed (variable)	11-13	rpm

Source: Tchobanoglous et al., 1993:558

Density Separation

There are three methods of density separation: air classification, liquid or dry medium, and inertia. Of these, only air classification is commonly used and will thus be explained in greater detail. The others will be discussed briefly. They are not used in the model.

Air classifiers. Air classifiers typically separate the light, mostly organic fraction from the heavy, mostly inorganic fraction. An upward air current carries the lights up, but allows the heavies to drop. The light fraction carried by the air stream must then be separated from the air, commonly by a cyclone.

The feed can be separated in three streams using a type of classifier called an "air knife," which blows air horizontally through a vertically dropping feed.

The separation efficiency of any air classifier depends on the turbulence and shear forces on the feed. Zigzag throats accomplish this by creating air vortices and breaking up falling material (Vesilind and Rimer, 1981:154-5). Classifiers using pulsed air flow have been proven to increase recovery (Stessel, 1983:180). Of course, impurities are present in the outputs from any classifier.

Early experiments showed that classifiers help to concentrate materials from MSW. Table 9 shows the results of one experiment in which the MSW was pre-shredded to minus 5 cm (2 in). The concentration of metals and glass increased from 18.8% in the raw refuse to 62.6% in the heavy fraction. Not quite so well separated, paper and plastic increased in concentration from 47.7% in the raw refuse to 65.9% in the light fraction.

Table 9. Composition of typical MSW and Air-Classified Heavies and Lights

Component	Typical MSW	Heavies	Lights
Fe	7.3	24.2	
Glass	10.8	36.1	
Aluminum	0.7	2.3	
Paper	43.2	3.6	60.2
Plastic	4.5	1.7	5.7
Miscellaneous	33.5	32.1	34.1
Total	100.0	100.0	100.0

Source: Diaz et al., 1982:76

In this data, none of the heavy fraction reported to the light fraction. According to Tchobanoglous et al. (1993:599), when an air classifier is preceded by a shredder, the light fraction can contain from 2 to 8% of the components of the heavy fraction by weight, and the heavy fraction can contain from 5 to 20% of the components of the light fraction. This analysis details several more components than the one by Diaz et al., where almost 1/3 of the weight is lumped together as "Miscellaneous." This increases the difficulty of comparing the two results. Diaz et al. provide recovery data (Table 10) that are sometimes less optimistic than the ranges provided by Tchobanoglous et al.

Table 10. Air Classifier Recovery Factors

Material	Fe	Al	Glass	Paper	Plastic	OIR	OR
Lights	0.10	0.50	0.60	0.98	0.98	0.20	0.70
Heavies	0.90	0.50	0.40	0.02	0.02	0.80	0.30

OIR = Other Inorganic Residue; OR = Other Organic Residue (Diaz et al., 1982:35)

Separation by Liquid or Dry Medium. Separation by liquid medium is called flotation. The liquid chosen has a density between those of the two materials to be separated. This method is used to separate soda bottles and caps from the denser base cups using water. Separation by dry medium separates materials whose densities vary by more than 0.2 g/cm^3 (12.5 lb/ft^3). In the dry fluidized bed method, the medium is fluidized from below by pressurized air. The waste is placed on top of the medium and objects denser than it work their way to the bottom. The pinch sluice works similarly, but the bed is not a simple rectangle. It is shallow and wide on the in end and narrow and deep on the out end. A mixture of waste and medium is introduced on the wide end and moves down the inclined sluices with air pushing the material lighter than the medium to the top (Rhyner et al., 1995:169-70).

Separation by Inertia. Common inertial separators include the cyclone, vibrating table (stoner), ballistic separator, and inclined conveyor with chain curtain. Cyclones swirl materials around carried by air and denser materials are pushed outward to the wall and drop. Vibrating tables (stoners) move perpendicular to the direction of flow. The tables move slowly in one direction and return rapidly in the other. Thus denser materials accumulate in the direction of slow movement. Ballistic separators use a rotor to proper materials. Higher density materials have higher inertia and are shot farther. The chain curtain moves perpendicular to containers sliding down an incline. Glass continues to slide while the less dense plastic and aluminum containers are brushed aside by the curtain (Rhyner et al., 1995:172-4).

Magnetic Separation

Unit operations that separate MSW based on magnetic properties include magnets in three configurations, which remove ferrous metals, and eddy current separators (ECSs), which remove all metals, but are particularly to separate nonferrous metals.

Magnets. Magnets can recover ferrous metals from MSW, such as tin cans for food. Both permanent and electromagnets are used. The maintenance and operational costs of permanent magnets are lower, but the electromagnet's intensity can be adjusted for varying applications. There are 3 basic configurations: pulleys, drums, and suspended magnets (Morgan, 1996:2).

Magnetic head pulleys. In the first configuration, the conveyor belt pulley on the discharge end of the belt has a magnet in it. This magnet is placed so as to hold metals past the free fall point. The conveyor belt should be cleated to ensure discharge of the ferrous materials. A splitter helps keep the free falling nonferrous materials separate from the stream of metals released a fraction of a second later (Morgan, 1996:2).

Drum magnets. A drum magnet consists of a stationary magnet within a rotary shell. Recovery of ferrous material will have a lower purity. The product may need to be combed through to make it salable (Morgan, 1996:2-3).

Suspended magnets. Suspended magnets consist of a box magnet, frame, pulleys, motor, and belt with cleats that move the recovered metals off. They draw ferrous metals up from the burden, carry them off, and release them, typically onto another conveyor. They are commonly referred to as “belt magnets,” and are often described as “self-cleaning.”

Most belt magnets' magnetic field is stronger in the center, and consequently they work better with trough belt conveyors (Gedgaudas, 1997:9). They can be mounted in line with the burden flow, or perpendicular. The latter type is referred to as a cross-belt magnet, and is more susceptible to jamming by large items. Walker Magnetics has developed the proprietary "Triplex Magnet." Its multiple magnets mix attracted ferrous metals laterally and transversely to liberate trapped impurities. Steel plating on the belt minimizes wear (Morgan, 1996:3).

Eddy current separators. Eddy current separators (ECS) use permanent, rare earth magnets with multiple poles to repel nonferrous metals, primarily aluminum. The magnet rotates, creating an alternating magnetic field and inducing eddy current flow in metallic particles. This creates a magnetic field in the particles that opposes the field in the magnet, causing repulsion. The repelled items are kept separate by a splitter. The shell around the magnet and the belt moving the material over it should be nonmetallic. The field could alternatively be produced by electric coils, but such devices have been found to require more energy, maintenance, and operation funding.

The force produced varies directly with the field intensity at the belt squared ($Gauss^2$) and the rotational speed of the magnet (rpm). How far a metallic object is repelled depends on its conductivity and density (see Table 11), relative surface area, shape, and size. Although copper's conductivity is higher, its density is about 3 times that of aluminum. Hence, an aluminum object will be thrown farther than a copper object of similar size and shape. Also, whole aluminum cans will be repelled farther than crushed cans (Morgan, 1996:4).

Belt speed in an ECS can be adjusted as high as 183 m/min (600 ft/minute). The speed should be adjusted to allow enough distance between particles, increasing the recovery (Morgan, 1996:5). For a constant belt speed, the recovery is indirectly proportional to the feed rate. One machine fed with particles from 5 to 10 cm (2 to 4 in) was found to recover 99% at only 0.063 tonnes/hr (0.069 tons/ hr), but had a much lower recovery of 66% at the higher feed rate of 1.5 tonnes/hr (1.65 tons/ hr) (Diaz et al., 1982:145-6).

ECSs can be economically very important because of the high revenue that can come from the sale of recovered Aluminum. The feed to an ECS is often the heavies from an air classifier with the ferrous component removed. The latter step is important as it prevents blockage of the flow and shielding of conductors from the magnetic field (Vesilind and Rimer, 1981:218).

Table 11. Conductivity-Density Ratios of Nonferrous Metals

Material	Conductivity / Density
Aluminum	14.0
Magnesium	12.9
Copper	6.7
Silver	6.0
Zinc	2.4
Gold	2.2
Brass	1.7
Nickel	1.4
Tin	1.2
Lead	0.4

(Morgan, 1996:7)

Electrostatic Separation. Electrostatic separation separates particles by charging and decharging them. Material is fed onto a rotating drum and charged by a corona electrode with 15,000 to 30,000 volts. Particles that lose their charge quickly fall of first.

Splitters separate the falling materials. Any particles adhering to the drum are removed by a brush. Applications of this technology today include separation of plastics from aluminum in food containers, purification of ore, demetallization of cable scrap, and recycling of circuit boards and automobile shredder residue (Kohnlechner, 1997:20).

Shredders

Shredding is mechanical size reduction of MSW. It is advantageous in that it increases the homogeneity, bulk density, and ratio of surface area to volume. The increased density decreases transportation volume and cost. It also decreases landfill volume and cost, since shredded wastes have an effective density 25% to 60 % greater than unshredded waste when compacted in the landfill (Rhyner et al., 1995:159). Several types of shredders have been used to size-reduce MSW include flailmills, hammermills, grinders, shears, and wet pulpers.

The advantage of shredders applicable to the model is the loss of moisture content due to heat generated during shredding. This reduces the weight of the waste and the associated landfill tipping fee. Diaz et al. (1982:35) claim that this loss is 20% of the moisture content of the waste before it enters the shredder, as shown in Table 12. Tchobanoglous et al. (1993:599) argue that 15% of moisture content is a good estimate, but that it varies from 5 to 25 % under normal circumstances. Notice that the figure given by Diaz et al. falls in this range. The moisture content itself varies from 15 to 40% depending on the geographic location and season of the year (Tchobanoglous et al., 1993:599). In Diaz' example, the moisture content is 33%, also falling in the range (35).

Table 12. Shredder Recovery Factors

Material	Fe	Al	Glass	Paper	Plastic	OIR	OR
Solid	1.00	1.00	1.00	1.00	1.00	1.00	1.00
H_2O	0.20	0.20	0.20	0.20	0.20	0.20	0.20

OIR = Other Inorganic Residue; OR = Other Organic Residue (Diaz et al., 1992:35)

The drawbacks of shredders include jams, fire, explosion, and dust. Jamming can damage the motor. Fires usually start during jams because there is enough time for kindling temperature to be reached. Explosions occur when propane tanks, gas cans or ammunition are impacted. The shredder should have an escape channel to the outside to direct explosions away from personnel and equipment. Dust can be reduced by spraying water on the waste. Unfortunately, this also increases the moisture content of the waste and the probability of leaching in the landfill, while simultaneously decreasing the effectiveness of the material as a fuel (Rhyner et al., 1995:162).

Drobney et al. estimated the energy requirements of shredding MSW to a nominal 15 cm (6 in) size as 8.2 to 16.4 kW*h/tonne (25,400 to 50,800 BTU/ton), with an average of 12 kW*h/tonne (37,200 BTU/ton). The power requirement is defined by the equation

$$P = 12 \text{ kW*h/tonne} \times Q \times (\text{size multiplier}) \times (\text{material multiplier}) \qquad (4)$$

where Q is the feed rate of material into the shredder in tonnes/h and the multipliers are as defined below in Table 13.

Table 13. Multipliers to Adjust Shredder Energy and Power Requirements

Product Size	Size Multiplier	Material Type	Material Multiplier
15 cm (6 in)	1.00	MSW	1.00
10 cm (4 in)	1.39	Picked MSW	0.65
5 cm (2 in)	1.64	Wood & fibers only	0.45
2.5 cm (1 in)	2.38	Automobile bodies	2.82

(Drobney et al., 1971 in Rhyner et al., 1995:163)

Flailmills. Flailmills consist of two parallel shafts rotating in opposite directions with hammers attached. They perform coarse shredding with a high flow rate and low energy requirement. They tear bags open, but allow difficult-to-shred items to pass through with little reduction (Rhyner et al., 1995:160).

Hammermills. Hammermills consist of a central spinning shaft with fixed or free-swinging hammers attached. A hammermill is classified as vertical or horizontal, in accordance with the direction of the shaft. The shaft is inside a durable cylindrical housing. The shredding occurs when materials are forced between the hammers and the housing. Waste is fed in at the top of the housing and discharges as the bottom. Items that resist shredding escape through a reject chute as the top. The hammers must be maintained regularly to minimize wear. Hardened steel is welded to their edges (Rhyner et al., 1995:160).

Grinders. Grinders are similar to the vertical hammermill; the shaft is vertical and the infeed chute is at the top. The shredding mechanism on the shaft, however, is star wheels. The housing is conical with the widest part at the top. This causes objects to be shredded smaller and smaller as they proceed down the cone until they exit via the discharge chute at the bottom (Rhyner et al., 1995:161).

Debaggers. A specialized type of shredding is performed by debagging systems. These include slitters, rippers, grinders, and shredders. These systems can be aimed at debagging recyclables, compostables, or both.

Optical-type Sorters

Specialized plastic sorters are available on the market. They mainly separate PET, HDPE, and PVC from each other by near-infrared or x-ray radiation. The machines also separate by color using imaging technology. The actual separation is effected by synchronized air blasts to move the identified items. Glass sorting by color is also possible by optical systems, but are not in widespread use (Recycling Today (Supplement), 1998:94-96; Rhyner et al., 1995:176).

Densification/Baling

Balers compress separated recyclables, which enhances their marketability and reduces storage space and transportation cost. Forklift vehicles typically used to move bales to temporary storage or onto trucks or rail cars. Raw MSW can be baled to cut use of landfill volume in half and reduce litter. Balers compress at 13,790 to 24,132 kPa (2,000 to 3,500 psi). The density of MSW bales is about 1,187 kg/m^3 (2000 pcy). Factors affecting bale quality include material type, pressure applied, time of pressure application, bale volume, and material moisture (Rhyner et al., 1995:176-7). Table 14 outlines the six types of balers, their cost ranges, their capacities in terms of tonnes (tons) per hour of paper, and the materials that they can densify.

Table 14. Baler Types and Attributes

Type	Cost Range $000s	Capacity, tph paper	Materials Handled
Single-Ram Extrusion	90-700	63.5 (70)	Paper, plastic, OCC, UBC
Single-Ram Closed-End	20-100	4.5 (5)	Paper, plastic, OCC, UBC, light extrusions
Two-ram	100-500	45.4 (50)	Paper, plastic, OCC, UBC, light extrusions
Vertical	5-40	2.7-4.5 (3-5)	Paper, plastic, OCC, UBC, light to med. extrusions, some scrap metal
Ferrous	180-1000	21.8 (24)	All types of heavy scrap metal
Shear/Baler/Logger	300-1500	7.3-18.1 (8-20)	All types of heavy scrap metal

OCC = old corrugated cardboard, UBC = used beverage container (Phillips, 1998:26)

For a small MRF such as the one Spangdahlem AB is considering, 2.7 tonnes (3 tons) per hour is adequate. Hence, a vertical baler or a single-ram closed-end baler would be suitable and inexpensive. The flow of waste at the base is less than 45 tonnes (50 tons) per week. If half of this is recovered and baled, then the baler would work for less than 9 hours per week.

Conveyors

Conveyors are used to transport waste to and from unit operations and for hand sorting. Conveyors that move by contact with rollers are the most common. Four basic types are used. A flat belt with side skirts is the simplest. A conveyor can also have troughed support idlers, which improves the magnetic separation and eliminates the need for side skirts. Drag conveyors are equipped with crossbars, which prevents slipping of material on inclined conveyors.

Rotating screws have been used to transport waste while simultaneously breaking bags open. Vibrating conveyors are mounted on springs and agitate the wastes in the desired direction. Pneumatic conveying systems have also been used.

IV. Methodology

As discussed at the end of Chapter Two of this thesis, a spreadsheet model for mass recovered and system cost followed by use of MCDM techniques is appropriate to determine which sequence(s) of unit operations will be optimum for Spangdahlem AB. This chapter of the thesis discusses in detail the methodology used -- the Spangdahlem waste characterization, setup of the spreadsheet model, formulations used to determine mass recovered by and cost of each alternative, and the MCDM methodology will be discussed. The next chapter will discuss the results of following this methodology.

Waste Characterization

Spangdahlem AB currently has two types of waste collection, one of material from stationary containers to be landfilled and another of recyclable materials. Table 15 shows the mass of each type of material collected.

Table 15. Waste Streams of Spangdahlem AB

Material	Mass, tonnes (tons)	% of total
Stationary Container Waste	8,805.7	49.89
Glass	882.0	5.03
Paper	3,810.0	21.72
Yellow Bag Waste	1,060.0	6.04
Plastic	99.0	0.56
Other metal	826.0	4.71
Wood	2042.0	11.64
Putrescible Waste	53.7	0.31
Tires	18.7	0.11
Total	17,597.1	100.00

(Spangdahlem AB and AFCEE, 1998)

Most recyclables are collected at the Base Recycling Center (BRC), others such as glass and paper from public bins, and household recyclables in designated yellow bags set out next to stationary containers. The yellow bag waste has not been characterized, but the waste in stationary containers was characterized by Parsons Engineering in December 1997. These results are shown in Table 16.

Table 16. Stationary container Waste Characterization, % by weight

Component	90% LCL	Mean	90% UCL
Glass	2.69	3.82	4.95
Bimetal cans	0.86	1.46	2.06
Plastic	7.55	8.83	10.11
Paper (clean)	12.06	15.54	19.02
Aluminum	1.29	1.65	2.01
Other metals	1.07	2.05	3.03
Yard waste	0.25	2.57	4.89
Wood	0.22	1.49	2.76
Putrescible (food) waste	24.59	29.98	35.37
Fluorescent/other light bulbs	0.00	0.07	0.16
Construction debris & dirt	0.94	4.04	7.14
Batteries & electrical	0.24	2.37	4.50
Household Hazardous Waste	0.00	1.42	3.27
Tires	0.00	0.63	1.80
Bulk goods	0.00	0.81	1.80
Ash	0.00	0.07	0.15
Textiles	1.50	2.32	3.14
Paper (soiled)	7.34	9.22	11.10
Other yellow-bag waste	1.33	1.99	2.65
Miscellaneous	6.87	9.67	12.47
Total		100.00	

LCL = Lower Confidence Limit, UCL = Upper Confidence Limit

(Spangdahlem AB and AFCEE, 1997:3-7,3-11)

These data were collected from 52 stationary containers based on volume measurements of all stationary containers. The volumes were converted to weights. The interval between the Lower Confidence Limit (LCL) and the Upper Confidence Limit (UCL) defines the range within which percents by weight for 90 out of 100 samples would fall. These limits represent the 90% confidence interval for each component. For aluminum, 90 out of every 100 samples of solid waste would contain between 1.29% and 2.01% by weight. To model separation of this waste stream through MRF processes, a single value is chosen to represent each component. The percent by weight mean value of each component is used in the model.

This characterization was carried out from 11 November to 17 December 1996. To some degree, it may not be representative of the annual mean. Tchobanoglous et al. (1993:141,144) address this issue. They estimate that the mass of MSW to be collected in a small community on any given week (the stationary containers were emptied once per week at the time of the study) can vary from the annual mean by a factor of 0.6 to 1.75. For a large community, the interval of factors decreases to 0.7-1.5. These intervals are exclusive of extreme values above the 99 and below the 1 percentile. The terms "large community" and "small community" are not defined, so it is unclear which category Spangdahlem AB falls under.

Residential waste generation rates usually reach their maximum during the Christmas holiday season and during spring housecleaning days (Tchobanoglous et al., 1993:141). As this study was completed before Christmas and spring, the variation is all the more likely to be inside the interval. Other seasonal variations are included in the factor, including that moisture content, and consequently the mass, of waste is lower in winter. Furthermore, the composition of waste is different in summer, including a higher portion of yard waste.

Therefore, the mass of waste found in the study of stationary containers is likely to be smaller than the annual average, as small as a factor of 0.6. The annual average, conversely, could be 1/0.6, or 1.67 times as large. The MRF should be designed to handle up to this flow, if not more for growth. If mass is actually higher each week, then most likely the recovered mass will be higher, and the benefits from its sale will increase.

The category "other yellow-bag wastes" refers to materials in the stationary containers that should have been segregated for recycling through the yellow bag program. Materials acceptable for placement in yellow bags are metals, plastics, and septic containers (layered plastic, aluminum, and paper). The metals category is more inclusive than in many stateside recycling programs. It takes in the typical tin cans and soda cans, but also includes aluminum foil and trays. Similarly, a broader range of plastic is acceptable, including bags, wrapping, bottles, cups, tubs, and packaging foams, whereas U.S. recycling programs commonly accept only PET (Type 1) HDPE (Type 2) plastics. Glass and paper are not taken in the yellow bags, but should be placed in containers located throughout the community.

The category "Paper" refers to all types of paper, including cardboard, newspaper, and office paper. The "Miscellaneous" materials were found to be roughly one-half diapers.

The 20 categories analyzed in the Parsons study of stationary container waste are reduced to 15 in the model by combining them. This is for simplification, and is justified by similar characteristics of combined categories, as well as minute mass fractions of some categories. The conversion is shown in Table 17.

Table 17. Categories Used by Parsons and in Spreadsheet Model

Parsons	Spreadsheet Model	Comment
Aluminum	1-Aluminum	All aluminum
Bimetal cans	2-Ferrous metals	
Other metals	2-Ferrous metals	
Plastic	3-Plastic	
Paper (clean)	4-Paper	Cardboard is presorted
Paper (soiled)	4-Paper	Cardboard is presorted
Glass	5-Glass	
Yard waste	6-Yard waste/ Food waste	
Food waste	6-Yard waste/ Food waste	
Wood	7-Wood	
C&D	8-C&D/bulbs/ash	
bulbs	8-C&D/bulbs/ash	
ash	8-C&D/bulbs/ash	
Batteries & electrical	9-Batteries & electrical	
HHW	10-HHW	
Textiles	11-Textiles	
yellow-bag waste in stationary container(YB)	12-yellow-bag waste in stationary container(YB)	
Miscellaneous	13-Miscellaneous	
Tires		Presorted
Bulk goods		Presorted

"Other metal" is assumed in the model to all be ferrous, although a small fraction may actually be nonferrous. The most common nonferrous metal in MSW is aluminum, which has its own category in the study. Hence, "Other metal" is combined with "Bimetal cans." "Food waste" and "Yard waste" are combined because they behave similarly in air classifiers and screens. Figure 5 reveals also that their size distributions are roughly equivalent (the figure refers to "Yard waste" with the word "Garden").

"Ash" and "Fluorescent/other light bulbs" are assumed to behave similarly to "Construction debris & dirt" (C&D). They are also a very small fraction of the mass (0.07% each). Most light bulbs are crushed in handling and transport and are thus similar in size to C&D. "Clean paper" and "Soiled paper" are combined since they behave similarly and arrive at the MRF unseparated.

The number of material categories to be processed through unit operations is further reduced to 13. As noted in Table 3, large bulky items must be presorted. Hence, all "Tires," "Bulk goods," and cardboard (part of "Clean paper" and "Soiled paper") are manually presorted. Perhaps some fraction of these materials would be missed in the presort, but this fraction is assumed to be negligible.

An interesting trend in the waste composition that should be noted is the high amount of food waste (putrescibles) at 30%. This is probably due to the fact that the base is not set up with sink waste grinders. For purposes of comparison, Tchobanoglous et al. (1993:52) have provided a typical waste stream characterization in the U.S. with and without recyclables and grindings from sink disposal units, shown in Table 18. Notice that food waste is less than 10% in any of the four categories. The category closest to the base's stationary container waste is "without recyclables, with grindings," the second column of numbers.

The waste stream at Spangdahlem will obviously differ from that typical of a U.S. military or civilian community. At the same time, the waste will differ from the typical waste stream in that country because base residents have access to imported American products through the Commissary and Base Exchange systems, and are likely to retain many habits of American culture.

Table 18. Typical U.S. Waste Characterization, as collected, % by weight

Component	Without recyclables Without grindings	Without recyclables With grindings	With recyclables Without grindings	With recyclables With grindings
Glass	8.0	7.9	9.1	9.0
Bimetal cans	6.0	6.0	5.8	5.8
Plastic	7.0	7.0	6.9	6.9
Paper	34.0	33.8	35.8	35.6
Cardboard	6.0	6.0	6.4	6.4
Aluminum	0.5	0.5	0.6	0.6
Other metals	3.0	3.0	3.0	3.0
Yard waste	18.5	18.4	17.3	17.2
Wood	2.0	2.0	1.8	1.8
Putrescible waste	9.0	9.4	8.0	8.4
Textiles	2.0	2.0	1.8	1.8
Dirt, ash, etc	3.0	3.0	2.7	2.7
Rubber	0.5	0.5	0.4	0.4
Leather	0.5	0.5	0.4	0.4
	100.0	100.0	100.0	100.0

(Tchobanoglous et al., 1993:52)

The high composition of organics noted above causes the stationary container waste to have a very high VS. A calculation is made in Table 19 below. It is evident that much source reduction, recycling, and/or treatment needs to be done to reduce the VS to the 5% German mandate.

Table 19. VS of Spangdahlem AB Stationary Container Waste Components

Component	% by weight	VS, % of Total Solids[a]	VS, % by weight
food	29.98	95-98	28.481
paper (clean)	15.54	90-95	13.986
paper (soiled)	9.22	90-96	8.298
yard waste	2.57	85-90	2.1845

([a]Tchobanoglous et al., 1993:88)

As mentioned previously, the composition of yellow-bag wastes at Spangdahlem AB is unknown. The facility in Trier, Germany, that processes the yellow bags from the area including Spangdahlem AB has data regarding the contents of the yellow bags it receives, as shown in Table 20. "Septic containers" refers to drink boxes and similar containers which consist of layered plastic, paper, and aluminum.

Table 20. Characterization of Wastes Processed at Trier Facility

Component	% by Weight
Steel	21.3
Aluminum	2.7
Plastic	31
Septic Containers	15
Waste	30
Total	**100**

(Schwarz, 9 November 1998)

Spreadsheet model

Each link in the train is any one of six common unit operations of MRFs: eddy current separator (ECS), magnet, air classifier, screen (including trommel), hand sort, and shredder. Of all the possible unit operations previously discussed, only these six were modeled. Densification and specialized equipment are not considered. A baler, for example, although it is perhaps the most common item in MRFs, does not contribute to waste separation and mass recovery. Most MRFs do not have more than six unit operations that actually separate materials. The Rumpke MRF in Dayton, OH uses only four: a magnet, manual sort, ECS, and trommel. All four of these are modeled in this thesis. For densification, the Rumpke MRF has four items: a baler, an aluminum baler, a tin can flattener, and a plastic bottle shredder. It also employs one specialized item, an X-ray sorter that removes PVC (Type 3 plastic) from other plastics.

The unit operations modeled are found commonly in MRFs in the U.S. and/or Germany. The MRF at Trier that processes yellow bags from the Base uses a picking line, magnet, ECS, and air classifier, all of which are modeled.

With six operations, the total number of feasible trains is:

$$6^1 + 6^2 + 6^3 + 6^4 + 6^5 + 6^6 = 6 + 36 + 216 + 1296 + 7776 + 46{,}656 = 55{,}986 \quad (5)$$

If each of these trains occupied one row of a Microsoft Excel spreadsheet, the size constraint for rows would almost be reached. An Excel worksheet is limited to 64,000 rows, 256 columns, and 32,000 characters per cell (Microsoft, 1997:592). The model can be unwieldy as it approaches these limits. For example, the bare bones model for stationary container waste occupies over 3 megabytes. When formulas are copied into all cells, the computer calculates very slowly, and can run out of memory.

Some practical rules (heuristics) are applied to eliminate many impractical combinations, reducing the number of alternatives by three-quarters to 13,807. One rule is that no more than two of the same machine are allowed in any train because of diminishing returns. This may seem like a limiting factor, but it already goes beyond current practice, where even two of any machine in a single train is quite rare. The Dayton and Trier MRFs cited have no duplicated unit operations. The largest of the Chicago "blue bag" MRFs has two of several unit operations, but this is because there are two identical processing lines.

Another simple rule is that a hand sort should not follow a shredder, since it is very difficult and dangerous to hand separate recyclables once they are shredded. No data was found on the efficiency for this situation, but it is likely to be very low.

Another simplification is that certain of the sorting devices are "binary machines." Binary machines are those producing two output streams that could each be processed through further unit operations. For instance, an air classifier is binary because it separates the incoming waste stream into two fractions, heavies and lights. A MRF manager may want to process the lights, or the heavies, or both. It is initially assumed for simplification that the lights are recovered as-is and the heavies will be further processed.

The other five machines are similarly classified and simplifying assumptions are made. Table 21 summarizes this information. A screen or trommel is a binary machine; the unders are recovered as-is and the overs will be further processed. Shredders are not binary; one of the two output streams is merely lost moisture, which cannot be further processed. Hand-sorted materials are not binary for our purposes, although some MRFs may further separate plastics by type, etc. Magnets are not binary, unless it is necessary to separate impurities from the recovered ferrous metals. It is assumed that this is not necessary. ECSs are not binary, unless it is necessary to separate ferrous metals or other impurities out of the recovered nonferrous stream. If an ECS is not preceded by a magnet, the recovered material from the ECS will be a mix of ferrous and nonferrous metals, which is not saleable. Hence, all theoretical process trains where an ECS is not preceded by a magnet are eliminated from consideration.

Table 21. Flow definitions

Unit Operation	Binary	Removed	Leftover (more sorting)
1 = ECS	No	all metals	nonmetals
2 = Magnet	No	ferrous metals	nonmetals
3 = Air classifier	Yes	Lights	Heavies
4 = screen/trommel	Yes	Unders	Overs
5 = hand sort	No	picked	not picked
6 = shredder	No	moisture	drier mass

Each train is evaluated in terms of recovery and cost. The set of recoveries and costs is then reduced for analysis by MCDM techniques. The use of MCDM to determine the optimum solution requires the judgment of a decision-maker (DM) to balance the tradeoffs between criteria. The Visual Interactive Method for Discrete Alternatives (VIMDA) software is used to eliminate dominated alternatives, leaving only non-dominated alternatives. Non-dominated alternatives are those which are no worse than any other alternative, and better than others in at least one criterion. If maximum diversion is not feasible economically or otherwise for the AF, the criterion of cost is added and the MCDM techniques are used to determine the optimum system. The DM analyzes the non-dominated alternatives until s/he determines which is optimal according to his/her utility function. This chosen alternative then becomes the course of action to be taken.

Formulations for Mass Recovery

To model the movement of the Spangdahlem waste stream through the various process trains, certain assumptions are made and equations for recovery are used. These are explained for processing of yellow-bag wastes through the MRF, and for processing of stationary container wastes through the MRF. So that formulas can be uniform, they contain nested “if statements”. For example, the glass in the stationary container waste stream will be separated to some extent by an air classifier, screen, or hand sort. The formula in English for what mass of glass is recovered from an air classifier in the first position in a train is as follows: If the first machine (say in cell A11) is an air classifier (coded as a 3), then the mass of glass recovered equals the fraction of glass in the light fraction (call it glass_lights) times the mass of glass in the inflow (call it In_Glass), otherwise return a value of 0 mass units of glass recovered. This formula is expressed mathematically in the spreadsheet as:

IF(A11=3,glass_lights*In_Glass,0) (6)

Similarly, if the first machine is a screen of any type (coded as a 4), then the mass of glass recovered equals the fraction of glass in the unders (call it glass_ unders) times the mass of glass in the inflow (In_Glass), otherwise return a value of 0. This formula is expressed mathematically in the spreadsheet as:

IF(A11=4,glass_unders*In_Glass,0) (7)

The last operation recovering glass is the hand sort (coded as a 5). The mass fraction of glass recovered by picking is expressed as glass_pick. Thus the spreadsheet formula is:

IF(A11=5,glass_pick*In_Glass,0) (8)

To get the computer to do all the work of deciding which machine is in the first slot, we nest these three if statements into one formula:

IF(A11=3,glass_lights*In_Glass,IF(A11=4,glass_unders*In_Glass,IF(A11=5,glass_pick*In_Glass,0))) (9)

The formulas for other materials and these three operations follow the same pattern. The component recoveries by unit operation are shown in Table 22. The columns of the table reveal which materials can be recovered by any unit operation, and which cannot. Notice from column 1 that only metal and aluminum are recovered by machine 1 (ECS). Column 2 shows that only metal is recovered by machine 2 (magnet). Columns 3 and 4 indicate that all components are recovered by machines 3 (air classifier) and 4 (screen). Column 5 reveals that only aluminum, metal, plastic, paper, glass, and septic containers are recovered by machine 5 (hand sort). Column 6 shows that only the waste fraction from yellow bags and Yard waste/ Food waste from stationary containers are affected by machine 6 (shredder).

Table 22. Component Recoveries by Unit Operation

Machine/ Component	1 ECS	2 Magnet	3 classifier	4 screen	5 sort	6 shred
Materials found in both yellow bags and stationary containers						
Aluminum	Rec_Al * In_Al	---	Al_lights* In_Al	Al_unders* In_Al	Al_pick* In_Al	---
Ferrous metals	Rec_Al * In_Fe	Rec_Fe* In_Fe	Fe_lights* In_Fe	Al_unders* In_Al	Al_pick* In_Fe	---
Plastic	---	---	Pl_lights* In_Pl	Pl_unders* In_Pl	Pl_pick* In_Pl	---
Materials found only in stationary containers						
Paper (clean/soiled)	---	---	Pap_lights* In_Pap	Pap_unders* In_Pap	Pap_pick *In_Pap	---
Glass	---	---	glas_lights *In_Glas	glas_unders* In_Glas	glas_pick *In_Glas	---
Yard waste/ Food waste	---	---	OR_lights* In_Food	Food_unders *In_Food	---	0.20* moisture
Wood	---	---	OR_lights* In_Wood	Wood_under s*In_Wood	---	---
C&D/bulbs/ ash	---	---	OIR_lights *In_CD	CD_unders* In_CD	---	---
Batteries & electrical	---	---	OIR_lights *In_elec	elec_unders* In_elec	---	---
HHW	---	---	OIR_lights *In_HHW	HHW_under s*In_HHW	---	---
Textiles	---	---	OR_lights* In_Tx	Tx_unders* In_Tx	---	---
yellow-bag waste in stationary container(YB)	---	---	OIR_lights *In_YB	YB_unders* In_YB	---	---
Miscellaneous	---	---	OR_lights* In_Misc	misc_unders *In_Misc	---	---
Materials found only in yellow bags						
Septics	---	---	OIR_lights *In_sept	sept_unders* In_sept	sept_pick *In_sept	---
waste	---	---	OR_lights* In_waste	waste_unders *In_waste	---	0.20* moisture

OIR = Other Inorganic Residue; OR = Other Organic Residue; --- = No removal

Note that the metal recovered from an ECS is expressed as Rec_Al*In_Fe instead of as Rec_Fe*In_Fe. Since no data are available on the recovery rates of metals in an

ECS, it is assumed that they are recovered at the same rate as pure nonferrous material. This assumption will decrease precision when metals and aluminum are processed simultaneously by an ECS as shielding of aluminum by metals and other fouling will occur. Hence, recoveries will be exaggerated to some degree. Furthermore, since no data are available on the recovery rates of metals by hand sort, it is again assumed that they are recovered at the same rate as pure nonferrous material. This assumption is supported by the fact that many items of metal, such as tin cans, are roughly the same size, shape and luster as nonferrous items, such as beverage cans.

In air classification, eight of the modeled components of Spangdahlem's MSW are not given an RFTF by Diaz et al. Diaz et al., however, have two "catch all" categories - Other Inorganic Residue (OIR) and Other Organic Residue (OR). The former is assigned to the categories of C&D, elec, HHW, and OYB while the latter is assigned to food, Misc, textiles, and wood. These groupings of OIR and OR are most likely to be somewhat different from those used by Diaz et al., and this is an inaccuracy of the model.

For screening, the aperture size is taken as ½ inch. The spreadsheet, however, will model any aperture size for which PSD information about all components is available. Four of the modeled components of Spangdahlem's MSW are not given a screen RFTF by Diaz et al. The PSD for these components was estimated by analyzing the data from the waste characterization (Spangdahlem AB and AFCEE, 1997:Appendix C). For the ½-inch screen, the estimated portion passing is 5% for Miscellaneous and 2% for Batteries & Electricals, Household Hazardous Waste, and Yellow Bag materials. The data from which these estimates were derived are found in Appendix A.

For hand sorting, recovery (%) and picking rates (tph) were taken from the literature and are shown in Tables 4, 5, and 6. Diaz et al. do not provide the recoveries for hand sorting as an RFTF, but in function the recovery used here is the same. The variable names that represented these quantities in Table 23 are also shown. The desired materials picked from stationary container waste are the first five of six materials listed, while the desired materials picked from yellow bags are the last four. Some materials are desirable in both scenarios (plastic, aluminum, and ferrous).

Table 23. Hand Sorting Recovery and Picking Rates Used in the Model

Material	Recovery (RFTF)	Variable Name	Picking Rate, tph/sorter	Variable Name
Paper	77.5%	Pap_pick	0.82 (0.90)	Pap_hand
Glass	87.5%	glas_pick	0.41 (0.45)	glas_hand
Plastic	87.5%	Pl_pick	0.18 (0.20)	Pl_hand
Aluminum	87.5%	Al_pick	0.054 (0.06)	Al_hand
Fe	80.0%	Al_pick	0.68 (0.75)	Al_hand
septic	80.0%	sept_pick	0.18 (0.20)	sept_hand

It is assumed that the amount of material that can be picked determines how many pickers are used. The number of pickers needed to sort aluminum at a given stage, for example, is calculated simply by dividing the amount of aluminum recoverable in tph (Al_In * Al_pick) by the picking rate (Al_hand) in tph/sorter. Similar calculations are performed for all other materials that are designated as pickable, and the total number of pickers at that stage is the sum of the number of pickers required for each material.

For shredding, nominal particle size after shredding is larger than aperture size of any screen(s) following in the same train. This simplification prevents midstream changes in the PSD that lead to changes in the fraction reporting to the overs.

The mass of materials not recovered is calculated and serves as the in-feed into the next unit operation. For any component, this mass is calculated simply by subtracting the mass recovered from the mass of the in-feed for that component. In the case of glass and hand sort used above, the formula would be (In_Glass) – (glass_pick*In_Glass). Another way of expressing the same formula is (1 - glass_pick) * (In_Glass).

Formulations for Benefit Minus Cost

The monetary cost of recycling their own waste is an important consideration for DMs at Spangdahlem AB. Costs are indicated by the difference of annual benefit and annual cost (B-C). Since operating a MRF at Spangdahlem AB is a decision that is both optional and incremental to the current waste management strategy, costs that are already being or have been paid are not considered in this analysis. For example, collection of waste and yellow bags are carried out by two ongoing contracts. Funds for the construction of a building that will serve as the MRF, approximately $2 million, have already been set aside. Only costs that vary with choice of processing equipment are considered. All other costs are considered equal, regardless of what unit operations are implemented. All costs are annualized.

The benefits and costs analyzed include: revenue from sale of extracted recyclables, the tipping fees saved from not landfilling reusable and separated wastes, amortized equipment costs, and labor expenditures for hand sorting. The formula used to calculate the B-C (per year) is as follows:

$$(Revenue) + (SavedTippingFee) - (Equipment) - (ManualLabor) \quad (10)$$

Revenue is calculated as the sum of products of the mass of each material and its sale price. Note that the water evaporated from the MSW during shredding brings tipping fee savings, but does not bring any revenue. The sale prices are for loose material (not baled) and are shown in Table 24 under "Processor." Notice that, pound for pound, aluminum is far and away the moneymaker. Of course, these prices change over time, and the model can be run for any historical, current, or projected price scenario. The market is currently in a lull, down from a record high in June 1995 when the price paid by end-users for an average ton of curbside recyclables was $136.83. In June 1997, that same figure was down to $45.19 (Berenyi, 1997:7).

Table 24. Material Sale Prices per Ton

Material	Processor	End User
Aluminum	$560.00	$940.00
HDPE natural	$60.00	$180.00
Clear PET	$20.00	$120.00
Steel, clean cans	$9.00	$43.00
Glass, clear/flint	$9.00	$32.00
Paper, white ledger	$55.00	$109.00
Cardboard	$2.00	$38.00

(www.wasteage.com/RCT/RecyclingTimes, The Markets Page, Oct. 15-Oct. 28, 1998)

The tipping fee (in German Marks per metric tonne) at the county landfill where waste from Spangdahlem AB currently are deposited is $DM165. At an exchange rate of 1.65 DM/US$, the fee translates to US$90.83 per English ton. At a generation rate of 17,362 tonnes (19,098 tons) of MSW per year (Spangdahlem AB and AFCEE, 1997: Appendix D), the tipping fee would be DM 2.865 million (US$ 1.735 million) if all MSW generated was landfilled. The annual amount saved in tipping fees is calculated by multiplying the tipping fee by the mass of material diverted. Since lost water from shredding reduces the weight of landfilled waste, it also reduces the amount paid in tipping fees.

Equipment costs vary as much as the cost of a car. It is assumed that low-end systems will be adequate. All items are assumed to have a useful life of 30 years and are amortized at a discount rate of 4%. This assumed life and discount rate may be optimistic. A small ECS costs $35,000 (Gedgaudas, 1997:14). A head pulley magnet costs $3,000 (Gedgaudas, 1997:10). An air classifier was priced at $15,000, and an adequate screen can be found for $5,000 (Alan Ross Machinery). A small hammermill (shredder) costs $8,000 (Graveman, 1997:18).

Labor costs were based on minimum wage ($5.15/hr) with no overtime. The German rate may be different, but it is possible to hire dependents of Air Force personnel at the U.S. minimum wage. The number of pickers required for any process train is calculated by dividing the flow rate of each material at the picking point by the picking rate. The sum of the calculations for all materials dictates that number of pickers required. The picking rates are based on the data presented in Table 4. The high value was chosen for aluminum (0.054 tonnes/hr, or 0.06 tons/hr) since it is the moneymaker. Since the high value (0.41 tonnes/hr, or 0.45 tons/hr) for separation of glass by color is the same as the low value for separation of mixed glass, it is used as a representative middle value. The value for paper is taken to be on the low end of the range for cardboard and newspaper since its size is smaller. The picking rate for plastic was taken as the midpoint (0.204 tonnes/hr, or 0.225 tons/hr) of the range. Table 5 provides the average recovery rate for ferrous metals as 5.41 tonnes (5.96 tons) per employee per day, which, assuming 8 hours of work per day, yields 0.68 tonnes/hr (0.75 tons/hr).

VIMDA Software

Dr. Pekka J. Korhonen of the Helsinki School of Economics developed the Visual Interactive Method for Discrete Alternatives (VIMDA) software (Korhonen, 1988:152-9). VIMDA is useful because it allows the DM to examine any efficient alternative without assuming anything about the DM's underlying utility function. The assumption that the utility function is unchanged during the interactive process is also unnecessary. The criteria can be quantitative or even ordinal, where the DM can only rank alternatives by each criterion (Korhonen, 1988:157). VIMDA is also fit for this research because it handles discrete data, and each alternative sequence of separation equipment is a discrete entity.

VIMDA eliminates dominated alternatives, thereby decreasing the number of alternatives the DM must consider. An alternative x_i, $i \in I$, is dominated if there is another alternative x_k, $k \in I$, such that $x_{ij} <= x_{kj}$ for all $j \in J$ (that is, x_i is no better than x_k for all criteria J) and $x_{ij} < x_{kj}$ for at least one j (that is, x_{ij} is inferior to x_{kj} such that x_{ij} and x_{kj} are not the same point).

VIMDA assumes there is one DM, a set of n alternatives (n>0) and p criteria (p>1) which form an n x p matrix X whose elements are denoted by x_{ij}, $i \in I = \{1, 2,..., n\}$ and $j \in J = \{1, 2,..., p\}$. VIMDA assumes that the criteria are to be maximized, i.e., the default ideal is the upper bound. If a criterion is to be minimized, as in the case of system cost, the DM can change the ideal from the upper bound (maximize) to the lower bound (minimize). The criteria used to judge the MRF systems, recovery (R) and benefit minus cost (B-C), are maximized.

To help the DM find the most preferred alternative, VIMDA projects the reference direction onto the N-set using the achievement (scalarizing) function. To explain how it does so, we will first explain two terms. The reference direction is the vector in the Y space from the current alternative to the point defined by the DM's aspiration levels. The achievement function finds out attainable and efficient alternatives (N-set) that bear some relation to the DM's aspirations. It is defined as:

$$f(\mathbf{g}, x_i, \mathbf{w}) = \max (g_j - x_{ij}) / w_j \qquad (11)$$

where $i \in I$, $\mathbf{g} \in$ (Y space) is a given reference goal vector called a reference point, and $\mathbf{w} \in$ (Y space) is a given weighting vector. If criterion j is maximized, as we have assumed, then $w_j > 0$. Otherwise $w_j < 0$.

The division by the weight may be confusing to many DMs. It means that the more important a criterion is, the lower its weight must be. This runs contrary to the logic of the objective function to maximize, where larger values of criteria are preferred.

We can find an efficient solution x_k, $k \in I$, by minimizing $f(\mathbf{g}, x_i, \mathbf{w})$, $i \in I$, for given $\mathbf{g}$ and $\mathbf{w}$. This method seems to correspond to the preference structure commonly referred to as "minimizing the maximum regret" or "minimax."

Given an initial solution x_h, $h \in I$, a reference point $\mathbf{g}$, and a weighting vector $\mathbf{w}$, we can define a parameterized achievement function F for the reference direction $\mathbf{d} = \mathbf{g} - x_h$ as follows:

$$F(t, \mathbf{d}, x_h, x_i, \mathbf{w}) = f(x_h + t\mathbf{d}, x_i, \mathbf{w}),\ t >= 0 \text{ and } i \in I \qquad (12)$$

This is comparable to the iterative Frank-Wolf method where $\mathbf{d}$ is the direction vector from the goal and t is the step size taken away from the initial solution to arrive at the optimal solution.

By solving the parametric programming problem Min F, we obtain a reduced set of decision alternatives x_m, $m \in M \in I$, as a solution. The index set M consists of the indices of the alternatives to be presented to the DM. M is assumed to be an ordered set

$$M = \{m_1, m_2, \ldots, m_k\} \text{ , } k <= n \qquad (13)$$

where for m_j, $m_h \in M$, $j < h$, there exists a t* such that x_{mj} is the solution of (min F), when $t = t^*$, and x_{mh} is not a solution for $t < t^*$.

Numerical Example. A numerical example is helpful in understanding the method used by VIMDA (Korhonen 1988; Korhonen and Karaivanova, 1998). Assume that the father of a family wants to buy a house and that he is interested in four criteria in the following order: affordability, condition, desirability of the neighborhood, and the desirability of the schools. He identifies five houses (alternatives) and assigns values from 0 (worst) to 9 (best) in each of the criteria for each house as in the following 5 x 4

$$X = \begin{bmatrix} 1 & 3 & 8 & 1 \\ 0 & 7 & 3 & 4 \\ 4 & 5 & 2 & 6 \\ 2 & 8 & 1 & 4 \\ 9 & 5 & 2 & 3 \end{bmatrix}$$

alternative matrix:

When these data are entered in the same matrix form into VIMDA, it first looks at the solutions to eliminate the dominated alternatives. House 1 (row 1) has the highest value (8) of any alternative for desirability of the neighborhood (column 3). House 3 has the highest value (6) of any alternative for desirability of the schools (column 4). House 4 has the highest value (8) of any alternative for condition (column 2). House 5 has the highest value (9) of any alternative for affordability (column 1). House 2 is not dominated by the other four houses because the value in at least one criterion is higher than each of the other houses. For example, houses 1, 3, and 5, whose values for this criterion are only 3, 5, and 5, respectively, do not dominate house 2 with its value for condition of 7. House 2 is also not dominated by house 4 because its value for desirability of the neighborhood (3) is higher than that of house 4 (1).

Let alternative 3: (4, 5, 2, 6) be the current alternative for the set reduction algorithm. Assume that the DM has specified (5, 6, 7, 5) as the aspiration level vector. This means that he wants at least these values for their respective criteria. It is immediately obvious by inspection that none of the five houses meets this level of aspiration, making VIMDA all the more useful in deciding which one to buy. The reference direction is determined to be (5, 6, 7, 5) - (4, 5, 2, 6) = (1, 1, 5, -1). This means that, for alternative 3, the values in the first and second criteria are 1 point below the aspiration level, the third criterion is 5 points below, and the fourth is 1 point above.

Find the value of the parameterized achievement function $v_i(t)$ for each alternative i, i = 1, 2, ..., 5 by the equation

$$v_i(t) = \max\ (x_{hj} + t\mathbf{d}_j - x_{ij})\ /w_j$$

Assuming that the weights all have an equal value of 1, this yields the results shown in Table 25. The calculations for each value of i, j, and t are shown, and the maximum values $v_i(t)$ are shown in the column on the right. The resultant graph of each $v_i(t)$ are plotted together in Figure 7. To find the ordered reduced set, take the lowest curves (Min F) as t goes from 0 to infinity. The lowest curve at t=0 is $v_3(t)$, so it is first in the ordered set. The curve $v_5(t)$ lies on top of $v_3(t)$, but it is not in the set because it cannot improve in $v_3(t)$. At a value of t between 0.8 and 0.9, $v_1(t)$ becomes the minimum and thus takes the second place in the set. After t=2.25, all five curves are parallel, so no more changes will be made to the set. The curves become parallel because j=3 eventually dominates all $v_i(t)$ as indicated by the highlighted numbers in Table 25. The reduced ordered set M, then, is (3, 1).

Table 25. Values of $v_i(t)$ for the Numerical Example

	j = 1	**j = 2**	**j = 3**	**j = 4**	**Maxima**
$v_1(t)$ = max of …	$(4+t*1-1)/w_1$ $= (t+3)/ w_1$	$(5+t*1-3)/w_2$ $= (t+2)/ w_2$	$(2+t*5-8)/w_3$ $= (5t-6)/ w_3$	$(6+(t*-1)-1)/w_4$ $= (-t+5)/ w_4$	
t=0	3	2	-6	5	5
t=1	4	3	-1	4	4
t=2	5	4	4	3	5
t=3	6	5	9	2	9
$v_2(t)$ = max of …	$(4+t*1-0)/w_1$ $= (t+4)/ w_1$	$(5+t*1-7)/w_2$ $= (t-2)/ w_2$	$(2+t*5-3)/w_3$ $= (5t-1)/ w_3$	$(6+(t*-1)-4)/w_4$ $= (-t+2)/ w_4$	
t=0	4	-2	-1	2	4
t=1	5	-1	4	1	5
t=2	6	0	9	0	9
t=3	7	1	14	-1	14
$v_3(t)$ = max of …	$(4+t*1-4)/w_1$ $= t/ w_1$	$(5+t*1-5)/w_2$ $= t/ w_2$	$(2+t*5-2)/w_3$ $= 5t/ w_3$	$(6+(t*-1)-6)/w_4$ $= -t/ w_4$	
t=0	0	0	0	0	0
t=1	1	1	5	-1	5
t=2	2	2	10	-2	10
t=3	3	3	15	-3	15
$v_4(t)$ = max of …	$(4+t*1-2)/w_1$ $= (t+2)/ w_1$	$(5+t*1-8)/w_2$ $= (t-3)/ w_2$	$(2+t*5-1)/w_3$ $= (5t+1)/ w_3$	$(6+(t*-1)-4)/w_4$ $= (-t+2)/ w_4$	
t=0	2	-3	1	2	2
t=1	3	-2	6	1	6
t=2	4	-1	11	0	11
t=3	5	0	16	-1	16
$v_5(t)$ = max of …	$(4+t*1-9)/w_1$ $= (t-5)/ w_1$	$(5+t*1-5)/w_2$ $= t/ w_2$	$(2+t*5-2)/w_3$ $= 5t/ w_3$	$(6+(t*-1)-3)/w_4$ $= (-t+3)/ w_4$	
t=0	-5	0	0	3	3
t=1	-4	1	5	2	5
t=2	-3	2	10	1	10
t=3	-2	3	15	0	15

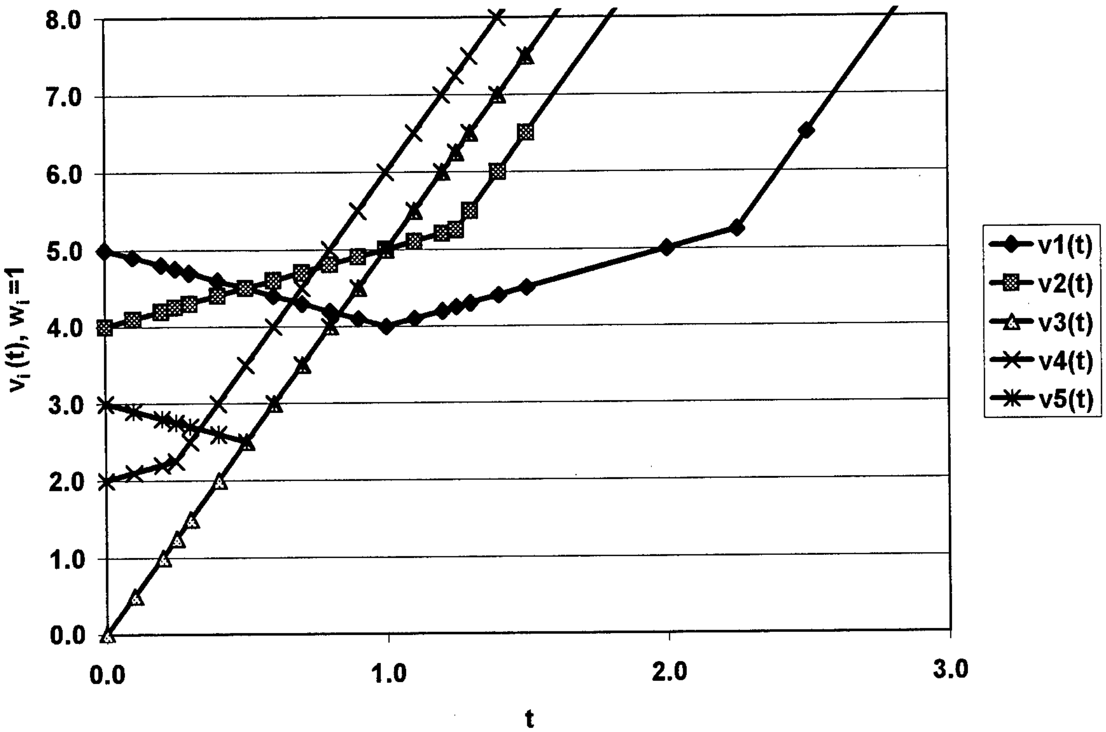


Figure 7. Graph of parameterized achievement functions for the five houses

V. Results

The previous chapter discussed the methodology used to model recovery of recyclables from various waste streams at Spangdahlem AB. This chapter will discuss the results of having applied that methodology. The model was analyzed in terms of the two specified criteria, mass recovered and benefit - cost. Each MRF configuration was analyzed for processing of yellow-bag waste only, stationary container waste only, and both wastes processed separately by the same configuration.

Mass Recovery Results

The MRF model was set up under the assumption that the weekly flow will be processed in one 8-hour day. All recoveries calculated, and presented hereafter, are in % of total mass processed.

Running the MRF model for processing of stationary container waste, it is determined that the maximum mass that can be recovered is 33.4%. For yellow bag wastes, the maximum performance is 68.9%. This figure is verified by the recovery claim of 70% made by the Trier yellow bag MRF (see Table 20). For processing of both wastes separately, the maximum recovery is 35.3% of the total. Besides the maximum recoveries, a DM would also be interested in knowing how each incremental stage performs. The maximum mass recovered by number of stages is presented in Table 25.

Although several of the maximum values in Table 26 appear to be the same, they are mathematically different. This difference, however, occurs at a level of accuracy not attainable based on inputs to the model. For both waste streams, the maximum mass recovered increases as the number of stages increases. On the other hand, these increases are smaller and smaller as the processing train grows. In other words, diminishing marginal returns applies to this situation.

Table 26. Range of Mass Recovered (%) by Number of Stages

Number of Stages	Stationary container Minimum	Stationary container Maximum	Yellow Bag Minimum	Yellow Bag Maximum	Both Minimum	Both Maximum
1	0.00	25.82	0.00	60.12	0.00	27.62
2	0.00	33.30	0.00	68.34	0.00	35.14
3	0.00	33.38	0.00	68.82	0.00	35.24
4	0.00	33.41	0.00	68.91	0.00	35.27
5	0.00	33.41	0.00	68.92	0.00	35.27
6	0.00	33.41	0.00	68.92	0.00	35.27

For the case of a single stage, the mass recovery results are presented in Table 27. For all three waste streams, hand sorting (5) is the best option, followed distantly by separation by magnet (2). The worst options contain solely screens and air classifiers. Although these are binary machines, neither of their output streams is considered recovered, as they are both still a mix of materials and are not saleable. The other "no-value-added" option is the shredder. The water lost during shredding is not saleable. The ECS (1) is missing as per the heuristic discussed above where it must be preceded by a magnet.

Table 27. Mass Recovery (%) for a Single Unit Operation

Stationary container	Yellow Bag	Both	Unit Operations Sequence(s)
25.82	60.12	27.62	5
3.16	19.17	4.00	2
0.00	0.00	0.00	3, 4, 6

For the case of two stages, the results seem to fall into four groups. The results are presented in Table 28. The top group consists of the one best option, hand sorting twice.

The next group is basically all other options with hand sorting in at least one stage. The third category is any option not previously listed that contains a magnet (2). The exception is the option with an air classifier (3) and hand sorting. Recall the assumption that the recovered stream is the light fraction. If the recovered stream were considered to be the heavy fraction, the option would rank differently. Notice that the option with the ECS (1) rises to the top. The last group is, again, any combination of 3, 4, and 6 exclusively.

Table 28. Mass Recovery (%) for Two Unit Operations

Stationary container	Yellow Bag	Both	Unit Operations Sequence(s)
33.30	68.34	35.14	55
26.21	62.52	28.12	52
26.19	62.36	28.08	25
25.82	60.12	27.62	53, 54, 56
25.36	57.67	27.05	45
5.06	23.76	6.04	21
4.94	26.66	6.08	35
3.47	21.09	4.40	22
3.16	19.17	4.00	23, 24, 26, 42, 62
2.84	17.25	3.60	32
0.00	0.00	0.00	Combinations of 3, 4, 6

For the case of three stages, the results are more complex. Since the operation which clearly yields the most mass, hand sorting, can only be done twice, the recovered mass is marginally larger than in the two-stage scenario. Similarly, the three "no-value-added" operations can be used up to two times. The mass recovered in options with only two stages of 3 and/or 4 and/or 6, with the other operation being anything different, is always better than zero. The results are summarized in Table 29.

Table 29. Mass Recovery (%) for Three Unit Operations

Stationary container	Yellow Bag	Both	Unit Operations Sequence(s)
33.38	68.82	35.24	525, 552, 255
33.30	68.34	35.14	553, 554, 556
33.27	68.22	35.11	545
33.02	67.04	34.81	455
26.52	64.18	28.50	535
26.45 to 4.91	63.09 to15.53	28.37 to3.24	Other combinations
0.00	0.00	0.00	Combinations of only 3, 4, 6

The mass recovery results for four through six stages provide the same basic insights. In four-stage MRFs, the best six sequences have two hand sorts (5), one magnet (2), and one ECS (1). The ten best five-stage MRFs add to this another ECS. The 45 best six-stage MRFs add to this another magnet. The worst sequences (no mass recovered) always have only air classifiers (3), screens (4), and shredders (6). These results are found in Appendix C.

Since hand sorting seems to dominate, it seems reasonable to inspect the effect of limiting the number of hand sorts to one and zero. Furthermore, MRFs do not typically have more than one stage of sorting. The analysis for a MRF processing both wastes is shown in Figure 8. When the maximum number of hand sorting stages is 2, 1, and 0, the maximum recoveries are 35.27% (see Table 25), 28.38%, and 6.14%, respectively. As expected, the recovery experiences diminishing marginal returns as the allowed number of hand sorts increases. The recovery is quite low with no hand sorting, which is a reasonable outcome given the electromechanical devices examined.

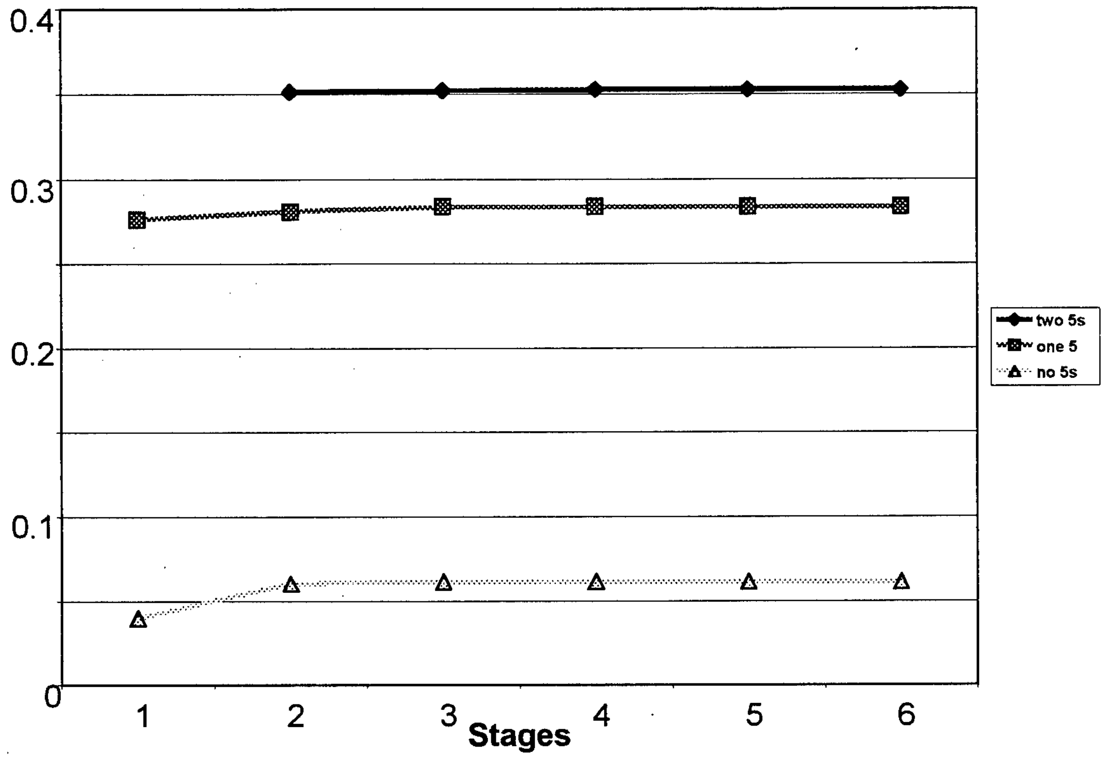


Figure 8. Effect of Number of Hand Sorts on Recovery of Both Wastes

The simplifying assumptions for air classifiers should also be scrutinized. The result of no recovery from an air classifier is admittedly simplistic. Air classifiers can be designed to perform separations more specific than simply lights from heavies (Stessel, 1998). The MRF at Trier, for example, processes source-separated paper and uses an air classifier to separate different types of paper from each other. However, there is little documentation in the literature as to the degree of separation achievable.

Even if an air classifier only splits a waste stream into lights and heavies, the lights may be used as refuse-derived fuel (RDF). The typical use of RDF is to produce heat, often for electrical generation. Hence, there may be more value to the light fraction at

Spangdahlem than is acknowledged here. Incineration is well established and increasing in Germany to ensure compliance with the VS and TOC mandates for 2005.

Benefit - Cost Results

Running the MRF model for processing of stationary container waste, it is determined that the maximum B-C is $923,995, as shown in Table 30. For yellow bag wastes, the maximum B-C is $77,196. For MRFs processing both streams, the maximum B-C is $1,018,709, exceeding the maximum for either stationary container waste or yellow-bag waste individually. Again, for all three waste streams, diminishing marginal returns are observed, and the curve is very flat, at greater than two stages. Also, the familiar pattern of zeros for minimums is present for the same reason as in mass; for each possible train length, there is at least one option that recovers no mass in the form of saleable product, and hence revenues are zero. Of the three waste streams considered, only the shredder reduces tipping fees as the friction created by shredding causes moisture loss, which equates to reduced mass at the landfill.

Table 30. Range of Benefit-Cost by Number of Stages

Number of Stages	Stationary container Minimum	Stationary container Maximum	Yellow Bag Minimum	Yellow Bag Maximum	Both Minimum	Both Maximum
1	0.00	222,400	0.00	61,027	0.00	319,746
2	0.00	872,579	0.00	68,419	0.00	969,926
3	0.00	873,250	0.00	68,591	0.00	970,596
4	0.00	920,735	0.00	70,332	0.00	1,017,941
5	0.00	923,686	0.00	77,195	0.00	1,018,613
6	0.00	923,995	0.00	77,196	0.00	1,018,709

Multi-Criteria Decision-Making Results

Seldom in the world do we have the fortune to judge by only one criterion. Hence, it is beneficial to plot the two criteria against each other in MCDM fashion to determine which alternatives are dominated and what the tradeoff is between the two criteria.

Based on the results for yellow bag wastes, the set of non-dominated solutions is enumerated in Table 31. All the trains consist exclusively of ECSs (1s), magnets (2s), and hand sorts (5s). Notice that as mass recovered increases, the benefit-cost decreases and the length of the efficient trains generally increases. This is consistent with previous findings.

Table 31. Non-Dominated Solutions for Yellow Bag Waste

Mass Recovered, % of yellow bag total mass	Benefit-Cost	Efficient Trains
68.92	61,027	522115
68.92	61,027	521125
68.92	61,027	521215
68.92	68,419	221155
68.92	68,419	211255
68.92	68,419	212155
68.92	68,591	21155
68.91	70,176	21255
68.91	70,176	22155
68.91	70,332	2155
63.12	71,553	52112
63.12	71,553	52121
63.12	71,553	52211
63.12	75,248	22115
63.12	75,248	21125
63.12	75,248	21215
63.12	75,421	2115
63.11	77,048	2215
63.11	77,048	2125
63.09	77,195	215

With these data, we can draw the efficient frontier, displayed in Figure 9. All dominated solutions lie in the area enclosed by the efficient frontier and the axes. Several of the points are so close together that they appear to be one point. The choices can be generalized to R=0.63 with B-C=$77,200, or R=0.69 with B-C $70,300 to make the range quicker to capture mentally.

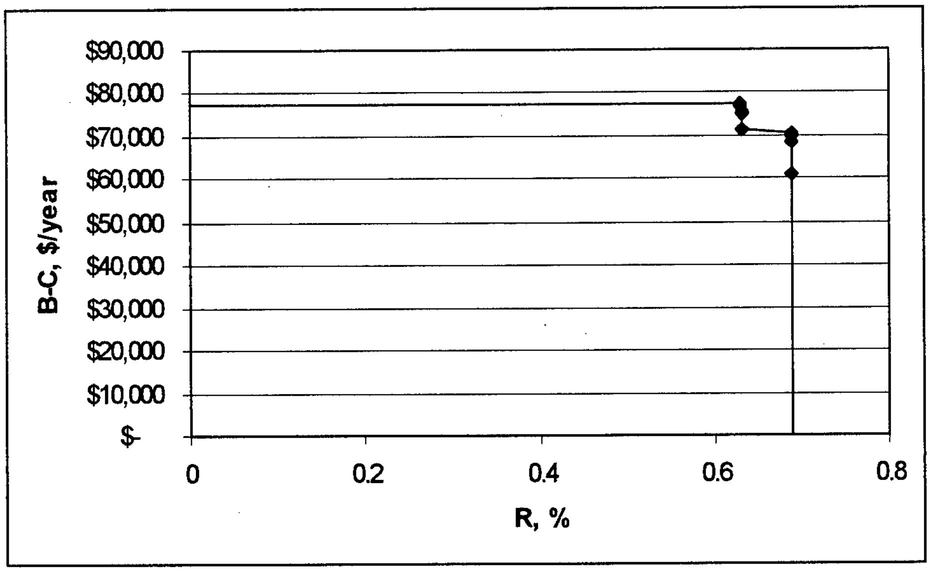


Figure 9. Efficient Frontier for Yellow-Bag Waste MRF

Based on the results for stationary container wastes, the set of non-dominated solutions is enumerated in Table 32. The optimal solution is a single point, so the efficient frontier draws out a simple box. All the top alternatives contain two stations for hand sorting (5s), two magnets (2s), and 2 ECSs (1s).

Table 32. Non-Dominated Solutions for Stationary Container Waste

Mass Recovered, % of stationary container total mass	Benefit-Cost	Efficient Trains
33.41	923,805	211255
33.41	923,805	212155
33.41	923,805	221155
33.41	923,805	211525
33.41	923,805	211552

Based on the results for a MRF processing both wastes, the set of non-dominated solutions is enumerated in Table 33. The optimal solution is a set of four points very close to each other. All the top alternatives contain two stations for hand sorting (5s), at least one magnet (2), and 2 ECSs (1s). For the first time, a three and a four appear in the efficient set. Notice that the values in both criteria are larger than those shown in Table 32, where only stationary container waste was processed. Compared to processing of yellow-bag waste only, the mass and B-C here are dramatically higher.

Table 33. Non-Dominated Solutions for Both Wastes

Mass Recovered, %	Benefit-Cost	Efficient Trains
35.27	954,927	211255
35.27	968,109	211552
35.27	968,687	211553
35.27	970,596	212515
35.27	1,017,941	211545
35.22	1,018,613	212455

Given the non-dominated set for all three scenarios, the efficient solutions can easily be combined into one efficient set of alternatives. The efficient points for stationary container waste and for yellow-bag waste are all dominated by the efficient points for a MRF processing both yellow-bag and stationary container wastes. Although the efficient points for the yellow-bag MRF recover a higher percent of the waste, this is greatly outweighed by the mass ratio of yellow-bag waste to both wastes. In diverting waste from the landfill, mass is the true criterion, not percent recovered. The global efficient frontier, then, contains the six efficient points for the MRF processing both streams, as shown in Figure 10. Some of the six points are not distinguishable because they are so close together.

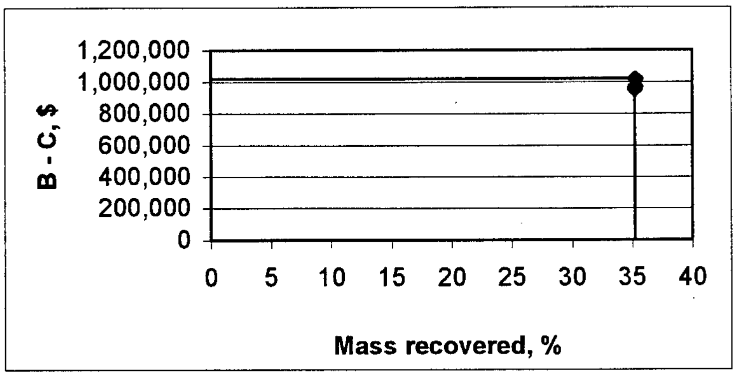


Figure 10. Efficient Frontier for All Three MRFs Considered

Analyzing the six efficient points with an additive value function yields the graph in Figure 11. Here each point is evaluated at various weights for the criteria of recovery, w_R, and is represented by a line. The weight for B-C is such that $w_R + w_{(B-C)} = 1$, and both weights range from 0 to 1.

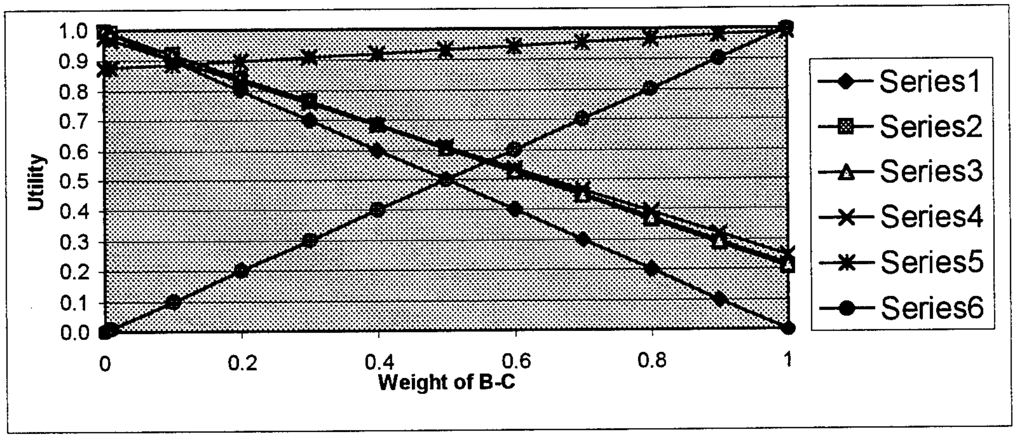


Figure 11. Analysis of Efficient Solutions with Additive Weighting

Looking at the graph, the maximum utility for any weight is evident. Notice that Series 5, representing the point (R=17.123, B-C=$1.018 million) and the MRF configuration 211545, has the maximum utility over most of the range of weights. No weighting scheme produces alternative 4 as the optimum. Given that the DM's preference structure is indeed additive, the DM will choose alternative 5 if the desired weight for B-C lies between about 0.22 and 0.99. These results are only valid if it is indeed correct to assume that the DM's preference structure is that of the additive value function. The advantage of VIMDA is that it makes no assumption about the DM's preference structure.

When the efficient alternatives are entered into VIMDA, and the aspirations are set at the maximum value for each criterion, VIMDA provides the display reproduced in Figure 12. The two lines represent the two criteria. Each alternative is represented by an imaginary vertical line at certain locations. The vertical cursor left of center in the display can be moved left and right among the alternatives. The left and right sides of the box each represent an alternative. Where the criteria lines bend, an alternative is located.

Thus, the cursor is on the third alternative from the left. Note that all 6 non-dominated alternatives are shown.

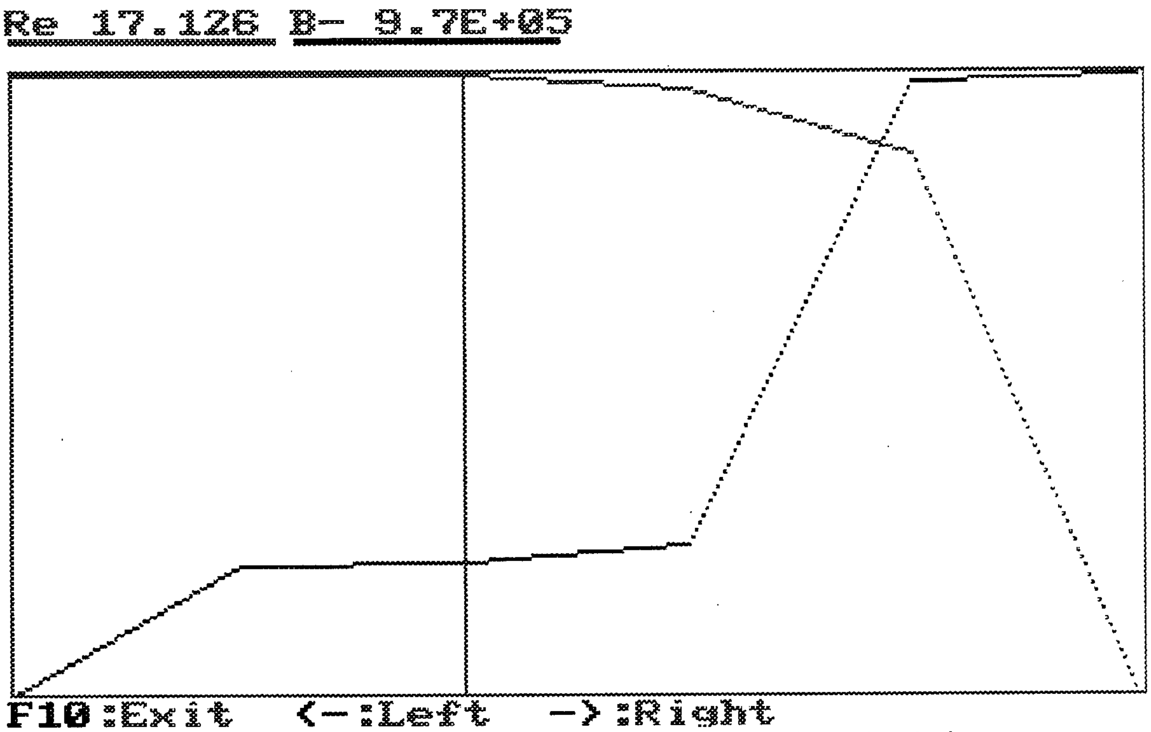


Figure 12. VIMDA Display of the Six Non-dominated Solutions

The alternative at the left, the "current alternative," has the lowest (worst) value of B-C and the highest (best) value of R. If the DM chooses this alternative, it means that R is all-important to the DM and B-C is of no consequence; the problem is, at this point, no longer a multiple criteria problem, but a single criteria problem. Moving right, the second alternative displayed has a higher value of B-C, but the value of R does not decrease noticeably. The third alternative has a slightly higher B-C, but R again decreases minutely. The vertical cursor line is sitting on this alternative. The fourth alternative shows a noticeable increase in B-C and decrease in R. The fifth alternative shows the largest increase in B-C and the largest drop in R thus far. The sixth alternative, on the right side of the display, has the highest value of B-C and the lowest value of R. If the DM chooses this alternative, it means that B-C is all-important to the DM and R is of no consequence, a single criteria problem.

In general, if R is more important to the DM than B-C (but not exclusively), the DM will choose from alternatives 2, 3, and 4. If B-C is more important to the DM than R (but not exclusively), the DM will choose alternative 5. It is left to the DM to make the final choice between these six alternatives.

If the DM selects the preferred solution and changes aspiration levels, the display can show fewer alternatives via the set reduction method described above. For example, if the DM chooses the alternative marked by the cursor in Figure 12, and then changes the aspiration level for mass recovery from the maximum possible down to 17.0, VIMDA will give the display shown in Figure 13. At this iteration, only four of the six efficient alternatives are displayed. Notice that the set reduction algorithm has eliminated those alternatives with a recovery less than that in the aspiration vector. The DM can continue iterating until satisfied with one alternative over all others.

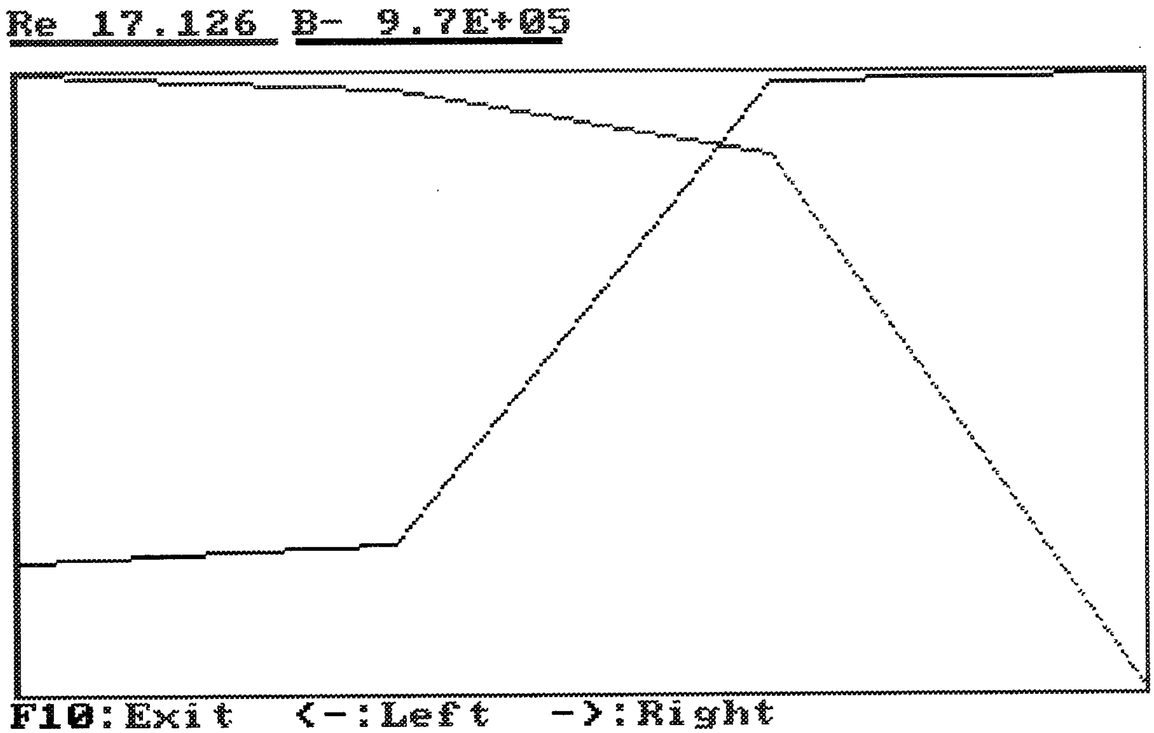


Figure 13: VIMDA Display at Second Iteration

Again, a DM should not consider operating a MRF that will process only one of the two wastes when the alternatives to process both wastes is available, unless there are compelling reasons not included in this analysis. Such compelling issues might include the level of operating funds available and the cash flow constraints. If the desired operation is not within the budget of the Spangdahlem Civil Engineer, it is not a viable option.

To keep this in perspective, however, it should be noted that the current system of landfilling all stationary container wastes incurs an annual loss of DM2.865 million (US$ 1.735 million) in tipping fees. The savings of the efficient alternatives range from $0.955 million to $1.019 million. Thus the annual cost if one of these alternatives is employed would be between $0.780 million and $0.716 million, a reduction of over 50%.

VI. Conclusions

Introduction

The previous chapter presented and interpreted the results of the MRF model for three waste streams and combinations at Spangdahlem AB. This chapter answers the research questions, discusses the strengths and weaknesses of the model, and presents topics for future research.

Answers to Research Questions

The maximum diversion of materials possible on the MSW stream at Spangdahlem AB using MRF technologies is 35.27% of the total of stationary-container and yellow-bag wastes. This is achieved by processing both wastes separately in a MRF configured in one of six ways listed in Table 33. These two wastes together represent 55.93% of all waste collected on the base (Spangdahlem AB and AFCEE, 1998:3-5; see Table 15), so the maximum diversion accomplished by the MRF represents a diversion of 19.73% of the base's entire waste stream. This diversion, added to the existing diversion of other recyclables, 44.07% of the entire waste stream, yields a total diversion of 63.80%. The associated annual savings is about $1 million, reducing the current expense rate by over 50%. It seems that building a MRF may be a good decision for the base if the program can be successfully managed.

To determine compliance with the most recent USAF waste reduction goals, compare the 50.11% that were being recycled at the end of 1997 with the goal of 40% reduction by FY2004. Obviously if Spangdahlem AB keeps pace with its current level of recycling, it will be compliant through FY2005. The concern is with reducing costs of waste management. Employing the suggested MRF would divert 63.80% of the total waste while simultaneously reducing costs.

German mandates for VS or TOC cannot be met with the MRF schemes. The VS of residue exiting the non-dominated MRF configurations presented is actually higher than that of the stationary container waste (53%) as calculated in Table 19. A composting program and use of kitchen waste grinders would significantly lower the VS and TOC of MSW to be landfilled, but still not to the stringent levels mandated. Before landfilling the residues of composting and MRF operations, the residues would probably have to be incinerated to ensure compliance. Incineration will likely increase costs of waste management for Spangdahlem AB. Reducing the mass of waste sent to the incinerator will save on these costs and produce a net benefit if incineration and landfilling of remains is more expensive than operating a MRF, composting, and so on.

Model Strengths

This effort represents the first publicly documented application of the methodology proposed by Diaz, et al. (1982). Rhyner, et al. (1995) discuss the technique, but do not use it, nor do they refer to any works that use it. If the technique has been applied elsewhere, that application is not published to the knowledge of the author. Some prior proprietary application by waste management businesses is also possible.

The spreadsheet model has several strong points. One is that unit processes are independent of each other, and previously unused or unexamined combinations can be evaluated. This is possible because PSD is taken into account. Another strength of the model is its flexibility. Any user desiring to evaluate alternatives for a specific waste stream can easily adjust the parameters, including screen aperture size, air classification split, recoveries of unit processes, recovery rates in manual sorting, cost and useful life of the equipment, interest rate, tipping fees, etc. Thus, the model can be applied to different circumstances, and can be updated to reflect field data on in-place equipment items.

Another of the model's strengths is its reliance on popular spreadsheet software. USAF and other managers are generally familiar with this tool, and can trust the results better than if they came from an unfamiliar tool. They could even do the modeling themselves rather than relying so heavily on analysts.

Model Weaknesses

The model also has several weaknesses. It does not address the concern of purity, which is essential to give a complete picture of recovery. Impure product is not always marketable, and will generally cut into profits considerably. The other choice is to further process recovered streams to increase their purity to saleable standards.

The model is not capable of analyzing branches in processing trains such as the further processing of recovered streams mentioned above. The model cannot account for the effects of a midstream change in PSD due to shredding if the nominal particle size is equal to or less than the aperture size of a downstream screen. The effect of shredding on recovery of the unit operations is not addressed. Some practitioners in the field claim that this increases the recovery of magnets and ECSs. It could significantly change the performance of an air classifier as well.

The model lumps all manual sorting into one operation when picking some materials may be unprofitable, or less profitable than desired. The ideal would be to evaluate the hand sorting of each material separately.

Suggestions for Further Study

This thesis was limited in scope, and much more can be done to determine what MSW management system is optimal. Additional unit operations and/or stages could be evaluated. Technologies and methods other than those used in MRFs could be evaluated, including source reduction, composting, digesting and incineration.

It might be useful to evaluate the waste system as a whole. Perhaps a different way of collecting the waste would improve the recovery. A more detailed characterization of yellow bag contents would be useful in making this determination.

If the reader is interested in obtaining a copy of VIMDA and did not receive it with this document, it can be obtained for free from the author at jjkpalmer@hotmail.com. It is also available from Dr. Korhonen, its creator. He can be reached at sissi82@hotmail.com, or korhonen@hkkk.fi, or korhonen@iiasa.ac.at

Appendix A: Composition of Four Components of Spangdahlem AB Waste

Sample	kg	"Miscellaneous" material	
36	6.5	abrasive paper, isocyanate foam, cleaning cloths, rubber gaskets, tape & binder	1.3%
3	2.0	broken window pane	0.4%
23	3.0	cat litter	0.6%
30	7.0	ceramics, vacuum dust	1.4%
48	0.5	crockery	0.1%
41	1.0	crockery broken	0.2%
31	2.5	crockery broken, Jay cloths	0.5%
38	2.0	crockery, vacuum dust, gloves, face mask	0.4%
24	17.5	diapers	3.5%
23	11.5	diapers	2.3%
48	6.0	diapers	1.2%
4	5.5	diapers	1.1%
13	15.0	diapers mostly	3.0%
15	14.0	diapers mostly	2.8%
3	8.5	diapers mostly	1.7%
16	4.0	diapers mostly	0.8%
43	21.5	diapers mostly (70%), sanitary towels	4.2%
42	27.5	diapers mostly, sanitary towels	5.4%
41	16.5	diapers mostly, shoes, carpet	3.3%
25	12.5	diapers, broken crockery, cleaning dirt, laundry fabric, mop head	2.5%
51	6.0	diapers, car wax, windscreen wipers, air filter, spark plugs, fanbelt, oil containers	1.2%
22	18.5	diapers, large pottery vase	3.6%
27	22.5	diapers, tape	4.4%
21	25.0	diapers, vacuum dust	4.9%
20	13.0	diapers, vacuum dust	2.6%
49	3.5	diapers, vacuum dust	0.7%
40	12.5	diapers, vacuum dust, sanitary towels	2.5%
26	7.5	film offcuts	1.5%
52	1.0	food - cheese wax & sausage skins	0.2%
14	40.0	glass foam fiber???	7.9%
18	2.5	Holiday decorations	0.5%
34	3.0	infra-red safety lights (about 30), descants, abrasives, rubber, cleaning clothes, sponges	0.6%
14	8.0	isocyanate foam, plastic, paper composite tape???	1.6%
50	36.0	medical wastes, including diapers	7.1%
39	1.0	mug, sanitary towels	0.2%
1	2.5	plastic-coated paper	0.5%

35	9.5	rubber carpeting, muslin from swabs, duct tapes, gel packs, EMI static shield packets	1.9%
33	1.0	sanitary towels, vacuum dirt	0.2%
37	0.5	scouring pads, fan belt	0.1%
20	10.0	Tarpaulin???	2.0%
45	2.0	wallpaper, paper rolls	0.4%
19	2.0	wind screen wipers, air filter, 1 roll tape, 1 diaper	0.4%
13	4.0	wooden roller blinds	0.8%
5	16.0		3.2%
29	14.0		2.8%
47	12.0		2.4%
6	10.5		2.1%
12	10.5		2.1%
28	8.5		1.7%
10	6.0		1.2%
11	4.0		0.8%
7	3.0		0.6%
2	2.5		0.5%
8	1.0		0.2%
9	1.0		0.2%
17	1.0		0.2%
32	0.5		0.1%
44	0.5		0.1%
46	0.0		0.0%
	507.0		

		% of Misc	% of total
diapers	261.0	51.5%	4.98%
other	91.0	17.9%	1.74%

Batteries & electricals

Sample	**kg**	**material**	**%**
37	50	computers	41%
28	22	vacuum, 2 videos, 1 transformer	18%
15	21.5	typewrite, radio	18%
27	7.5	2 batteries (heavy!)	6%
10	3		2%
2	2.3	Transformer, PCBs, switch parts	2%
4	2	car radio, 2 batteries	2%
30	2	hairdryer, batteries, headphone	2%
43	1.5	rice cooker, capacitors	1%
9	1.5	Transormer, calculator	1%
51	1	2 batteries, 1 circuit board	1%
49	1	2 batteries, 1 calculator, 1 game boy	1%
11	1	food mixer	1%

23	1	radio	1%
40	1	Xmas lights, ball toy	1%
12	1		1%
2	0.75	batteries	1%
18	0.5	hairdryer	0%
20	0.5	phone	0%
1	0.5	light capacitors, 1 PCB	0%
21	0	1 battery	
34	0	1 capacitor, 1 cable	
38	0	1 capacitor, wire	
5	0	2 batteries	
22	0	2 batteries	
36	0	2 batteries	
41	0	2 batteries, 1 capacitor	
39	0	4 batteries	
6	0	6 batteries	
16	0	clock parts	
14	0	switch	
3	0		
7	0		
8	0		
13	0		
17	0		
19	0		
24	0		
25	0		
26	0		
29	0		
31	0		
32	0		
33	0		
35	0		
42	0		
44	0		
45	0		
46	0		
47	0		
48	0		
50	0		
52	0		
	121.5		

Sample	kg	Household HazWaste material

19	44.5	facility=Auto garage. Unfortunately, no comment for this mass	63%
51	3	oily rags, bitumen can	4%
36	3	oily/solvent/paint rags, wood w/ solvent	4%
27	3	R12, R502, R134a, CPCS/HCFCS cylinder	4%
2	2	empty motor oil/antifreeze containers	3%
51	2	lighter fluid	3%
5	2		3%
3	1.5	empty paint can, etc	2%
34	1.5	iol container, hair gel, aerosol, neoprene can	2%
18	1	aerosol (2), cleaner, spray oil	1%
25	1	aerosol (2), gel, oil	1%
22	1	aerosol (3), empty motor oil containers	1%
49	1	aerosol cans (8), 2 syringes (no needles)	1%
42	1	aerosols, vehicle sealant	1%
12	1	lighter fluid	1%
30	1		1%
43	0.5	aerosol cans (3)	1%
11	0.5		1%
47	0	2 bottles antibiotics, 1 asthma inhaler	
40	0	aerosol (1)	
29	0	aerosol (1)	
13	0	aerosol (1)	
9	0	aerosol (1)	
44	0	aerosol (1), 1 oil container	
41	0	aerosol (1), 1 pack tylenol	
10	0	aerosol (2)	
16	0	aerosol (2), perscription cream	
23	0	aerosols (3)	
17	0	windshield fluid	
52	0		
50	0		
48	0		
46	0		
45	0		
39	0		
38	0		
37	0		
35	0		
33	0		
32	0		
31	0		
28	0		
26	0		
24	0		
21	0		

20	0
15	0
14	0
8	0
7	0
6	0
4	0
1	0
	70.5

Other Yellow-Bag Waste

Sample	kg	material
2	11.0	
31	6	
32	5.5	
39	4	milk/drink cartons
26	4	
5	3.5	
6	3.5	
26	3	milk cartons
33	2.5	ketchup packets
7	2.5	
38	2	milk/drink cartons
4	2.0	
8	2.0	
13	2	
40	2	
43	2	
50	1.5	food wraps, sterile packs
12	1.5	
15	1.5	
21	1.5	
28	1.5	
29	1.5	
30	1.5	
35	1.5	
36	1.5	
45	1.5	
3	1.0	
10	1.0	
11	1.0	
16	1	
20	1	
22	1	

23	1	
24	1	
25	1	
27	1	
34	1	
41	1	
42	1	
44	1	
47	1	
49	1	
1	0.5	drink cartons
18	0.5	trace
9	0.5	
17	0.5	
48	0.5	
51	0.5	
37	0	trace
52	0	trace
14	0	
19	0	
46	0	

Appendix B: Model of MRF for Stationary Container Waste

Based on 1 week of waste

Component	Al	Fe	glass	food	C&D	Misc	elec	HH	OYB	textil	Woo	pape	Plas
tons/hr	0.76	1.61	1.76	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06
										Total mass incoming			44.27

KEY:
1 = ECS
2 = Magnet
3 = Air classifier
4 = screen/trom
5 = hand sort
6 = shredder

Machines involoved (all materials are affected by machines 3 & 4)

Al	Fe	glass	food	C&D	Misc	elec	HH	OYB	textil	Woo	pape	Plas
1,5	1,2,5	5	6								5	5

						1st Recovered													1st Leftover		
1st	2nd	3rd	4th	5th	6th	Al	Fe	glass	food	C&D	Misc	elec	HH	OYB	extile	Wood	paper	Plas	Al	Fe	glass
1						0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
2						0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
3						0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70
4						0.02	0.00	0.00	7.04	1.48	0.22	0.02	0.01	0.02	0.02	0.03	0.00	0.08	0.74	1.61	1.76
5						0.66	1.41	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.71	3.55	0.09	0.20	0.22
6						0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	1.61	1.76
1	1					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
1	2					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
1	3					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
1	4					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
1	5					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
1	6					0.72	1.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.08	1.76
2	1					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
2	2					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
2	3					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
2	4					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
2	5					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
2	6					0.00	1.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.16	1.76
3	1					0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70
3	2					0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70
3	3					0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70
3	4					0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70
3	5					0.38	0.16	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75	0.48	10.11	3.98	0.38	1.45	0.70

Reco	Leftover (more sorting)									Air Classifier Performance, Diaz									
all me	nonmetals	Rec_Al	95%	% recovered						Al	Fe	glass	food	C&D	Misc	elec	HH	OYB	extile
ferrou	nonmetals	Rec_Fe	90%	% recovered					Lights	50%	10%	60%	70%	20%	70%	20%	20%	20%	70%
Lights	Heavies								Heavies	50%	90%	40%	30%	80%	30%	80%	80%	80%	30%
Under	Overs												OR	OIR	OR	OIR	OIR	OIR	OR
picke	not picked																		
lost m	drier mass																		
										2nd Recovered									
food	C&D	Misc	elec	HH	OYB	extile	Wood	paper	Plas	Al	Fe	glass	food	C&D	Misc	elec	HH	OYB	extile
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06										
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06										
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08										
7.94	0.44	4.23	1.07	0.64	0.90	1.05	0.65	10.32	3.98										
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	5.61	0.51										
14.30	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06										
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.04	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.02	0.01	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.00	0.00	0.00	7.04	1.48	0.22	0.02	0.01	0.02	0.02
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.03	0.06	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.72	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.38	0.02	1.05	10.48	0.38	3.11	0.22	0.13	0.18	0.75
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.02	0.00	0.00	7.04	1.48	0.22	0.02	0.01	0.02	0.02
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.66	0.13	1.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.00
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08	0.36	1.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08	0.00	1.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08	0.19	0.15	0.42	3.14	0.31	0.93	0.17	0.10	0.15	0.22
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08	0.01	0.00	0.00	2.11	1.18	0.07	0.02	0.01	0.01	0.01
4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08	0.33	1.16	0.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00

					Picking Rate		**tph/sorter**								Screen Data, % retained (und			
Wood	paper	Plas			Pape	77.5%	0.90	only "clean"								Al	Fe	glass
70%	98%	98%			Glass	87.5%	0.45								1/2"	3%	0%	0%
30%	2%	2%			Plasti	87.5%	0.20								1/2"	3%	0%	0%
OR					Alumi	87.5%	0.06								1"	10%	0%	14%
					Fe	80.0%	0.75								2"	25%	5%	15%
															4"	86%	55%	98%
			2nd Leftover													3rd Recovered		
Wood	paper	Plas	Al	Fe	glass	food	C&D	Misc	elec	HHW	OYB	extile	Wood	paper	Plas	Al	Fe	glass
0.00	0.00	0.00	0.00	0.00	1.76	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.00	0.00	0.00	0.04	0.01	1.76	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.48	10.11	3.98	0.02	0.07	0.70	4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08			
0.03	0.00	0.08	0.04	0.08	1.76	7.94	0.44	4.23	1.07	0.64	0.90	1.05	0.65	10.32	3.98			
0.00	4.71	3.55	0.00	0.02	0.22	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	5.61	0.51			
0.00	0.00	0.00	0.04	0.08	1.76	14.30	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.00	0.00	0.00	0.04	0.01	1.76	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.00	0.00	0.00	0.76	0.02	1.76	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.48	10.11	3.98	0.38	0.15	0.70	4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08			
0.03	0.00	0.08	0.74	0.16	1.76	7.94	0.44	4.23	1.07	0.64	0.90	1.05	0.65	10.32	3.98			
0.00	4.71	3.55	0.09	0.03	0.22	14.97	1.92	4.45	1.09	0.65	0.92	1.07	0.69	5.61	0.51			
0.00	0.00	0.00	0.76	0.16	1.76	14.30	1.92	4.45	1.09	0.65	0.92	1.07	0.69	10.32	4.06			
0.00	0.00	0.00	0.02	0.07	0.70	4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08			
0.00	0.00	0.00	0.38	0.15	0.70	4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.21	0.08			
0.14	0.20	0.08	0.19	1.31	0.28	1.35	1.23	0.40	0.70	0.42	0.59	0.10	0.06	0.00	0.00			
0.01	0.00	0.00	0.37	1.45	0.70	2.38	0.35	1.27	0.85	0.51	0.72	0.31	0.20	0.21	0.08			
0.00	0.09	0.07	0.05	0.29	0.09	4.49	1.54	1.33	0.87	0.52	0.73	0.32	0.21	0.11	0.01			

rs), Diaz p52

food	C&D	isc(wa	elec	HHW	OYB	textiles	Wood	paper	Plas
47%	77%	5%	2%	2%	2%	2%	5%	0%	2%
47%	77%	5%				2%	5%	0%	2%
63%	83%	15%				7%	14%	1%	2%
70%	93%	30%				21%	15%	5%	10%
80%	96%	50%				50%	64%	25%	36%

food	C&D	Misc	elec	HHW	OYB	textiles	Wood	paper	Plas

							in thousands				n,useful life, yrs				Al
							Recycling Today,	$ 35	1 = ECS		30				$ 560.00
							Recycling Today,	$ 3	2 = Magnet		30			i="APR"=	
							rassmach.com ad	$ 15	3 = Air class		30			4%	
	How do I account for RDF as recovered?							$ 5	4 = screen/t		30			(P/A,i%,n)	
							based on min wage	$ 0	5 = hand so		8	hrs/day		0.0578301	
							picking stations	$ -	5 = hand so		30				presorted tir
1,5	1,2,5	5	6	5	5		Recycling Today,	$ 8	6 = shredde		30				
		Total Recovered						ANNUAL COSTS PER MACHINE						TOTAL	PROFIT
Al	Fe	glass	water	paper	Plas	Total	#picker	1st	2nd	3rd	4th	5th	6th	COST/YR	Al
0.72	1.53	0.00	0.00	0.00	0.00	2.25	0.00	2.024						$ 2,024	$ 404
0.00	1.45	0.00	0.00	0.00	0.00	1.45	0.00	0.173						$ 173	$ -
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.867						$ 867	$ -
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.289						$ 289	$ -
0.66	1.41	1.54	0.00	4.71	3.55	11.88	40.38	86.51						$ 86,506	$ 372
0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.434						$ 434	$ -
0.76	1.61	0.00	0.00	0.00	0.00	2.37	0.00	2.024	2.024					$ 4,048	$ 424
0.72	1.61	0.00	0.00	0.00	0.00	2.33	0.00	2.024	0.173					$ 2,198	$ 404
0.72	1.53	0.00	0.00	0.00	0.00	2.25	0.00	2.024	0.867					$ 2,892	$ 404
0.72	1.53	0.00	0.00	0.00	0.00	2.25	0.00	2.024	0.289					$ 2,313	$ 404
0.75	1.60	1.54	0.00	4.71	3.55	12.15	27.11	2.024	58.08					$ 60,103	$ 422
0.72	1.53	0.00	0.67	0.00	0.00	2.25	0.00	2.024	0.434					$ 2,458	$ 404
0.72	1.61	0.00	0.00	0.00	0.00	2.33	0.00	0.173	2.024					$ 2,198	$ 404
0.00	1.60	0.00	0.00	0.00	0.00	1.60	0.00	0.173	0.173					$ 347	$ -
0.00	1.45	0.00	0.00	0.00	0.00	1.45	0.00	0.173	0.867					$ 1,041	$ -
0.00	1.45	0.00	0.00	0.00	0.00	1.45	0.00	0.173	0.289					$ 463	$ -
0.66	1.58	1.54	0.00	4.71	3.55	12.05	38.67	0.173	82.84					$ 83,013	$ 372
0.00	1.45	0.00	0.67	0.00	0.00	1.45	0.00	0.173	0.434					$ 607	$ -
0.36	1.38	0.00	0.00	0.00	0.00	1.74	0.00	0.867	2.024					$ 2,892	$ 202
0.00	1.31	0.00	0.00	0.00	0.00	1.31	0.00	0.867	0.173					$ 1,041	$ -
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.867	0.867					$ 1,735	$ -
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.867	0.289					$ 1,157	$ -
0.33	1.16	0.62	0.00	0.09	0.07	2.27	9.41	0.867	20.17					$ 21,037	$ 186

Fe	glass	paper	Plas		Tipping_Fee	
$ 9.00	$9.00	$55.00	$40.00	per ton	$90.83	US$/ton
clean steel c	flint/clear	white ledger	avg of HDPE & PET		1.6515	DM$/US$
					150	DM$/ton
					165	DM$/tonn
s & OCC bring revenue						Higher is
						Better
ROM RECYCLABLES				TOTAL	Tipping $	Benefit/
Fe	glass	paper	Plas	GAINS/YR	Spent/Yr	Cost
$ 14	$ -	$ -	$ -	173,718.62	$1,587,315	0.1093
$ 13	$ -	$ -	$ -	5,440.56	$1,617,609	0.0034
$ -	$ -	$ -	$ -	-	$1,672,514	-
$ -	$ -	$ -	$ -	-	$1,672,514	-
$ 13	$ 14	$ 259	$ 142	332,642.50	$1,223,735	0.2539
$ -	$ -	$ -	$ -	-	$1,672,514	-
$ 14	$ -	$ -	$ -	182,404.55	$1,583,055	0.1149
$ 14	$ -	$ -	$ -	173,990.65	$1,584,569	0.1097
$ 14	$ -	$ -	$ -	173,718.62	$1,587,315	0.1092
$ 14	$ -	$ -	$ -	173,718.62	$1,587,315	0.1093
$ 14	$ 14	$ 259	$ 142	354,334.66	$1,213,314	0.2783
$ 14	$ -	$ -	$ -	173,718.62	$1,587,315	0.1093
$ 14	$ -	$ -	$ -	173,990.65	$1,584,569	0.1097
$ 14	$ -	$ -	$ -	5,984.61	$1,612,118	0.0037
$ 13	$ -	$ -	$ -	5,440.56	$1,617,609	0.0034
$ 13	$ -	$ -	$ -	5,440.56	$1,617,609	0.0034
$ 14	$ 14	$ 259	$ 142	333,277.23	$1,217,330	0.2563
$ 13	$ -	$ -	$ -	5,440.56	$1,617,609	0.0034
$ 12	$ -	$ -	$ -	89,156.43	$1,606,732	0.0554
$ 12	$ -	$ -	$ -	4,896.50	$1,623,100	0.0030
$ -	$ -	$ -	$ -	-	$1,672,514	-
$ -	$ -	$ -	$ -	-	$1,672,514	-
$ 10	$ 6	$ 5	$ 3	87,350.00	$1,586,561	0.0543

	A	B	C	D	E	F
1						
2						
3						
4						ent
5						/hr
6						
7						
8						
9						
10						
11						
12	1st	2n	3rd	4th	5th	6th
13	1					
14	2					
15	3					
16	4					
17	5					
18	6					
19	1	1				
20	1	2				
21	1	3				
22	1	4				
23	1	5				
24	1	6				
25	2	1				
26	2	2				
27	2	3				
28	2	4				
29	2	5				
30	2	6				

	G
1	
2	
3	Based on 1 week of waste
4	Al
5	=+'%'!F10
6	
7	
8	
9	Machines involoved (all materials are affected by machines 3 & 4)
10	1,5
11	
12	Al
13	=IF(A13="","",IF(A13=1,Rec_Al*Main_Al,IF(A13=3,Al_lights*Main_Al,IF(A13=4,Al_unders*Main_Al,IF(A13=5,Al_pick*Main_Al,0)))))
14	=IF(A14="","",IF(A14=1,Rec_Al*Main_Al,IF(A14=3,Al_lights*Main_Al,IF(A14=4,Al_unders*Main_Al,IF(A14=5,Al_pick*Main_Al,0)))))
15	=IF(A15="","",IF(A15=1,Rec_Al*Main_Al,IF(A15=3,Al_lights*Main_Al,IF(A15=4,Al_unders*Main_Al,IF(A15=5,Al_pick*Main_Al,0)))))
16	=IF(A16="","",IF(A16=1,Rec_Al*Main_Al,IF(A16=3,Al_lights*Main_Al,IF(A16=4,Al_unders*Main_Al,IF(A16=5,Al_pick*Main_Al,0)))))
17	=IF(A17="","",IF(A17=1,Rec_Al*Main_Al,IF(A17=3,Al_lights*Main_Al,IF(A17=4,Al_unders*Main_Al,IF(A17=5,Al_pick*Main_Al,0)))))
18	=IF(A18="","",IF(A18=1,Rec_Al*Main_Al,IF(A18=3,Al_lights*Main_Al,IF(A18=4,Al_unders*Main_Al,IF(A18=5,Al_pick*Main_Al,0)))))
19	=IF(A19="","",IF(A19=1,Rec_Al*Main_Al,IF(A19=3,Al_lights*Main_Al,IF(A19=4,Al_unders*Main_Al,IF(A19=5,Al_pick*Main_Al,0)))))
20	=IF(A20="","",IF(A20=1,Rec_Al*Main_Al,IF(A20=3,Al_lights*Main_Al,IF(A20=4,Al_unders*Main_Al,IF(A20=5,Al_pick*Main_Al,0)))))
21	=IF(A21="","",IF(A21=1,Rec_Al*Main_Al,IF(A21=3,Al_lights*Main_Al,IF(A21=4,Al_unders*Main_Al,IF(A21=5,Al_pick*Main_Al,0)))))
22	=IF(A22="","",IF(A22=1,Rec_Al*Main_Al,IF(A22=3,Al_lights*Main_Al,IF(A22=4,Al_unders*Main_Al,IF(A22=5,Al_pick*Main_Al,0)))))
23	=IF(A23="","",IF(A23=1,Rec_Al*Main_Al,IF(A23=3,Al_lights*Main_Al,IF(A23=4,Al_unders*Main_Al,IF(A23=5,Al_pick*Main_Al,0)))))
24	=IF(A24="","",IF(A24=1,Rec_Al*Main_Al,IF(A24=3,Al_lights*Main_Al,IF(A24=4,Al_unders*Main_Al,IF(A24=5,Al_pick*Main_Al,0)))))
25	=IF(A25="","",IF(A25=1,Rec_Al*Main_Al,IF(A25=3,Al_lights*Main_Al,IF(A25=4,Al_unders*Main_Al,IF(A25=5,Al_pick*Main_Al,0)))))
26	=IF(A26="","",IF(A26=1,Rec_Al*Main_Al,IF(A26=3,Al_lights*Main_Al,IF(A26=4,Al_unders*Main_Al,IF(A26=5,Al_pick*Main_Al,0)))))
27	=IF(A27="","",IF(A27=1,Rec_Al*Main_Al,IF(A27=3,Al_lights*Main_Al,IF(A27=4,Al_unders*Main_Al,IF(A27=5,Al_pick*Main_Al,0)))))
28	=IF(A28="","",IF(A28=1,Rec_Al*Main_Al,IF(A28=3,Al_lights*Main_Al,IF(A28=4,Al_unders*Main_Al,IF(A28=5,Al_pick*Main_Al,0)))))
29	=IF(A29="","",IF(A29=1,Rec_Al*Main_Al,IF(A29=3,Al_lights*Main_Al,IF(A29=4,Al_unders*Main_Al,IF(A29=5,Al_pick*Main_Al,0)))))
30	=IF(A30="","",IF(A30=1,Rec_Al*Main_Al,IF(A30=3,Al_lights*Main_Al,IF(A30=4,Al_unders*Main_Al,IF(A30=5,Al_pick*Main_Al,0)))))

	H
1	
2	
3	
4	Fe
5	=+('%'!C6+'%'!C11)*'%'!$A$28
6	
7	
8	
9	
10	1,2,5
11	1st Recovered
12	Fe
13	=IF(A13="","",IF(A13=2,Rec_Fe*Main_Fe,IF(A13=1,Rec_Al*Main_Fe,IF(A13=3,Fe_lights*Main_Fe,IF(A13=4,Fe_unders*Main_Fe,IF(A13=5,Al_pick*Main_Fe,0))
14	=IF(A14="","",IF(A14=2,Rec_Fe*Main_Fe,IF(A14=1,Rec_Al*Main_Fe,IF(A14=3,Fe_lights*Main_Fe,IF(A14=4,Fe_unders*Main_Fe,IF(A14=5,Al_pick*Main_Fe,0))
15	=IF(A15="","",IF(A15=2,Rec_Fe*Main_Fe,IF(A15=1,Rec_Al*Main_Fe,IF(A15=3,Fe_lights*Main_Fe,IF(A15=4,Fe_unders*Main_Fe,IF(A15=5,Al_pick*Main_Fe,0))
16	=IF(A16="","",IF(A16=2,Rec_Fe*Main_Fe,IF(A16=1,Rec_Al*Main_Fe,IF(A16=3,Fe_lights*Main_Fe,IF(A16=4,Fe_unders*Main_Fe,IF(A16=5,Al_pick*Main_Fe,0))
17	=IF(A17="","",IF(A17=2,Rec_Fe*Main_Fe,IF(A17=1,Rec_Al*Main_Fe,IF(A17=3,Fe_lights*Main_Fe,IF(A17=4,Fe_unders*Main_Fe,IF(A17=5,Al_pick*Main_Fe,0))
18	=IF(A18="","",IF(A18=2,Rec_Fe*Main_Fe,IF(A18=1,Rec_Al*Main_Fe,IF(A18=3,Fe_lights*Main_Fe,IF(A18=4,Fe_unders*Main_Fe,IF(A18=5,Al_pick*Main_Fe,0))
19	=IF(A19="","",IF(A19=2,Rec_Fe*Main_Fe,IF(A19=1,Rec_Al*Main_Fe,IF(A19=3,Fe_lights*Main_Fe,IF(A19=4,Fe_unders*Main_Fe,IF(A19=5,Al_pick*Main_Fe,0))
20	=IF(A20="","",IF(A20=2,Rec_Fe*Main_Fe,IF(A20=1,Rec_Al*Main_Fe,IF(A20=3,Fe_lights*Main_Fe,IF(A20=4,Fe_unders*Main_Fe,IF(A20=5,Al_pick*Main_Fe,0))
21	=IF(A21="","",IF(A21=2,Rec_Fe*Main_Fe,IF(A21=1,Rec_Al*Main_Fe,IF(A21=3,Fe_lights*Main_Fe,IF(A21=4,Fe_unders*Main_Fe,IF(A21=5,Al_pick*Main_Fe,0))
22	=IF(A22="","",IF(A22=2,Rec_Fe*Main_Fe,IF(A22=1,Rec_Al*Main_Fe,IF(A22=3,Fe_lights*Main_Fe,IF(A22=4,Fe_unders*Main_Fe,IF(A22=5,Al_pick*Main_Fe,0))
23	=IF(A23="","",IF(A23=2,Rec_Fe*Main_Fe,IF(A23=1,Rec_Al*Main_Fe,IF(A23=3,Fe_lights*Main_Fe,IF(A23=4,Fe_unders*Main_Fe,IF(A23=5,Al_pick*Main_Fe,0))
24	=IF(A24="","",IF(A24=2,Rec_Fe*Main_Fe,IF(A24=1,Rec_Al*Main_Fe,IF(A24=3,Fe_lights*Main_Fe,IF(A24=4,Fe_unders*Main_Fe,IF(A24=5,Al_pick*Main_Fe,0))
25	=IF(A25="","",IF(A25=2,Rec_Fe*Main_Fe,IF(A25=1,Rec_Al*Main_Fe,IF(A25=3,Fe_lights*Main_Fe,IF(A25=4,Fe_unders*Main_Fe,IF(A25=5,Al_pick*Main_Fe,0))
26	=IF(A26="","",IF(A26=2,Rec_Fe*Main_Fe,IF(A26=1,Rec_Al*Main_Fe,IF(A26=3,Fe_lights*Main_Fe,IF(A26=4,Fe_unders*Main_Fe,IF(A26=5,Al_pick*Main_Fe,0))
27	=IF(A27="","",IF(A27=2,Rec_Fe*Main_Fe,IF(A27=1,Rec_Al*Main_Fe,IF(A27=3,Fe_lights*Main_Fe,IF(A27=4,Fe_unders*Main_Fe,IF(A27=5,Al_pick*Main_Fe,0))
28	=IF(A28="","",IF(A28=2,Rec_Fe*Main_Fe,IF(A28=1,Rec_Al*Main_Fe,IF(A28=3,Fe_lights*Main_Fe,IF(A28=4,Fe_unders*Main_Fe,IF(A28=5,Al_pick*Main_Fe,0))
29	=IF(A29="","",IF(A29=2,Rec_Fe*Main_Fe,IF(A29=1,Rec_Al*Main_Fe,IF(A29=3,Fe_lights*Main_Fe,IF(A29=4,Fe_unders*Main_Fe,IF(A29=5,Al_pick*Main_Fe,0))
30	=IF(A30="","",IF(A30=2,Rec_Fe*Main_Fe,IF(A30=1,Rec_Al*Main_Fe,IF(A30=3,Fe_lights*Main_Fe,IF(A30=4,Fe_unders*Main_Fe,IF(A30=5,Al_pick*Main_Fe,0))

	I
1	
2	
3	
4	glass
5	=+'%'!F5
6	
7	
8	
9	
10	5
11	
12	glass
13	=IF(A13="","",IF(A13=3,glass_lights*Main_Glass,IF(A13=4,glass_unders*Main_Glass,IF(A13=5,glass_pick*Main_Glass,0))))
14	=IF(A14="","",IF(A14=3,glass_lights*Main_Glass,IF(A14=4,glass_unders*Main_Glass,IF(A14=5,glass_pick*Main_Glass,0))))
15	=IF(A15="","",IF(A15=3,glass_lights*Main_Glass,IF(A15=4,glass_unders*Main_Glass,IF(A15=5,glass_pick*Main_Glass,0))))
16	=IF(A16="","",IF(A16=3,glass_lights*Main_Glass,IF(A16=4,glass_unders*Main_Glass,IF(A16=5,glass_pick*Main_Glass,0))))
17	=IF(A17="","",IF(A17=3,glass_lights*Main_Glass,IF(A17=4,glass_unders*Main_Glass,IF(A17=5,glass_pick*Main_Glass,0))))
18	=IF(A18="","",IF(A18=3,glass_lights*Main_Glass,IF(A18=4,glass_unders*Main_Glass,IF(A18=5,glass_pick*Main_Glass,0))))
19	=IF(A19="","",IF(A19=3,glass_lights*Main_Glass,IF(A19=4,glass_unders*Main_Glass,IF(A19=5,glass_pick*Main_Glass,0))))
20	=IF(A20="","",IF(A20=3,glass_lights*Main_Glass,IF(A20=4,glass_unders*Main_Glass,IF(A20=5,glass_pick*Main_Glass,0))))
21	=IF(A21="","",IF(A21=3,glass_lights*Main_Glass,IF(A21=4,glass_unders*Main_Glass,IF(A21=5,glass_pick*Main_Glass,0))))
22	=IF(A22="","",IF(A22=3,glass_lights*Main_Glass,IF(A22=4,glass_unders*Main_Glass,IF(A22=5,glass_pick*Main_Glass,0))))
23	=IF(A23="","",IF(A23=3,glass_lights*Main_Glass,IF(A23=4,glass_unders*Main_Glass,IF(A23=5,glass_pick*Main_Glass,0))))
24	=IF(A24="","",IF(A24=3,glass_lights*Main_Glass,IF(A24=4,glass_unders*Main_Glass,IF(A24=5,glass_pick*Main_Glass,0))))
25	=IF(A25="","",IF(A25=3,glass_lights*Main_Glass,IF(A25=4,glass_unders*Main_Glass,IF(A25=5,glass_pick*Main_Glass,0))))
26	=IF(A26="","",IF(A26=3,glass_lights*Main_Glass,IF(A26=4,glass_unders*Main_Glass,IF(A26=5,glass_pick*Main_Glass,0))))
27	=IF(A27="","",IF(A27=3,glass_lights*Main_Glass,IF(A27=4,glass_unders*Main_Glass,IF(A27=5,glass_pick*Main_Glass,0))))
28	=IF(A28="","",IF(A28=3,glass_lights*Main_Glass,IF(A28=4,glass_unders*Main_Glass,IF(A28=5,glass_pick*Main_Glass,0))))
29	=IF(A29="","",IF(A29=3,glass_lights*Main_Glass,IF(A29=4,glass_unders*Main_Glass,IF(A29=5,glass_pick*Main_Glass,0))))
30	=IF(A30="","",IF(A30=3,glass_lights*Main_Glass,IF(A30=4,glass_unders*Main_Glass,IF(A30=5,glass_pick*Main_Glass,0))))

	J
1	
2	
3	
4	food
5	=+'%'!F14+'%'!F12
6	
7	
8	
9	
10	6
11	
12	food
13	=IF(A13="","",IF(A13=3,food_lights*Main_Food,IF(A13=4,food_unders*Main_Food,IF(A13=6,Assume!$A$7*Main_Food,0))))
14	=IF(A14="","",IF(A14=3,food_lights*Main_Food,IF(A14=4,food_unders*Main_Food,IF(A14=6,Assume!$A$7*Main_Food,0))))
15	=IF(A15="","",IF(A15=3,food_lights*Main_Food,IF(A15=4,food_unders*Main_Food,IF(A15=6,Assume!$A$7*Main_Food,0))))
16	=IF(A16="","",IF(A16=3,food_lights*Main_Food,IF(A16=4,food_unders*Main_Food,IF(A16=6,Assume!$A$7*Main_Food,0))))
17	=IF(A17="","",IF(A17=3,food_lights*Main_Food,IF(A17=4,food_unders*Main_Food,IF(A17=6,Assume!$A$7*Main_Food,0))))
18	=IF(A18="","",IF(A18=3,food_lights*Main_Food,IF(A18=4,food_unders*Main_Food,IF(A18=6,Assume!$A$7*Main_Food,0))))
19	=IF(A19="","",IF(A19=3,food_lights*Main_Food,IF(A19=4,food_unders*Main_Food,IF(A19=6,Assume!$A$7*Main_Food,0))))
20	=IF(A20="","",IF(A20=3,food_lights*Main_Food,IF(A20=4,food_unders*Main_Food,IF(A20=6,Assume!$A$7*Main_Food,0))))
21	=IF(A21="","",IF(A21=3,food_lights*Main_Food,IF(A21=4,food_unders*Main_Food,IF(A21=6,Assume!$A$7*Main_Food,0))))
22	=IF(A22="","",IF(A22=3,food_lights*Main_Food,IF(A22=4,food_unders*Main_Food,IF(A22=6,Assume!$A$7*Main_Food,0))))
23	=IF(A23="","",IF(A23=3,food_lights*Main_Food,IF(A23=4,food_unders*Main_Food,IF(A23=6,Assume!$A$7*Main_Food,0))))
24	=IF(A24="","",IF(A24=3,food_lights*Main_Food,IF(A24=4,food_unders*Main_Food,IF(A24=6,Assume!$A$7*Main_Food,0))))
25	=IF(A25="","",IF(A25=3,food_lights*Main_Food,IF(A25=4,food_unders*Main_Food,IF(A25=6,Assume!$A$7*Main_Food,0))))
26	=IF(A26="","",IF(A26=3,food_lights*Main_Food,IF(A26=4,food_unders*Main_Food,IF(A26=6,Assume!$A$7*Main_Food,0))))
27	=IF(A27="","",IF(A27=3,food_lights*Main_Food,IF(A27=4,food_unders*Main_Food,IF(A27=6,Assume!$A$7*Main_Food,0))))
28	=IF(A28="","",IF(A28=3,food_lights*Main_Food,IF(A28=4,food_unders*Main_Food,IF(A28=6,Assume!$A$7*Main_Food,0))))
29	=IF(A29="","",IF(A29=3,food_lights*Main_Food,IF(A29=4,food_unders*Main_Food,IF(A29=6,Assume!$A$7*Main_Food,0))))
30	=IF(A30="","",IF(A30=3,food_lights*Main_Food,IF(A30=4,food_unders*Main_Food,IF(A30=6,Assume!$A$7*Main_Food,0))))

	K
1	
2	
3	
4	C&D
5	=+'%'!F16+'%'!F21+'%'!F15
6	
7	
8	
9	
10	
11	
12	C&D
13	=IF(A13="","",IF(A13=3,CD_lights*Main_CD,IF(A13=4,CD_unders*Main_CD,0)))
14	=IF(A14="","",IF(A14=3,CD_lights*Main_CD,IF(A14=4,CD_unders*Main_CD,0)))
15	=IF(A15="","",IF(A15=3,CD_lights*Main_CD,IF(A15=4,CD_unders*Main_CD,0)))
16	=IF(A16="","",IF(A16=3,CD_lights*Main_CD,IF(A16=4,CD_unders*Main_CD,0)))
17	=IF(A17="","",IF(A17=3,CD_lights*Main_CD,IF(A17=4,CD_unders*Main_CD,0)))
18	=IF(A18="","",IF(A18=3,CD_lights*Main_CD,IF(A18=4,CD_unders*Main_CD,0)))
19	=IF(A19="","",IF(A19=3,CD_lights*Main_CD,IF(A19=4,CD_unders*Main_CD,0)))
20	=IF(A20="","",IF(A20=3,CD_lights*Main_CD,IF(A20=4,CD_unders*Main_CD,0)))
21	=IF(A21="","",IF(A21=3,CD_lights*Main_CD,IF(A21=4,CD_unders*Main_CD,0)))
22	=IF(A22="","",IF(A22=3,CD_lights*Main_CD,IF(A22=4,CD_unders*Main_CD,0)))
23	=IF(A23="","",IF(A23=3,CD_lights*Main_CD,IF(A23=4,CD_unders*Main_CD,0)))
24	=IF(A24="","",IF(A24=3,CD_lights*Main_CD,IF(A24=4,CD_unders*Main_CD,0)))
25	=IF(A25="","",IF(A25=3,CD_lights*Main_CD,IF(A25=4,CD_unders*Main_CD,0)))
26	=IF(A26="","",IF(A26=3,CD_lights*Main_CD,IF(A26=4,CD_unders*Main_CD,0)))
27	=IF(A27="","",IF(A27=3,CD_lights*Main_CD,IF(A27=4,CD_unders*Main_CD,0)))
28	=IF(A28="","",IF(A28=3,CD_lights*Main_CD,IF(A28=4,CD_unders*Main_CD,0)))
29	=IF(A29="","",IF(A29=3,CD_lights*Main_CD,IF(A29=4,CD_unders*Main_CD,0)))
30	=IF(A30="","",IF(A30=3,CD_lights*Main_CD,IF(A30=4,CD_unders*Main_CD,0)))

	L
1	
2	
3	
4	Misc
5	=+'%'!F25
6	
7	
8	
9	
10	
11	
12	Misc
13	=IF(A13="","",IF(A13=3,misc_lights*Main_Misc,IF(A13=4,misc_unders*Main_Misc,0)))
14	=IF(A14="","",IF(A14=3,misc_lights*Main_Misc,IF(A14=4,misc_unders*Main_Misc,0)))
15	=IF(A15="","",IF(A15=3,misc_lights*Main_Misc,IF(A15=4,misc_unders*Main_Misc,0)))
16	=IF(A16="","",IF(A16=3,misc_lights*Main_Misc,IF(A16=4,misc_unders*Main_Misc,0)))
17	=IF(A17="","",IF(A17=3,misc_lights*Main_Misc,IF(A17=4,misc_unders*Main_Misc,0)))
18	=IF(A18="","",IF(A18=3,misc_lights*Main_Misc,IF(A18=4,misc_unders*Main_Misc,0)))
19	=IF(A19="","",IF(A19=3,misc_lights*Main_Misc,IF(A19=4,misc_unders*Main_Misc,0)))
20	=IF(A20="","",IF(A20=3,misc_lights*Main_Misc,IF(A20=4,misc_unders*Main_Misc,0)))
21	=IF(A21="","",IF(A21=3,misc_lights*Main_Misc,IF(A21=4,misc_unders*Main_Misc,0)))
22	=IF(A22="","",IF(A22=3,misc_lights*Main_Misc,IF(A22=4,misc_unders*Main_Misc,0)))
23	=IF(A23="","",IF(A23=3,misc_lights*Main_Misc,IF(A23=4,misc_unders*Main_Misc,0)))
24	=IF(A24="","",IF(A24=3,misc_lights*Main_Misc,IF(A24=4,misc_unders*Main_Misc,0)))
25	=IF(A25="","",IF(A25=3,misc_lights*Main_Misc,IF(A25=4,misc_unders*Main_Misc,0)))
26	=IF(A26="","",IF(A26=3,misc_lights*Main_Misc,IF(A26=4,misc_unders*Main_Misc,0)))
27	=IF(A27="","",IF(A27=3,misc_lights*Main_Misc,IF(A27=4,misc_unders*Main_Misc,0)))
28	=IF(A28="","",IF(A28=3,misc_lights*Main_Misc,IF(A28=4,misc_unders*Main_Misc,0)))
29	=IF(A29="","",IF(A29=3,misc_lights*Main_Misc,IF(A29=4,misc_unders*Main_Misc,0)))
30	=IF(A30="","",IF(A30=3,misc_lights*Main_Misc,IF(A30=4,misc_unders*Main_Misc,0)))

	M
1	
2	
3	
4	elec
5	=+'%'!F17
6	
7	
8	
9	
10	
11	
12	elec
13	=IF($A13="","",IF($A13=3,elec_lights*Main_elec,IF($A13=4,elec_unders*Main_elec,0)))
14	=IF($A14="","",IF($A14=3,elec_lights*Main_elec,IF($A14=4,elec_unders*Main_elec,0)))
15	=IF($A15="","",IF($A15=3,elec_lights*Main_elec,IF($A15=4,elec_unders*Main_elec,0)))
16	=IF($A16="","",IF($A16=3,elec_lights*Main_elec,IF($A16=4,elec_unders*Main_elec,0)))
17	=IF($A17="","",IF($A17=3,elec_lights*Main_elec,IF($A17=4,elec_unders*Main_elec,0)))
18	=IF($A18="","",IF($A18=3,elec_lights*Main_elec,IF($A18=4,elec_unders*Main_elec,0)))
19	=IF($A19="","",IF($A19=3,elec_lights*Main_elec,IF($A19=4,elec_unders*Main_elec,0)))
20	=IF($A20="","",IF($A20=3,elec_lights*Main_elec,IF($A20=4,elec_unders*Main_elec,0)))
21	=IF($A21="","",IF($A21=3,elec_lights*Main_elec,IF($A21=4,elec_unders*Main_elec,0)))
22	=IF($A22="","",IF($A22=3,elec_lights*Main_elec,IF($A22=4,elec_unders*Main_elec,0)))
23	=IF($A23="","",IF($A23=3,elec_lights*Main_elec,IF($A23=4,elec_unders*Main_elec,0)))
24	=IF($A24="","",IF($A24=3,elec_lights*Main_elec,IF($A24=4,elec_unders*Main_elec,0)))
25	=IF($A25="","",IF($A25=3,elec_lights*Main_elec,IF($A25=4,elec_unders*Main_elec,0)))
26	=IF($A26="","",IF($A26=3,elec_lights*Main_elec,IF($A26=4,elec_unders*Main_elec,0)))
27	=IF($A27="","",IF($A27=3,elec_lights*Main_elec,IF($A27=4,elec_unders*Main_elec,0)))
28	=IF($A28="","",IF($A28=3,elec_lights*Main_elec,IF($A28=4,elec_unders*Main_elec,0)))
29	=IF($A29="","",IF($A29=3,elec_lights*Main_elec,IF($A29=4,elec_unders*Main_elec,0)))
30	=IF($A30="","",IF($A30=3,elec_lights*Main_elec,IF($A30=4,elec_unders*Main_elec,0)))

	N
1	
2	
3	
4	HHW
5	=+'%'!F18
6	
7	
8	
9	
10	
11	
12	HHW
13	=IF($A13="","",IF($A13=3,HHW_lights*Main_HHW,IF($A13=4,HHW_unders*Main_HHW,0)))
14	=IF($A14="","",IF($A14=3,HHW_lights*Main_HHW,IF($A14=4,HHW_unders*Main_HHW,0)))
15	=IF($A15="","",IF($A15=3,HHW_lights*Main_HHW,IF($A15=4,HHW_unders*Main_HHW,0)))
16	=IF($A16="","",IF($A16=3,HHW_lights*Main_HHW,IF($A16=4,HHW_unders*Main_HHW,0)))
17	=IF($A17="","",IF($A17=3,HHW_lights*Main_HHW,IF($A17=4,HHW_unders*Main_HHW,0)))
18	=IF($A18="","",IF($A18=3,HHW_lights*Main_HHW,IF($A18=4,HHW_unders*Main_HHW,0)))
19	=IF($A19="","",IF($A19=3,HHW_lights*Main_HHW,IF($A19=4,HHW_unders*Main_HHW,0)))
20	=IF($A20="","",IF($A20=3,HHW_lights*Main_HHW,IF($A20=4,HHW_unders*Main_HHW,0)))
21	=IF($A21="","",IF($A21=3,HHW_lights*Main_HHW,IF($A21=4,HHW_unders*Main_HHW,0)))
22	=IF($A22="","",IF($A22=3,HHW_lights*Main_HHW,IF($A22=4,HHW_unders*Main_HHW,0)))
23	=IF($A23="","",IF($A23=3,HHW_lights*Main_HHW,IF($A23=4,HHW_unders*Main_HHW,0)))
24	=IF($A24="","",IF($A24=3,HHW_lights*Main_HHW,IF($A24=4,HHW_unders*Main_HHW,0)))
25	=IF($A25="","",IF($A25=3,HHW_lights*Main_HHW,IF($A25=4,HHW_unders*Main_HHW,0)))
26	=IF($A26="","",IF($A26=3,HHW_lights*Main_HHW,IF($A26=4,HHW_unders*Main_HHW,0)))
27	=IF($A27="","",IF($A27=3,HHW_lights*Main_HHW,IF($A27=4,HHW_unders*Main_HHW,0)))
28	=IF($A28="","",IF($A28=3,HHW_lights*Main_HHW,IF($A28=4,HHW_unders*Main_HHW,0)))
29	=IF($A29="","",IF($A29=3,HHW_lights*Main_HHW,IF($A29=4,HHW_unders*Main_HHW,0)))
30	=IF($A30="","",IF($A30=3,HHW_lights*Main_HHW,IF($A30=4,HHW_unders*Main_HHW,0)))

	O
1	
2	
3	
4	OYB
5	=+'%'!F24
6	
7	
8	
9	
10	
11	
12	OYB
13	=IF($A13="","",IF($A13=3,OYB_lights*Main_OYB,IF($A13=4,OYB_unders*Main_OYB,0)))
14	=IF($A14="","",IF($A14=3,OYB_lights*Main_OYB,IF($A14=4,OYB_unders*Main_OYB,0)))
15	=IF($A15="","",IF($A15=3,OYB_lights*Main_OYB,IF($A15=4,OYB_unders*Main_OYB,0)))
16	=IF($A16="","",IF($A16=3,OYB_lights*Main_OYB,IF($A16=4,OYB_unders*Main_OYB,0)))
17	=IF($A17="","",IF($A17=3,OYB_lights*Main_OYB,IF($A17=4,OYB_unders*Main_OYB,0)))
18	=IF($A18="","",IF($A18=3,OYB_lights*Main_OYB,IF($A18=4,OYB_unders*Main_OYB,0)))
19	=IF($A19="","",IF($A19=3,OYB_lights*Main_OYB,IF($A19=4,OYB_unders*Main_OYB,0)))
20	=IF($A20="","",IF($A20=3,OYB_lights*Main_OYB,IF($A20=4,OYB_unders*Main_OYB,0)))
21	=IF($A21="","",IF($A21=3,OYB_lights*Main_OYB,IF($A21=4,OYB_unders*Main_OYB,0)))
22	=IF($A22="","",IF($A22=3,OYB_lights*Main_OYB,IF($A22=4,OYB_unders*Main_OYB,0)))
23	=IF($A23="","",IF($A23=3,OYB_lights*Main_OYB,IF($A23=4,OYB_unders*Main_OYB,0)))
24	=IF($A24="","",IF($A24=3,OYB_lights*Main_OYB,IF($A24=4,OYB_unders*Main_OYB,0)))
25	=IF($A25="","",IF($A25=3,OYB_lights*Main_OYB,IF($A25=4,OYB_unders*Main_OYB,0)))
26	=IF($A26="","",IF($A26=3,OYB_lights*Main_OYB,IF($A26=4,OYB_unders*Main_OYB,0)))
27	=IF($A27="","",IF($A27=3,OYB_lights*Main_OYB,IF($A27=4,OYB_unders*Main_OYB,0)))
28	=IF($A28="","",IF($A28=3,OYB_lights*Main_OYB,IF($A28=4,OYB_unders*Main_OYB,0)))
29	=IF($A29="","",IF($A29=3,OYB_lights*Main_OYB,IF($A29=4,OYB_unders*Main_OYB,0)))
30	=IF($A30="","",IF($A30=3,OYB_lights*Main_OYB,IF($A30=4,OYB_unders*Main_OYB,0)))

	P
1	
2	
3	
4	textiles
5	=+'%'!F22
6	
7	
8	
9	
10	
11	
12	textiles
13	=IF(A13="","",IF(A13=3,tex_lights*Main_tex,IF(A13=4,tex_unders*Main_tex,0)))
14	=IF(A14="","",IF(A14=3,tex_lights*Main_tex,IF(A14=4,tex_unders*Main_tex,0)))
15	=IF(A15="","",IF(A15=3,tex_lights*Main_tex,IF(A15=4,tex_unders*Main_tex,0)))
16	=IF(A16="","",IF(A16=3,tex_lights*Main_tex,IF(A16=4,tex_unders*Main_tex,0)))
17	=IF(A17="","",IF(A17=3,tex_lights*Main_tex,IF(A17=4,tex_unders*Main_tex,0)))
18	=IF(A18="","",IF(A18=3,tex_lights*Main_tex,IF(A18=4,tex_unders*Main_tex,0)))
19	=IF(A19="","",IF(A19=3,tex_lights*Main_tex,IF(A19=4,tex_unders*Main_tex,0)))
20	=IF(A20="","",IF(A20=3,tex_lights*Main_tex,IF(A20=4,tex_unders*Main_tex,0)))
21	=IF(A21="","",IF(A21=3,tex_lights*Main_tex,IF(A21=4,tex_unders*Main_tex,0)))
22	=IF(A22="","",IF(A22=3,tex_lights*Main_tex,IF(A22=4,tex_unders*Main_tex,0)))
23	=IF(A23="","",IF(A23=3,tex_lights*Main_tex,IF(A23=4,tex_unders*Main_tex,0)))
24	=IF(A24="","",IF(A24=3,tex_lights*Main_tex,IF(A24=4,tex_unders*Main_tex,0)))
25	=IF(A25="","",IF(A25=3,tex_lights*Main_tex,IF(A25=4,tex_unders*Main_tex,0)))
26	=IF(A26="","",IF(A26=3,tex_lights*Main_tex,IF(A26=4,tex_unders*Main_tex,0)))
27	=IF(A27="","",IF(A27=3,tex_lights*Main_tex,IF(A27=4,tex_unders*Main_tex,0)))
28	=IF(A28="","",IF(A28=3,tex_lights*Main_tex,IF(A28=4,tex_unders*Main_tex,0)))
29	=IF(A29="","",IF(A29=3,tex_lights*Main_tex,IF(A29=4,tex_unders*Main_tex,0)))
30	=IF(A30="","",IF(A30=3,tex_lights*Main_tex,IF(A30=4,tex_unders*Main_tex,0)))

	Q
1	
2	
3	
4	Wood
5	=+'%'!F13
6	
7	
8	
9	
10	
11	
12	Wood
13	=IF(A13="","",IF(A13=3,wood_lights*Main_wood,IF(A13=4,wood_unders*Main_wood,0)))
14	=IF(A14="","",IF(A14=3,wood_lights*Main_wood,IF(A14=4,wood_unders*Main_wood,0)))
15	=IF(A15="","",IF(A15=3,wood_lights*Main_wood,IF(A15=4,wood_unders*Main_wood,0)))
16	=IF(A16="","",IF(A16=3,wood_lights*Main_wood,IF(A16=4,wood_unders*Main_wood,0)))
17	=IF(A17="","",IF(A17=3,wood_lights*Main_wood,IF(A17=4,wood_unders*Main_wood,0)))
18	=IF(A18="","",IF(A18=3,wood_lights*Main_wood,IF(A18=4,wood_unders*Main_wood,0)))
19	=IF(A19="","",IF(A19=3,wood_lights*Main_wood,IF(A19=4,wood_unders*Main_wood,0)))
20	=IF(A20="","",IF(A20=3,wood_lights*Main_wood,IF(A20=4,wood_unders*Main_wood,0)))
21	=IF(A21="","",IF(A21=3,wood_lights*Main_wood,IF(A21=4,wood_unders*Main_wood,0)))
22	=IF(A22="","",IF(A22=3,wood_lights*Main_wood,IF(A22=4,wood_unders*Main_wood,0)))
23	=IF(A23="","",IF(A23=3,wood_lights*Main_wood,IF(A23=4,wood_unders*Main_wood,0)))
24	=IF(A24="","",IF(A24=3,wood_lights*Main_wood,IF(A24=4,wood_unders*Main_wood,0)))
25	=IF(A25="","",IF(A25=3,wood_lights*Main_wood,IF(A25=4,wood_unders*Main_wood,0)))
26	=IF(A26="","",IF(A26=3,wood_lights*Main_wood,IF(A26=4,wood_unders*Main_wood,0)))
27	=IF(A27="","",IF(A27=3,wood_lights*Main_wood,IF(A27=4,wood_unders*Main_wood,0)))
28	=IF(A28="","",IF(A28=3,wood_lights*Main_wood,IF(A28=4,wood_unders*Main_wood,0)))
29	=IF(A29="","",IF(A29=3,wood_lights*Main_wood,IF(A29=4,wood_unders*Main_wood,0)))
30	=IF(A30="","",IF(A30=3,wood_lights*Main_wood,IF(A30=4,wood_unders*Main_wood,0)))

	R
1	
2	
3	
4	paper
5	=+'%'!F8+'%'!F23
6	Total mass incoming
7	
8	
9	
10	5
11	
12	paper
13	=IF(A13="","",IF(A13=3,paper_lights*Main_Paper,IF(A13=4,paper_unders*Main_Paper,IF(A13=5,paper_pick*'%'!$G$8*Main_Paper,0))))
14	=IF(A14="","",IF(A14=3,paper_lights*Main_Paper,IF(A14=4,paper_unders*Main_Paper,IF(A14=5,paper_pick*'%'!$G$8*Main_Paper,0))))
15	=IF(A15="","",IF(A15=3,paper_lights*Main_Paper,IF(A15=4,paper_unders*Main_Paper,IF(A15=5,paper_pick*'%'!$G$8*Main_Paper,0))))
16	=IF(A16="","",IF(A16=3,paper_lights*Main_Paper,IF(A16=4,paper_unders*Main_Paper,IF(A16=5,paper_pick*'%'!$G$8*Main_Paper,0))))
17	=IF(A17="","",IF(A17=3,paper_lights*Main_Paper,IF(A17=4,paper_unders*Main_Paper,IF(A17=5,paper_pick*'%'!$G$8*Main_Paper,0))))
18	=IF(A18="","",IF(A18=3,paper_lights*Main_Paper,IF(A18=4,paper_unders*Main_Paper,IF(A18=5,paper_pick*'%'!$G$8*Main_Paper,0))))
19	=IF(A19="","",IF(A19=3,paper_lights*Main_Paper,IF(A19=4,paper_unders*Main_Paper,IF(A19=5,paper_pick*'%'!$G$8*Main_Paper,0))))
20	=IF(A20="","",IF(A20=3,paper_lights*Main_Paper,IF(A20=4,paper_unders*Main_Paper,IF(A20=5,paper_pick*'%'!$G$8*Main_Paper,0))))
21	=IF(A21="","",IF(A21=3,paper_lights*Main_Paper,IF(A21=4,paper_unders*Main_Paper,IF(A21=5,paper_pick*'%'!$G$8*Main_Paper,0))))
22	=IF(A22="","",IF(A22=3,paper_lights*Main_Paper,IF(A22=4,paper_unders*Main_Paper,IF(A22=5,paper_pick*'%'!$G$8*Main_Paper,0))))
23	=IF(A23="","",IF(A23=3,paper_lights*Main_Paper,IF(A23=4,paper_unders*Main_Paper,IF(A23=5,paper_pick*'%'!$G$8*Main_Paper,0))))
24	=IF(A24="","",IF(A24=3,paper_lights*Main_Paper,IF(A24=4,paper_unders*Main_Paper,IF(A24=5,paper_pick*'%'!$G$8*Main_Paper,0))))
25	=IF(A25="","",IF(A25=3,paper_lights*Main_Paper,IF(A25=4,paper_unders*Main_Paper,IF(A25=5,paper_pick*'%'!$G$8*Main_Paper,0))))
26	=IF(A26="","",IF(A26=3,paper_lights*Main_Paper,IF(A26=4,paper_unders*Main_Paper,IF(A26=5,paper_pick*'%'!$G$8*Main_Paper,0))))
27	=IF(A27="","",IF(A27=3,paper_lights*Main_Paper,IF(A27=4,paper_unders*Main_Paper,IF(A27=5,paper_pick*'%'!$G$8*Main_Paper,0))))
28	=IF(A28="","",IF(A28=3,paper_lights*Main_Paper,IF(A28=4,paper_unders*Main_Paper,IF(A28=5,paper_pick*'%'!$G$8*Main_Paper,0))))
29	=IF(A29="","",IF(A29=3,paper_lights*Main_Paper,IF(A29=4,paper_unders*Main_Paper,IF(A29=5,paper_pick*'%'!$G$8*Main_Paper,0))))
30	=IF(A30="","",IF(A30=3,paper_lights*Main_Paper,IF(A30=4,paper_unders*Main_Paper,IF(A30=5,paper_pick*'%'!$G$8*Main_Paper,0))))

	S	T	U
1			
2			
3		**KEY:**	
4	Plas	1 = ECS	
5	=+'%'!F7	2 = Magnet	
6	=+SUM(G5:S5)	3 = Air classifier	
7		4 = screen/tromel	
8		5 = hand sort	
9		6 = shredder	
10	5		
11			1st Leftover
12	Plas	Al	Fe
13	=IF(A13="","",IF(A13=3,plas_lights*Main_Plas,IF(A13=4,plas_unders*Main_Plas,IF(A13=5,plas_pick*Main_Plas,0))))	=+Main_Al-G13	=+Main_Fe-H13
14	=IF(A14="","",IF(A14=3,plas_lights*Main_Plas,IF(A14=4,plas_unders*Main_Plas,IF(A14=5,plas_pick*Main_Plas,0))))	=+Main_Al-G14	=+Main_Fe-H14
15	=IF(A15="","",IF(A15=3,plas_lights*Main_Plas,IF(A15=4,plas_unders*Main_Plas,IF(A15=5,plas_pick*Main_Plas,0))))	=+Main_Al-G15	=+Main_Fe-H15
16	=IF(A16="","",IF(A16=3,plas_lights*Main_Plas,IF(A16=4,plas_unders*Main_Plas,IF(A16=5,plas_pick*Main_Plas,0))))	=+Main_Al-G16	=+Main_Fe-H16
17	=IF(A17="","",IF(A17=3,plas_lights*Main_Plas,IF(A17=4,plas_unders*Main_Plas,IF(A17=5,plas_pick*Main_Plas,0))))	=+Main_Al-G17	=+Main_Fe-H17
18	=IF(A18="","",IF(A18=3,plas_lights*Main_Plas,IF(A18=4,plas_unders*Main_Plas,IF(A18=5,plas_pick*Main_Plas,0))))	=+Main_Al-G18	=+Main_Fe-H18
19	=IF(A19="","",IF(A19=3,plas_lights*Main_Plas,IF(A19=4,plas_unders*Main_Plas,IF(A19=5,plas_pick*Main_Plas,0))))	=+Main_Al-G19	=+Main_Fe-H19
20	=IF(A20="","",IF(A20=3,plas_lights*Main_Plas,IF(A20=4,plas_unders*Main_Plas,IF(A20=5,plas_pick*Main_Plas,0))))	=+Main_Al-G20	=+Main_Fe-H20
21	=IF(A21="","",IF(A21=3,plas_lights*Main_Plas,IF(A21=4,plas_unders*Main_Plas,IF(A21=5,plas_pick*Main_Plas,0))))	=+Main_Al-G21	=+Main_Fe-H21
22	=IF(A22="","",IF(A22=3,plas_lights*Main_Plas,IF(A22=4,plas_unders*Main_Plas,IF(A22=5,plas_pick*Main_Plas,0))))	=+Main_Al-G22	=+Main_Fe-H22
23	=IF(A23="","",IF(A23=3,plas_lights*Main_Plas,IF(A23=4,plas_unders*Main_Plas,IF(A23=5,plas_pick*Main_Plas,0))))	=+Main_Al-G23	=+Main_Fe-H23
24	=IF(A24="","",IF(A24=3,plas_lights*Main_Plas,IF(A24=4,plas_unders*Main_Plas,IF(A24=5,plas_pick*Main_Plas,0))))	=+Main_Al-G24	=+Main_Fe-H24
25	=IF(A25="","",IF(A25=3,plas_lights*Main_Plas,IF(A25=4,plas_unders*Main_Plas,IF(A25=5,plas_pick*Main_Plas,0))))	=+Main_Al-G25	=+Main_Fe-H25
26	=IF(A26="","",IF(A26=3,plas_lights*Main_Plas,IF(A26=4,plas_unders*Main_Plas,IF(A26=5,plas_pick*Main_Plas,0))))	=+Main_Al-G26	=+Main_Fe-H26
27	=IF(A27="","",IF(A27=3,plas_lights*Main_Plas,IF(A27=4,plas_unders*Main_Plas,IF(A27=5,plas_pick*Main_Plas,0))))	=+Main_Al-G27	=+Main_Fe-H27
28	=IF(A28="","",IF(A28=3,plas_lights*Main_Plas,IF(A28=4,plas_unders*Main_Plas,IF(A28=5,plas_pick*Main_Plas,0))))	=+Main_Al-G28	=+Main_Fe-H28
29	=IF(A29="","",IF(A29=3,plas_lights*Main_Plas,IF(A29=4,plas_unders*Main_Plas,IF(A29=5,plas_pick*Main_Plas,0))))	=+Main_Al-G29	=+Main_Fe-H29
30	=IF(A30="","",IF(A30=3,plas_lights*Main_Plas,IF(A30=4,plas_unders*Main_Plas,IF(A30=5,plas_pick*Main_Plas,0))))	=+Main_Al-G30	=+Main_Fe-H30

	V	W	X	Y	Z	AA	AB
1							
2							
3		Recovered	Leftover (more so				
4		all metals	nonmetals		Rec_Al	0.95	% recovered
5		ferrous metals	nonmetals		Rec_Fe	0.9	% recovered
6		Lights	Heavies				
7		Unders	Overs				
8		picked	not picked				
9		lost moisture	drier mass				
10							
11							
12	glass	food	C&D	Misc	elec	HHW	OYB
13	=+Main_Glass-I13	=+Main_Food-J13	=+Main_CD-K13	=+Main_Misc-L13	=+Main_elec-M13	=+Main_HHW-N13	=+Main_OYB-O13
14	=+Main_Glass-I14	=+Main_Food-J14	=+Main_CD-K14	=+Main_Misc-L14	=+Main_elec-M14	=+Main_HHW-N14	=+Main_OYB-O14
15	=+Main_Glass-I15	=+Main_Food-J15	=+Main_CD-K15	=+Main_Misc-L15	=+Main_elec-M15	=+Main_HHW-N15	=+Main_OYB-O15
16	=+Main_Glass-I16	=+Main_Food-J16	=+Main_CD-K16	=+Main_Misc-L16	=+Main_elec-M16	=+Main_HHW-N16	=+Main_OYB-O16
17	=+Main_Glass-I17	=+Main_Food-J17	=+Main_CD-K17	=+Main_Misc-L17	=+Main_elec-M17	=+Main_HHW-N17	=+Main_OYB-O17
18	=+Main_Glass-I18	=+Main_Food-J18	=+Main_CD-K18	=+Main_Misc-L18	=+Main_elec-M18	=+Main_HHW-N18	=+Main_OYB-O18
19	=+Main_Glass-I19	=+Main_Food-J19	=+Main_CD-K19	=+Main_Misc-L19	=+Main_elec-M19	=+Main_HHW-N19	=+Main_OYB-O19
20	=+Main_Glass-I20	=+Main_Food-J20	=+Main_CD-K20	=+Main_Misc-L20	=+Main_elec-M20	=+Main_HHW-N20	=+Main_OYB-O20
21	=+Main_Glass-I21	=+Main_Food-J21	=+Main_CD-K21	=+Main_Misc-L21	=+Main_elec-M21	=+Main_HHW-N21	=+Main_OYB-O21
22	=+Main_Glass-I22	=+Main_Food-J22	=+Main_CD-K22	=+Main_Misc-L22	=+Main_elec-M22	=+Main_HHW-N22	=+Main_OYB-O22
23	=+Main_Glass-I23	=+Main_Food-J23	=+Main_CD-K23	=+Main_Misc-L23	=+Main_elec-M23	=+Main_HHW-N23	=+Main_OYB-O23
24	=+Main_Glass-I24	=+Main_Food-J24	=+Main_CD-K24	=+Main_Misc-L24	=+Main_elec-M24	=+Main_HHW-N24	=+Main_OYB-O24
25	=+Main_Glass-I25	=+Main_Food-J25	=+Main_CD-K25	=+Main_Misc-L25	=+Main_elec-M25	=+Main_HHW-N25	=+Main_OYB-O25
26	=+Main_Glass-I26	=+Main_Food-J26	=+Main_CD-K26	=+Main_Misc-L26	=+Main_elec-M26	=+Main_HHW-N26	=+Main_OYB-O26
27	=+Main_Glass-I27	=+Main_Food-J27	=+Main_CD-K27	=+Main_Misc-L27	=+Main_elec-M27	=+Main_HHW-N27	=+Main_OYB-O27
28	=+Main_Glass-I28	=+Main_Food-J28	=+Main_CD-K28	=+Main_Misc-L28	=+Main_elec-M28	=+Main_HHW-N28	=+Main_OYB-O28
29	=+Main_Glass-I29	=+Main_Food-J29	=+Main_CD-K29	=+Main_Misc-L29	=+Main_elec-M29	=+Main_HHW-N29	=+Main_OYB-O29
30	=+Main_Glass-I30	=+Main_Food-J30	=+Main_CD-K30	=+Main_Misc-L30	=+Main_elec-M30	=+Main_HHW-N30	=+Main_OYB-O30

	AC	AD	AE	AF
1				
2				
3				
4				
5				Lights
6				Heavies
7				
8				
9				
10				
11				
12	textiles	Wood	paper	Plas
13	=+Main_tex-P13	=+Main_wood-Q13	=+Main_Paper-R13	=+Main_Plas-S13
14	=+Main_tex-P14	=+Main_wood-Q14	=+Main_Paper-R14	=+Main_Plas-S14
15	=+Main_tex-P15	=+Main_wood-Q15	=+Main_Paper-R15	=+Main_Plas-S15
16	=+Main_tex-P16	=+Main_wood-Q16	=+Main_Paper-R16	=+Main_Plas-S16
17	=+Main_tex-P17	=+Main_wood-Q17	=+Main_Paper-R17	=+Main_Plas-S17
18	=+Main_tex-P18	=+Main_wood-Q18	=+Main_Paper-R18	=+Main_Plas-S18
19	=+Main_tex-P19	=+Main_wood-Q19	=+Main_Paper-R19	=+Main_Plas-S19
20	=+Main_tex-P20	=+Main_wood-Q20	=+Main_Paper-R20	=+Main_Plas-S20
21	=+Main_tex-P21	=+Main_wood-Q21	=+Main_Paper-R21	=+Main_Plas-S21
22	=+Main_tex-P22	=+Main_wood-Q22	=+Main_Paper-R22	=+Main_Plas-S22
23	=+Main_tex-P23	=+Main_wood-Q23	=+Main_Paper-R23	=+Main_Plas-S23
24	=+Main_tex-P24	=+Main_wood-Q24	=+Main_Paper-R24	=+Main_Plas-S24
25	=+Main_tex-P25	=+Main_wood-Q25	=+Main_Paper-R25	=+Main_Plas-S25
26	=+Main_tex-P26	=+Main_wood-Q26	=+Main_Paper-R26	=+Main_Plas-S26
27	=+Main_tex-P27	=+Main_wood-Q27	=+Main_Paper-R27	=+Main_Plas-S27
28	=+Main_tex-P28	=+Main_wood-Q28	=+Main_Paper-R28	=+Main_Plas-S28
29	=+Main_tex-P29	=+Main_wood-Q29	=+Main_Paper-R29	=+Main_Plas-S29
30	=+Main_tex-P30	=+Main_wood-Q30	=+Main_Paper-R30	=+Main_Plas-S30

Appendix D: Model of MRF for Yellow Bag Waste

						Based on 1 week of waste								KEY:		Recov	Leftover (more sorting)									Air Cl
					Component	Al	Fe	septic	waste	Plas		1060	tpy	1 = ECS		all me	nonmetals									Al
					tons/hr	0.07	0.54	0.38	0.76	0.79		20.38	tpw	2 = Magnet		ferrou	nonmetals								Lights	50%
										2.55		8.00	hpw	3 = Air classifier		Lights	Heavies								Heavies	50%
						2.7%	21.3%	15.0%	30.0%	31.0%		2.55	tph	4 = screen/tromel		Under	Overs									
										100%				5 = hand sort		picked	not picked				Rec_Al	95%	% recovered			
						Machines involoved (all materials are affected by machi								6 = shredder		lost m	drier mass				Rec_Fe	90%	% recovered			
						1,5	1,2,5	1,5,6	6 (only	5																
						1st Recovered					1st Leftover					2nd Recovered					2nd Leftover					3r
1st	2nd	3rd	4th	5th	6th	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al
2						0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79											
3						0.03	0.05	0.08	0.54	0.77	0.03	0.49	0.31	0.23	0.02											
4						0.00	0.00	0.01	0.04	0.02	0.07	0.54	0.37	0.73	0.77											
5						0.06	0.47	0.31	0.00	0.69	0.01	0.07	0.08	0.76	0.10											
6						0.00	0.00	0.00	0.03	0.00	0.07	0.54	0.38	0.73	0.79											
2	1					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.38	0.76	0.79	
2	2					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.00	0.05	0.00	0.00	0.00	0.07	0.01	0.38	0.76	0.79	
2	3					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.03	0.01	0.08	0.54	0.77	0.03	0.05	0.31	0.23	0.02	
2	4					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.00	0.00	0.01	0.04	0.02	0.07	0.05	0.37	0.73	0.77	
2	5					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.06	0.04	0.31	0.00	0.69	0.01	0.01	0.08	0.76	0.10	
2	6					0.00	0.49	0.00	0.00	0.00	0.07	0.05	0.38	0.76	0.79	0.00	0.00	0.00	0.03	0.00	0.07	0.05	0.38	0.73	0.79	
3	2					0.03	0.05	0.08	0.54	0.77	0.03	0.49	0.31	0.23	0.02	0.00	0.44	0.00	0.00	0.00	0.03	0.05	0.31	0.23	0.02	
3	3					0.03	0.05	0.08	0.54	0.77	0.03	0.49	0.31	0.23	0.02	0.02	0.05	0.06	0.16	0.02	0.02	0.44	0.24	0.07	0.00	
3	4					0.03	0.05	0.08	0.54	0.77	0.03	0.49	0.31	0.23	0.02	0.00	0.00	0.01	0.01	0.00	0.03	0.49	0.30	0.22	0.02	
3	5					0.03	0.05	0.08	0.54	0.77	0.03	0.49	0.31	0.23	0.02	0.03	0.39	0.24	0.00	0.01	0.00	0.10	0.06	0.23	0.00	

sifier Performance, Diaz					Air classifier							Screen Data, % passing (unders), Diaz p52								Picking Rates	
Fe	septic	waste	Plas		Fracti	Recov	Leftover						Al	Fe	septic	waste	Plas			Paper	77.5%
10%	20%	70%	98%		Lights	95%	5%					1/2"	3%	0%	2%	5%	2%	Copy data for		Glass	87.5%
90%	80%	30%	2%		Heavi	2%	98%					1/2"	3%	0%			2%			Plastic	87.5%
	OIR	OR			Source: TTV							1"	10%	0%			2%			Alumin	87.5%
												2"	25%	5%			10%			Fe	80.0%
												4"	86%	55%			36%			septic	80.0%
Recovered					3rd Leftover				4th Recovered					4th Leftover					5th Recovered		
Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic

tph/sorter																			
0.90	only "clean"																		
0.45																			
0.20																			
0.06																			
0.75																			
0.20																			
																	1,5	1,2,5	
		5th Leftover					6th Recovered					6th Leftover							
waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic	waste	Plas	Al	Fe	septic
																	0.00	0.49	0.00
																	0.00	0.00	0.00
																	0.00	0.00	0.00
																	0.06	0.47	0.31
																	0.00	0.00	0.00
																	0.07	0.54	0.00
																	0.00	0.54	0.00
																	0.00	0.49	0.00
																	0.00	0.49	0.00
																	0.06	0.53	0.31
																	0.00	0.49	0.00
																	0.00	0.44	0.00
																	0.00	0.00	0.00
																	0.00	0.00	0.00
																	0.03	0.39	0.24

			in thousands				useful life, yrs				Al	Fe	septic	Plas		Tipping_Fee		
			Recycling Today,	$ 35	1 = ECS		30				$560.00	$ 9.00	$ -	$40.00	per ton	$90.83	US$/ton	
			Recycling Today,	$ 3	2 = Magnet		30			i="APR"=		clean steel cans		avg of HDPE & PET		1.6515	DM$/US$	
			rassmach.com ad	$ 15	3 = Air clas		30			6%						150	DM$/ton	
				$ 5	4 = screen/t		30			(P/A,i%,n)						165	DM$/tonne	
			based on min wage	$ 0	5 = hand so		8	hrs/day		0.072649								
			picking stations	$-	5 = hand so		30										Higher is	
	5		Recycling Today,	$ 8	6 = shredde		30										Better	
Recovered				ANNUAL COSTS PER MACHINE						TOTAL	ROFIT FROM RECYCLABLES				TOTAL	Tipping $	Benefit/	
waste	Plas	Total	#picker	1st	2nd	3rd	4th	5th	6th	COST/YR	Al	Fe	septic	Plas	GAINS/YR	Saved/Yr	Cost	B-C
0.00	0.00	0.49	0.00	0.218						$ 218	$ -	$ 4	0	$ -	1,828.82	$ 18,456	93.1	$ 20,067
0.00	0.00	0.00	0.00	1.09						$ 1,090	$ -	$ -	0	$ -	-	$ -	-	$ (1,090)
0.00	0.00	0.00	0.00	0.363						$ 363	$ -	$ -	0	$ -	-	$ -	-	$ (363)
0.00	0.69	1.53	6.71	14.38						$ 14,381	$ 34	$ 4	0	$ 28	27,302.82	$ 57,886	5.9	$ 70,808
0.03	0.00	0.00	0.00	0.545						$ 545	$ -	$ -	0	$ -	-	$ -	-	$ (545)
0.00	0.00	0.61	0.00	0.218	2.54					$ 2,761	$ 37	$ 5	0	$ -	17,247.70	$ 22,874	14.5	$ 37,361
0.00	0.00	0.54	0.00	0.218	0.22					$ 436	$ -	$ 5	0	$ -	2,011.70	$ 20,302	51.2	$ 21,878
0.00	0.00	0.49	0.00	0.218	1.09					$ 1,308	$ -	$ 4	0	$ -	1,828.82	$ 18,456	15.5	$ 18,977
0.00	0.00	0.49	0.00	0.218	0.36					$ 581	$ -	$ 4	0	$ -	1,828.82	$ 18,456	34.9	$ 19,704
0.00	0.69	1.59	6.14	0.218	13.1					$ 13,366	$ 34	$ 5	0	$ 28	27,516.18	$ 60,039	6.6	$ 74,189
0.03	0.00	0.49	0.00	0.218	0.54					$ 763	$ -	$ 4	0	$ -	1,828.82	$ 18,456	26.6	$ 19,522
0.00	0.00	0.44	0.00	1.09	0.22					$ 1,308	$ -	$ 4	0	$ -	1,645.94	$ 16,611	14.0	$ 16,949
0.00	0.00	0.00	0.00	1.09	1.09					$ 2,179	$ -	$ -	0	$ -	-	$ -	-	$ (2,179)
0.00	0.00	0.00	0.00	1.09	0.36					$ 1,453	$ -	$ -	0	$ -	-	$ -	-	$ (1,453)
0.00	0.01	0.68	2.36	1.09	5.06					$ 6,147	$ 17	$ 4	0	$ 1	8,704.97	$ 25,667	5.6	$ 28,225

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	A	B	C	D	E	F	G
1							
2							
3							Based on 1 week of waste
4						ent	Al
5						/hr	=+G7*$M$7
6							
7							0.027
8							
9							Machines involoved (all materials are affected by machines 3 & 4)
10							1,5
11							
12	1st	2n	3rd	4th	5th	6th	Al
13	2						=IF(A13="","",IF(A13=1,Rec_Al*Main_Al,IF(A13=3,Al_lights*Main_Al,IF(A13=4,Al_unders*Main_Al,IF(A13=5,Al_pick*Main_Al,0)))))
14	3						=IF(A14="","",IF(A14=1,Rec_Al*Main_Al,IF(A14=3,Al_lights*Main_Al,IF(A14=4,Al_unders*Main_Al,IF(A14=5,Al_pick*Main_Al,0)))))
15	4						=IF(A15="","",IF(A15=1,Rec_Al*Main_Al,IF(A15=3,Al_lights*Main_Al,IF(A15=4,Al_unders*Main_Al,IF(A15=5,Al_pick*Main_Al,0)))))
16	5						=IF(A16="","",IF(A16=1,Rec_Al*Main_Al,IF(A16=3,Al_lights*Main_Al,IF(A16=4,Al_unders*Main_Al,IF(A16=5,Al_pick*Main_Al,0)))))
17	6						=IF(A17="","",IF(A17=1,Rec_Al*Main_Al,IF(A17=3,Al_lights*Main_Al,IF(A17=4,Al_unders*Main_Al,IF(A17=5,Al_pick*Main_Al,0)))))
18	2	1					=IF(A18="","",IF(A18=1,Rec_Al*Main_Al,IF(A18=3,Al_lights*Main_Al,IF(A18=4,Al_unders*Main_Al,IF(A18=5,Al_pick*Main_Al,0)))))
19	2	2					=IF(A19="","",IF(A19=1,Rec_Al*Main_Al,IF(A19=3,Al_lights*Main_Al,IF(A19=4,Al_unders*Main_Al,IF(A19=5,Al_pick*Main_Al,0)))))
20	2	3					=IF(A20="","",IF(A20=1,Rec_Al*Main_Al,IF(A20=3,Al_lights*Main_Al,IF(A20=4,Al_unders*Main_Al,IF(A20=5,Al_pick*Main_Al,0)))))
21	2	4					=IF(A21="","",IF(A21=1,Rec_Al*Main_Al,IF(A21=3,Al_lights*Main_Al,IF(A21=4,Al_unders*Main_Al,IF(A21=5,Al_pick*Main_Al,0)))))
22	2	5					=IF(A22="","",IF(A22=1,Rec_Al*Main_Al,IF(A22=3,Al_lights*Main_Al,IF(A22=4,Al_unders*Main_Al,IF(A22=5,Al_pick*Main_Al,0)))))
23	2	6					=IF(A23="","",IF(A23=1,Rec_Al*Main_Al,IF(A23=3,Al_lights*Main_Al,IF(A23=4,Al_unders*Main_Al,IF(A23=5,Al_pick*Main_Al,0)))))
24	3	2					=IF(A24="","",IF(A24=1,Rec_Al*Main_Al,IF(A24=3,Al_lights*Main_Al,IF(A24=4,Al_unders*Main_Al,IF(A24=5,Al_pick*Main_Al,0)))))
25	3	3					=IF(A25="","",IF(A25=1,Rec_Al*Main_Al,IF(A25=3,Al_lights*Main_Al,IF(A25=4,Al_unders*Main_Al,IF(A25=5,Al_pick*Main_Al,0)))))
26	3	4					=IF(A26="","",IF(A26=1,Rec_Al*Main_Al,IF(A26=3,Al_lights*Main_Al,IF(A26=4,Al_unders*Main_Al,IF(A26=5,Al_pick*Main_Al,0)))))
27	3	5					=IF(A27="","",IF(A27=1,Rec_Al*Main_Al,IF(A27=3,Al_lights*Main_Al,IF(A27=4,Al_unders*Main_Al,IF(A27=5,Al_pick*Main_Al,0)))))

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	H
1	
2	
3	
4	Fe
5	=+H7*$M$7
6	
7	0.213
8	
9	
10	1,2,5
11	1st Recovered
12	Fe
13	=IF(A13="","",IF(A13=2,Rec_Fe*Main_Fe,IF(A13=1,Rec_Al*Main_Fe,IF(A13=3,Fe_lights*Main_Fe,IF(A13=4,Fe_unders*Main_Fe,IF(A13=5,Al_pick*Main_Fe,0))))))
14	=IF(A14="","",IF(A14=2,Rec_Fe*Main_Fe,IF(A14=1,Rec_Al*Main_Fe,IF(A14=3,Fe_lights*Main_Fe,IF(A14=4,Fe_unders*Main_Fe,IF(A14=5,Al_pick*Main_Fe,0))))))
15	=IF(A15="","",IF(A15=2,Rec_Fe*Main_Fe,IF(A15=1,Rec_Al*Main_Fe,IF(A15=3,Fe_lights*Main_Fe,IF(A15=4,Fe_unders*Main_Fe,IF(A15=5,Al_pick*Main_Fe,0))))))
16	=IF(A16="","",IF(A16=2,Rec_Fe*Main_Fe,IF(A16=1,Rec_Al*Main_Fe,IF(A16=3,Fe_lights*Main_Fe,IF(A16=4,Fe_unders*Main_Fe,IF(A16=5,Al_pick*Main_Fe,0))))))
17	=IF(A17="","",IF(A17=2,Rec_Fe*Main_Fe,IF(A17=1,Rec_Al*Main_Fe,IF(A17=3,Fe_lights*Main_Fe,IF(A17=4,Fe_unders*Main_Fe,IF(A17=5,Al_pick*Main_Fe,0))))))
18	=IF(A18="","",IF(A18=2,Rec_Fe*Main_Fe,IF(A18=1,Rec_Al*Main_Fe,IF(A18=3,Fe_lights*Main_Fe,IF(A18=4,Fe_unders*Main_Fe,IF(A18=5,Al_pick*Main_Fe,0))))))
19	=IF(A19="","",IF(A19=2,Rec_Fe*Main_Fe,IF(A19=1,Rec_Al*Main_Fe,IF(A19=3,Fe_lights*Main_Fe,IF(A19=4,Fe_unders*Main_Fe,IF(A19=5,Al_pick*Main_Fe,0))))))
20	=IF(A20="","",IF(A20=2,Rec_Fe*Main_Fe,IF(A20=1,Rec_Al*Main_Fe,IF(A20=3,Fe_lights*Main_Fe,IF(A20=4,Fe_unders*Main_Fe,IF(A20=5,Al_pick*Main_Fe,0))))))
21	=IF(A21="","",IF(A21=2,Rec_Fe*Main_Fe,IF(A21=1,Rec_Al*Main_Fe,IF(A21=3,Fe_lights*Main_Fe,IF(A21=4,Fe_unders*Main_Fe,IF(A21=5,Al_pick*Main_Fe,0))))))
22	=IF(A22="","",IF(A22=2,Rec_Fe*Main_Fe,IF(A22=1,Rec_Al*Main_Fe,IF(A22=3,Fe_lights*Main_Fe,IF(A22=4,Fe_unders*Main_Fe,IF(A22=5,Al_pick*Main_Fe,0))))))
23	=IF(A23="","",IF(A23=2,Rec_Fe*Main_Fe,IF(A23=1,Rec_Al*Main_Fe,IF(A23=3,Fe_lights*Main_Fe,IF(A23=4,Fe_unders*Main_Fe,IF(A23=5,Al_pick*Main_Fe,0))))))
24	=IF(A24="","",IF(A24=2,Rec_Fe*Main_Fe,IF(A24=1,Rec_Al*Main_Fe,IF(A24=3,Fe_lights*Main_Fe,IF(A24=4,Fe_unders*Main_Fe,IF(A24=5,Al_pick*Main_Fe,0))))))
25	=IF(A25="","",IF(A25=2,Rec_Fe*Main_Fe,IF(A25=1,Rec_Al*Main_Fe,IF(A25=3,Fe_lights*Main_Fe,IF(A25=4,Fe_unders*Main_Fe,IF(A25=5,Al_pick*Main_Fe,0))))))
26	=IF(A26="","",IF(A26=2,Rec_Fe*Main_Fe,IF(A26=1,Rec_Al*Main_Fe,IF(A26=3,Fe_lights*Main_Fe,IF(A26=4,Fe_unders*Main_Fe,IF(A26=5,Al_pick*Main_Fe,0))))))
27	=IF(A27="","",IF(A27=2,Rec_Fe*Main_Fe,IF(A27=1,Rec_Al*Main_Fe,IF(A27=3,Fe_lights*Main_Fe,IF(A27=4,Fe_unders*Main_Fe,IF(A27=5,Al_pick*Main_Fe,0))))))

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	I
1	
2	
3	
4	septic
5	=+I7*$M$7
6	
7	0.15
8	
9	
10	1,5,6
11	
12	septic
13	=IF(A13="","",IF(A13=3,septic_lights*Main_septic,IF(A13=4,septic_unders*Main_septic,IF(A13=5,septic_pick*Main_septic,0))))
14	=IF(A14="","",IF(A14=3,septic_lights*Main_septic,IF(A14=4,septic_unders*Main_septic,IF(A14=5,septic_pick*Main_septic,0))))
15	=IF(A15="","",IF(A15=3,septic_lights*Main_septic,IF(A15=4,septic_unders*Main_septic,IF(A15=5,septic_pick*Main_septic,0))))
16	=IF(A16="","",IF(A16=3,septic_lights*Main_septic,IF(A16=4,septic_unders*Main_septic,IF(A16=5,septic_pick*Main_septic,0))))
17	=IF(A17="","",IF(A17=3,septic_lights*Main_septic,IF(A17=4,septic_unders*Main_septic,IF(A17=5,septic_pick*Main_septic,0))))
18	=IF(A18="","",IF(A18=3,septic_lights*Main_septic,IF(A18=4,septic_unders*Main_septic,IF(A18=5,septic_pick*Main_septic,0))))
19	=IF(A19="","",IF(A19=3,septic_lights*Main_septic,IF(A19=4,septic_unders*Main_septic,IF(A19=5,septic_pick*Main_septic,0))))
20	=IF(A20="","",IF(A20=3,septic_lights*Main_septic,IF(A20=4,septic_unders*Main_septic,IF(A20=5,septic_pick*Main_septic,0))))
21	=IF(A21="","",IF(A21=3,septic_lights*Main_septic,IF(A21=4,septic_unders*Main_septic,IF(A21=5,septic_pick*Main_septic,0))))
22	=IF(A22="","",IF(A22=3,septic_lights*Main_septic,IF(A22=4,septic_unders*Main_septic,IF(A22=5,septic_pick*Main_septic,0))))
23	=IF(A23="","",IF(A23=3,septic_lights*Main_septic,IF(A23=4,septic_unders*Main_septic,IF(A23=5,septic_pick*Main_septic,0))))
24	=IF(A24="","",IF(A24=3,septic_lights*Main_septic,IF(A24=4,septic_unders*Main_septic,IF(A24=5,septic_pick*Main_septic,0))))
25	=IF(A25="","",IF(A25=3,septic_lights*Main_septic,IF(A25=4,septic_unders*Main_septic,IF(A25=5,septic_pick*Main_septic,0))))
26	=IF(A26="","",IF(A26=3,septic_lights*Main_septic,IF(A26=4,septic_unders*Main_septic,IF(A26=5,septic_pick*Main_septic,0))))
27	=IF(A27="","",IF(A27=3,septic_lights*Main_septic,IF(A27=4,septic_unders*Main_septic,IF(A27=5,septic_pick*Main_septic,0))))

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	J
1	
2	
3	
4	waste
5	=+J7*$M$7
6	
7	0.3
8	
9	
10	6 (only?)
11	
12	waste
13	=IF(A13="","",IF(A13=3,waste_lights*Main_waste,IF(A13=4,waste_unders*Main_waste,IF(A13=6,Assume!$A$7*Main_waste,0))))
14	=IF(A14="","",IF(A14=3,waste_lights*Main_waste,IF(A14=4,waste_unders*Main_waste,IF(A14=6,Assume!$A$7*Main_waste,0))))
15	=IF(A15="","",IF(A15=3,waste_lights*Main_waste,IF(A15=4,waste_unders*Main_waste,IF(A15=6,Assume!$A$7*Main_waste,0))))
16	=IF(A16="","",IF(A16=3,waste_lights*Main_waste,IF(A16=4,waste_unders*Main_waste,IF(A16=6,Assume!$A$7*Main_waste,0))))
17	=IF(A17="","",IF(A17=3,waste_lights*Main_waste,IF(A17=4,waste_unders*Main_waste,IF(A17=6,Assume!$A$7*Main_waste,0))))
18	=IF(A18="","",IF(A18=3,waste_lights*Main_waste,IF(A18=4,waste_unders*Main_waste,IF(A18=6,Assume!$A$7*Main_waste,0))))
19	=IF(A19="","",IF(A19=3,waste_lights*Main_waste,IF(A19=4,waste_unders*Main_waste,IF(A19=6,Assume!$A$7*Main_waste,0))))
20	=IF(A20="","",IF(A20=3,waste_lights*Main_waste,IF(A20=4,waste_unders*Main_waste,IF(A20=6,Assume!$A$7*Main_waste,0))))
21	=IF(A21="","",IF(A21=3,waste_lights*Main_waste,IF(A21=4,waste_unders*Main_waste,IF(A21=6,Assume!$A$7*Main_waste,0))))
22	=IF(A22="","",IF(A22=3,waste_lights*Main_waste,IF(A22=4,waste_unders*Main_waste,IF(A22=6,Assume!$A$7*Main_waste,0))))
23	=IF(A23="","",IF(A23=3,waste_lights*Main_waste,IF(A23=4,waste_unders*Main_waste,IF(A23=6,Assume!$A$7*Main_waste,0))))
24	=IF(A24="","",IF(A24=3,waste_lights*Main_waste,IF(A24=4,waste_unders*Main_waste,IF(A24=6,Assume!$A$7*Main_waste,0))))
25	=IF(A25="","",IF(A25=3,waste_lights*Main_waste,IF(A25=4,waste_unders*Main_waste,IF(A25=6,Assume!$A$7*Main_waste,0))))
26	=IF(A26="","",IF(A26=3,waste_lights*Main_waste,IF(A26=4,waste_unders*Main_waste,IF(A26=6,Assume!$A$7*Main_waste,0))))
27	=IF(A27="","",IF(A27=3,waste_lights*Main_waste,IF(A27=4,waste_unders*Main_waste,IF(A27=6,Assume!$A$7*Main_waste,0))))

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	K	L	M
1			
2			
3			
4	Plas		1060
5	=+K7*$M$7		=+M4/52
6	=+SUM(G5:K5)		8
7	0.31		=+M5/M6
8	=+SUM(G7:K7)		
9			
10	5		
11			1st Leftover
12	Plas	Al	Fe
13	=IF(A13="","",IF(A13=3,plas_lights*Main_Plas,IF(A13=4,plas_unders*Main_Plas,IF(A13=5,plas_pick*Main_Plas,0))))	=+Main_Al-G13	=+Main_Fe-H13
14	=IF(A14="","",IF(A14=3,plas_lights*Main_Plas,IF(A14=4,plas_unders*Main_Plas,IF(A14=5,plas_pick*Main_Plas,0))))	=+Main_Al-G14	=+Main_Fe-H14
15	=IF(A15="","",IF(A15=3,plas_lights*Main_Plas,IF(A15=4,plas_unders*Main_Plas,IF(A15=5,plas_pick*Main_Plas,0))))	=+Main_Al-G15	=+Main_Fe-H15
16	=IF(A16="","",IF(A16=3,plas_lights*Main_Plas,IF(A16=4,plas_unders*Main_Plas,IF(A16=5,plas_pick*Main_Plas,0))))	=+Main_Al-G16	=+Main_Fe-H16
17	=IF(A17="","",IF(A17=3,plas_lights*Main_Plas,IF(A17=4,plas_unders*Main_Plas,IF(A17=5,plas_pick*Main_Plas,0))))	=+Main_Al-G17	=+Main_Fe-H17
18	=IF(A18="","",IF(A18=3,plas_lights*Main_Plas,IF(A18=4,plas_unders*Main_Plas,IF(A18=5,plas_pick*Main_Plas,0))))	=+Main_Al-G18	=+Main_Fe-H18
19	=IF(A19="","",IF(A19=3,plas_lights*Main_Plas,IF(A19=4,plas_unders*Main_Plas,IF(A19=5,plas_pick*Main_Plas,0))))	=+Main_Al-G19	=+Main_Fe-H19
20	=IF(A20="","",IF(A20=3,plas_lights*Main_Plas,IF(A20=4,plas_unders*Main_Plas,IF(A20=5,plas_pick*Main_Plas,0))))	=+Main_Al-G20	=+Main_Fe-H20
21	=IF(A21="","",IF(A21=3,plas_lights*Main_Plas,IF(A21=4,plas_unders*Main_Plas,IF(A21=5,plas_pick*Main_Plas,0))))	=+Main_Al-G21	=+Main_Fe-H21
22	=IF(A22="","",IF(A22=3,plas_lights*Main_Plas,IF(A22=4,plas_unders*Main_Plas,IF(A22=5,plas_pick*Main_Plas,0))))	=+Main_Al-G22	=+Main_Fe-H22
23	=IF(A23="","",IF(A23=3,plas_lights*Main_Plas,IF(A23=4,plas_unders*Main_Plas,IF(A23=5,plas_pick*Main_Plas,0))))	=+Main_Al-G23	=+Main_Fe-H23
24	=IF(A24="","",IF(A24=3,plas_lights*Main_Plas,IF(A24=4,plas_unders*Main_Plas,IF(A24=5,plas_pick*Main_Plas,0))))	=+Main_Al-G24	=+Main_Fe-H24
25	=IF(A25="","",IF(A25=3,plas_lights*Main_Plas,IF(A25=4,plas_unders*Main_Plas,IF(A25=5,plas_pick*Main_Plas,0))))	=+Main_Al-G25	=+Main_Fe-H25
26	=IF(A26="","",IF(A26=3,plas_lights*Main_Plas,IF(A26=4,plas_unders*Main_Plas,IF(A26=5,plas_pick*Main_Plas,0))))	=+Main_Al-G26	=+Main_Fe-H26
27	=IF(A27="","",IF(A27=3,plas_lights*Main_Plas,IF(A27=4,plas_unders*Main_Plas,IF(A27=5,plas_pick*Main_Plas,0))))	=+Main_Al-G27	=+Main_Fe-H27

Appendix E: Formulas in Model of MRF for Yellow Bag Waste

	N	O	P
1			
2			
3		**KEY:**	
4	tpy	1 = ECS	
5	tpw	2 = Magnet	
6	hpw	3 = Air classifier	
7	tph	4 = screen/tromel	
8		5 = hand sort	
9		6 = shredder	
10			
11			
12	septic	waste	Plas
13	=+Main_septic-I13	=+Main_waste-J13	=+Main_Plas-K13
14	=+Main_septic-I14	=+Main_waste-J14	=+Main_Plas-K14
15	=+Main_septic-I15	=+Main_waste-J15	=+Main_Plas-K15
16	=+Main_septic-I16	=+Main_waste-J16	=+Main_Plas-K16
17	=+Main_septic-I17	=+Main_waste-J17	=+Main_Plas-K17
18	=+Main_septic-I18	=+Main_waste-J18	=+Main_Plas-K18
19	=+Main_septic-I19	=+Main_waste-J19	=+Main_Plas-K19
20	=+Main_septic-I20	=+Main_waste-J20	=+Main_Plas-K20
21	=+Main_septic-I21	=+Main_waste-J21	=+Main_Plas-K21
22	=+Main_septic-I22	=+Main_waste-J22	=+Main_Plas-K22
23	=+Main_septic-I23	=+Main_waste-J23	=+Main_Plas-K23
24	=+Main_septic-I24	=+Main_waste-J24	=+Main_Plas-K24
25	=+Main_septic-I25	=+Main_waste-J25	=+Main_Plas-K25
26	=+Main_septic-I26	=+Main_waste-J26	=+Main_Plas-K26
27	=+Main_septic-I27	=+Main_waste-J27	=+Main_Plas-K27

	BO
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	1,5
11	
12	AI
13	=+OR($A13=1,$A13=5)*G13+OR($B13=1,$B13=5)*Q13+OR($C13=1,$C13=5)*AA13+OR($D13=1,$D13=5)*AK13+OR($E13=1,$E13=5)*AU13+OR($F13=1,$F13=5)
14	=+OR($A14=1,$A14=5)*G14+OR($B14=1,$B14=5)*Q14+OR($C14=1,$C14=5)*AA14+OR($D14=1,$D14=5)*AK14+OR($E14=1,$E14=5)*AU14+OR($F14=1,$F14=5)
15	=+OR($A15=1,$A15=5)*G15+OR($B15=1,$B15=5)*Q15+OR($C15=1,$C15=5)*AA15+OR($D15=1,$D15=5)*AK15+OR($E15=1,$E15=5)*AU15+OR($F15=1,$F15=5)
16	=+OR($A16=1,$A16=5)*G16+OR($B16=1,$B16=5)*Q16+OR($C16=1,$C16=5)*AA16+OR($D16=1,$D16=5)*AK16+OR($E16=1,$E16=5)*AU16+OR($F16=1,$F16=5)
17	=+OR($A17=1,$A17=5)*G17+OR($B17=1,$B17=5)*Q17+OR($C17=1,$C17=5)*AA17+OR($D17=1,$D17=5)*AK17+OR($E17=1,$E17=5)*AU17+OR($F17=1,$F17=5)
18	=+OR($A18=1,$A18=5)*G18+OR($B18=1,$B18=5)*Q18+OR($C18=1,$C18=5)*AA18+OR($D18=1,$D18=5)*AK18+OR($E18=1,$E18=5)*AU18+OR($F18=1,$F18=5)
19	=+OR($A19=1,$A19=5)*G19+OR($B19=1,$B19=5)*Q19+OR($C19=1,$C19=5)*AA19+OR($D19=1,$D19=5)*AK19+OR($E19=1,$E19=5)*AU19+OR($F19=1,$F19=5)
20	=+OR($A20=1,$A20=5)*G20+OR($B20=1,$B20=5)*Q20+OR($C20=1,$C20=5)*AA20+OR($D20=1,$D20=5)*AK20+OR($E20=1,$E20=5)*AU20+OR($F20=1,$F20=5)
21	=+OR($A21=1,$A21=5)*G21+OR($B21=1,$B21=5)*Q21+OR($C21=1,$C21=5)*AA21+OR($D21=1,$D21=5)*AK21+OR($E21=1,$E21=5)*AU21+OR($F21=1,$F21=5)
22	=+OR($A22=1,$A22=5)*G22+OR($B22=1,$B22=5)*Q22+OR($C22=1,$C22=5)*AA22+OR($D22=1,$D22=5)*AK22+OR($E22=1,$E22=5)*AU22+OR($F22=1,$F22=5)
23	=+OR($A23=1,$A23=5)*G23+OR($B23=1,$B23=5)*Q23+OR($C23=1,$C23=5)*AA23+OR($D23=1,$D23=5)*AK23+OR($E23=1,$E23=5)*AU23+OR($F23=1,$F23=5)
24	=+OR($A24=1,$A24=5)*G24+OR($B24=1,$B24=5)*Q24+OR($C24=1,$C24=5)*AA24+OR($D24=1,$D24=5)*AK24+OR($E24=1,$E24=5)*AU24+OR($F24=1,$F24=5)
25	=+OR($A25=1,$A25=5)*G25+OR($B25=1,$B25=5)*Q25+OR($C25=1,$C25=5)*AA25+OR($D25=1,$D25=5)*AK25+OR($E25=1,$E25=5)*AU25+OR($F25=1,$F25=5)
26	=+OR($A26=1,$A26=5)*G26+OR($B26=1,$B26=5)*Q26+OR($C26=1,$C26=5)*AA26+OR($D26=1,$D26=5)*AK26+OR($E26=1,$E26=5)*AU26+OR($F26=1,$F26=5)
27	=+OR($A27=1,$A27=5)*G27+OR($B27=1,$B27=5)*Q27+OR($C27=1,$C27=5)*AA27+OR($D27=1,$D27=5)*AK27+OR($E27=1,$E27=5)*AU27+OR($F27=1,$F27=5)

	BP
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	1,2,5
11	
12	Fe
13	=+OR($A13=1,$A13=2,$A13=5)*H13+OR($B13=1,$B13=2,$B13=5)*R13+OR($C13=1,$C13=2,$C13=5)*AB13+OR($D13=1,$D13=2,$D13=5)*AL13+OR($E13=1,$E13
14	=+OR($A14=1,$A14=2,$A14=5)*H14+OR($B14=1,$B14=2,$B14=5)*R14+OR($C14=1,$C14=2,$C14=5)*AB14+OR($D14=1,$D14=2,$D14=5)*AL14+OR($E14=1,$E14
15	=+OR($A15=1,$A15=2,$A15=5)*H15+OR($B15=1,$B15=2,$B15=5)*R15+OR($C15=1,$C15=2,$C15=5)*AB15+OR($D15=1,$D15=2,$D15=5)*AL15+OR($E15=1,$E15
16	=+OR($A16=1,$A16=2,$A16=5)*H16+OR($B16=1,$B16=2,$B16=5)*R16+OR($C16=1,$C16=2,$C16=5)*AB16+OR($D16=1,$D16=2,$D16=5)*AL16+OR($E16=1,$E16
17	=+OR($A17=1,$A17=2,$A17=5)*H17+OR($B17=1,$B17=2,$B17=5)*R17+OR($C17=1,$C17=2,$C17=5)*AB17+OR($D17=1,$D17=2,$D17=5)*AL17+OR($E17=1,$E17
18	=+OR($A18=1,$A18=2,$A18=5)*H18+OR($B18=1,$B18=2,$B18=5)*R18+OR($C18=1,$C18=2,$C18=5)*AB18+OR($D18=1,$D18=2,$D18=5)*AL18+OR($E18=1,$E18
19	=+OR($A19=1,$A19=2,$A19=5)*H19+OR($B19=1,$B19=2,$B19=5)*R19+OR($C19=1,$C19=2,$C19=5)*AB19+OR($D19=1,$D19=2,$D19=5)*AL19+OR($E19=1,$E19
20	=+OR($A20=1,$A20=2,$A20=5)*H20+OR($B20=1,$B20=2,$B20=5)*R20+OR($C20=1,$C20=2,$C20=5)*AB20+OR($D20=1,$D20=2,$D20=5)*AL20+OR($E20=1,$E20
21	=+OR($A21=1,$A21=2,$A21=5)*H21+OR($B21=1,$B21=2,$B21=5)*R21+OR($C21=1,$C21=2,$C21=5)*AB21+OR($D21=1,$D21=2,$D21=5)*AL21+OR($E21=1,$E21
22	=+OR($A22=1,$A22=2,$A22=5)*H22+OR($B22=1,$B22=2,$B22=5)*R22+OR($C22=1,$C22=2,$C22=5)*AB22+OR($D22=1,$D22=2,$D22=5)*AL22+OR($E22=1,$E22
23	=+OR($A23=1,$A23=2,$A23=5)*H23+OR($B23=1,$B23=2,$B23=5)*R23+OR($C23=1,$C23=2,$C23=5)*AB23+OR($D23=1,$D23=2,$D23=5)*AL23+OR($E23=1,$E23
24	=+OR($A24=1,$A24=2,$A24=5)*H24+OR($B24=1,$B24=2,$B24=5)*R24+OR($C24=1,$C24=2,$C24=5)*AB24+OR($D24=1,$D24=2,$D24=5)*AL24+OR($E24=1,$E24
25	=+OR($A25=1,$A25=2,$A25=5)*H25+OR($B25=1,$B25=2,$B25=5)*R25+OR($C25=1,$C25=2,$C25=5)*AB25+OR($D25=1,$D25=2,$D25=5)*AL25+OR($E25=1,$E25
26	=+OR($A26=1,$A26=2,$A26=5)*H26+OR($B26=1,$B26=2,$B26=5)*R26+OR($C26=1,$C26=2,$C26=5)*AB26+OR($D26=1,$D26=2,$D26=5)*AL26+OR($E26=1,$E26
27	=+OR($A27=1,$A27=2,$A27=5)*H27+OR($B27=1,$B27=2,$B27=5)*R27+OR($C27=1,$C27=2,$C27=5)*AB27+OR($D27=1,$D27=2,$D27=5)*AL27+OR($E27=1,$E27

	BQ
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	septic
13	=+IF($A13=5,I13,0)+IF($B13=5,S13,0)+IF($C13=5,AC13,0)+IF($D13=5,AM13,0)+IF($E13=5,AW13,0)+IF($F13=5,BG13,0)
14	=+IF($A14=5,I14,0)+IF($B14=5,S14,0)+IF($C14=5,AC14,0)+IF($D14=5,AM14,0)+IF($E14=5,AW14,0)+IF($F14=5,BG14,0)
15	=+IF($A15=5,I15,0)+IF($B15=5,S15,0)+IF($C15=5,AC15,0)+IF($D15=5,AM15,0)+IF($E15=5,AW15,0)+IF($F15=5,BG15,0)
16	=+IF($A16=5,I16,0)+IF($B16=5,S16,0)+IF($C16=5,AC16,0)+IF($D16=5,AM16,0)+IF($E16=5,AW16,0)+IF($F16=5,BG16,0)
17	=+IF($A17=5,I17,0)+IF($B17=5,S17,0)+IF($C17=5,AC17,0)+IF($D17=5,AM17,0)+IF($E17=5,AW17,0)+IF($F17=5,BG17,0)
18	=+IF($A18=5,I18,0)+IF($B18=5,S18,0)+IF($C18=5,AC18,0)+IF($D18=5,AM18,0)+IF($E18=5,AW18,0)+IF($F18=5,BG18,0)
19	=+IF($A19=5,I19,0)+IF($B19=5,S19,0)+IF($C19=5,AC19,0)+IF($D19=5,AM19,0)+IF($E19=5,AW19,0)+IF($F19=5,BG19,0)
20	=+IF($A20=5,I20,0)+IF($B20=5,S20,0)+IF($C20=5,AC20,0)+IF($D20=5,AM20,0)+IF($E20=5,AW20,0)+IF($F20=5,BG20,0)
21	=+IF($A21=5,I21,0)+IF($B21=5,S21,0)+IF($C21=5,AC21,0)+IF($D21=5,AM21,0)+IF($E21=5,AW21,0)+IF($F21=5,BG21,0)
22	=+IF($A22=5,I22,0)+IF($B22=5,S22,0)+IF($C22=5,AC22,0)+IF($D22=5,AM22,0)+IF($E22=5,AW22,0)+IF($F22=5,BG22,0)
23	=+IF($A23=5,I23,0)+IF($B23=5,S23,0)+IF($C23=5,AC23,0)+IF($D23=5,AM23,0)+IF($E23=5,AW23,0)+IF($F23=5,BG23,0)
24	=+IF($A24=5,I24,0)+IF($B24=5,S24,0)+IF($C24=5,AC24,0)+IF($D24=5,AM24,0)+IF($E24=5,AW24,0)+IF($F24=5,BG24,0)
25	=+IF($A25=5,I25,0)+IF($B25=5,S25,0)+IF($C25=5,AC25,0)+IF($D25=5,AM25,0)+IF($E25=5,AW25,0)+IF($F25=5,BG25,0)
26	=+IF($A26=5,I26,0)+IF($B26=5,S26,0)+IF($C26=5,AC26,0)+IF($D26=5,AM26,0)+IF($E26=5,AW26,0)+IF($F26=5,BG26,0)
27	=+IF($A27=5,I27,0)+IF($B27=5,S27,0)+IF($C27=5,AC27,0)+IF($D27=5,AM27,0)+IF($E27=5,AW27,0)+IF($F27=5,BG27,0)

	BR
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	Recovered
12	waste
13	=+IF($A13=6,J13,0)+IF($B13=6,T13,0)+IF($C13=6,AD13,0)+IF($D13=6,AN13,0)+IF($E13=6,AX13,0)+IF($F13=6,BH13,0)
14	=+IF($A14=6,J14,0)+IF($B14=6,T14,0)+IF($C14=6,AD14,0)+IF($D14=6,AN14,0)+IF($E14=6,AX14,0)+IF($F14=6,BH14,0)
15	=+IF($A15=6,J15,0)+IF($B15=6,T15,0)+IF($C15=6,AD15,0)+IF($D15=6,AN15,0)+IF($E15=6,AX15,0)+IF($F15=6,BH15,0)
16	=+IF($A16=6,J16,0)+IF($B16=6,T16,0)+IF($C16=6,AD16,0)+IF($D16=6,AN16,0)+IF($E16=6,AX16,0)+IF($F16=6,BH16,0)
17	=+IF($A17=6,J17,0)+IF($B17=6,T17,0)+IF($C17=6,AD17,0)+IF($D17=6,AN17,0)+IF($E17=6,AX17,0)+IF($F17=6,BH17,0)
18	=+IF($A18=6,J18,0)+IF($B18=6,T18,0)+IF($C18=6,AD18,0)+IF($D18=6,AN18,0)+IF($E18=6,AX18,0)+IF($F18=6,BH18,0)
19	=+IF($A19=6,J19,0)+IF($B19=6,T19,0)+IF($C19=6,AD19,0)+IF($D19=6,AN19,0)+IF($E19=6,AX19,0)+IF($F19=6,BH19,0)
20	=+IF($A20=6,J20,0)+IF($B20=6,T20,0)+IF($C20=6,AD20,0)+IF($D20=6,AN20,0)+IF($E20=6,AX20,0)+IF($F20=6,BH20,0)
21	=+IF($A21=6,J21,0)+IF($B21=6,T21,0)+IF($C21=6,AD21,0)+IF($D21=6,AN21,0)+IF($E21=6,AX21,0)+IF($F21=6,BH21,0)
22	=+IF($A22=6,J22,0)+IF($B22=6,T22,0)+IF($C22=6,AD22,0)+IF($D22=6,AN22,0)+IF($E22=6,AX22,0)+IF($F22=6,BH22,0)
23	=+IF($A23=6,J23,0)+IF($B23=6,T23,0)+IF($C23=6,AD23,0)+IF($D23=6,AN23,0)+IF($E23=6,AX23,0)+IF($F23=6,BH23,0)
24	=+IF($A24=6,J24,0)+IF($B24=6,T24,0)+IF($C24=6,AD24,0)+IF($D24=6,AN24,0)+IF($E24=6,AX24,0)+IF($F24=6,BH24,0)
25	=+IF($A25=6,J25,0)+IF($B25=6,T25,0)+IF($C25=6,AD25,0)+IF($D25=6,AN25,0)+IF($E25=6,AX25,0)+IF($F25=6,BH25,0)
26	=+IF($A26=6,J26,0)+IF($B26=6,T26,0)+IF($C26=6,AD26,0)+IF($D26=6,AN26,0)+IF($E26=6,AX26,0)+IF($F26=6,BH26,0)
27	=+IF($A27=6,J27,0)+IF($B27=6,T27,0)+IF($C27=6,AD27,0)+IF($D27=6,AN27,0)+IF($E27=6,AX27,0)+IF($F27=6,BH27,0)

	BS	BT
1		
2		
3		
4		Recycling Today, 8/97 Supplem
5		Recycling Today, 8/97 Supplem
6		
7		
8		
9		
10	5	Recycling Today, 11\97 Supple
11		
12	Plas	Total
13	=+IF($A13=5,K13,0)+IF($B13=5,U13,0)+IF($C13=5,AE13,0)+IF($D13=5,AO13,0)+IF($E13=5,AY13,0)+IF($F13=5,BI13,0)	=+BO13+BP13+BQ13+BS13
14	=+IF($A14=5,K14,0)+IF($B14=5,U14,0)+IF($C14=5,AE14,0)+IF($D14=5,AO14,0)+IF($E14=5,AY14,0)+IF($F14=5,BI14,0)	=+BO14+BP14+BQ14+BS14
15	=+IF($A15=5,K15,0)+IF($B15=5,U15,0)+IF($C15=5,AE15,0)+IF($D15=5,AO15,0)+IF($E15=5,AY15,0)+IF($F15=5,BI15,0)	=+BO15+BP15+BQ15+BS15
16	=+IF($A16=5,K16,0)+IF($B16=5,U16,0)+IF($C16=5,AE16,0)+IF($D16=5,AO16,0)+IF($E16=5,AY16,0)+IF($F16=5,BI16,0)	=+BO16+BP16+BQ16+BS16
17	=+IF($A17=5,K17,0)+IF($B17=5,U17,0)+IF($C17=5,AE17,0)+IF($D17=5,AO17,0)+IF($E17=5,AY17,0)+IF($F17=5,BI17,0)	=+BO17+BP17+BQ17+BS17
18	=+IF($A18=5,K18,0)+IF($B18=5,U18,0)+IF($C18=5,AE18,0)+IF($D18=5,AO18,0)+IF($E18=5,AY18,0)+IF($F18=5,BI18,0)	=+BO18+BP18+BQ18+BS18
19	=+IF($A19=5,K19,0)+IF($B19=5,U19,0)+IF($C19=5,AE19,0)+IF($D19=5,AO19,0)+IF($E19=5,AY19,0)+IF($F19=5,BI19,0)	=+BO19+BP19+BQ19+BS19
20	=+IF($A20=5,K20,0)+IF($B20=5,U20,0)+IF($C20=5,AE20,0)+IF($D20=5,AO20,0)+IF($E20=5,AY20,0)+IF($F20=5,BI20,0)	=+BO20+BP20+BQ20+BS20
21	=+IF($A21=5,K21,0)+IF($B21=5,U21,0)+IF($C21=5,AE21,0)+IF($D21=5,AO21,0)+IF($E21=5,AY21,0)+IF($F21=5,BI21,0)	=+BO21+BP21+BQ21+BS21
22	=+IF($A22=5,K22,0)+IF($B22=5,U22,0)+IF($C22=5,AE22,0)+IF($D22=5,AO22,0)+IF($E22=5,AY22,0)+IF($F22=5,BI22,0)	=+BO22+BP22+BQ22+BS22
23	=+IF($A23=5,K23,0)+IF($B23=5,U23,0)+IF($C23=5,AE23,0)+IF($D23=5,AO23,0)+IF($E23=5,AY23,0)+IF($F23=5,BI23,0)	=+BO23+BP23+BQ23+BS23
24	=+IF($A24=5,K24,0)+IF($B24=5,U24,0)+IF($C24=5,AE24,0)+IF($D24=5,AO24,0)+IF($E24=5,AY24,0)+IF($F24=5,BI24,0)	=+BO24+BP24+BQ24+BS24
25	=+IF($A25=5,K25,0)+IF($B25=5,U25,0)+IF($C25=5,AE25,0)+IF($D25=5,AO25,0)+IF($E25=5,AY25,0)+IF($F25=5,BI25,0)	=+BO25+BP25+BQ25+BS25
26	=+IF($A26=5,K26,0)+IF($B26=5,U26,0)+IF($C26=5,AE26,0)+IF($D26=5,AO26,0)+IF($E26=5,AY26,0)+IF($F26=5,BI26,0)	=+BO26+BP26+BQ26+BS26
27	=+IF($A27=5,K27,0)+IF($B27=5,U27,0)+IF($C27=5,AE27,0)+IF($D27=5,AO27,0)+IF($E27=5,AY27,0)+IF($F27=5,BI27,0)	=+BO27+BP27+BQ27+BS27

	BU
1	
2	
3	
4	
5	
6	rassmach.com ad
7	
8	based on min wage
9	picking stations
10	
11	
12	#pickers
13	=IF(A13=5,$G13/Al_hand+$H13/Fe_hand+$I13/septic_hand+$K13/plas_hand,0)+IF(B13=5,$Q13/Al_hand+$R13/Fe_hand+$S13/septic_hand+$U13/plas_hand,0)+IF(
14	=IF(A14=5,$G14/Al_hand+$H14/Fe_hand+$I14/septic_hand+$K14/plas_hand,0)+IF(B14=5,$Q14/Al_hand+$R14/Fe_hand+$S14/septic_hand+$U14/plas_hand,0)+IF(
15	=IF(A15=5,$G15/Al_hand+$H15/Fe_hand+$I15/septic_hand+$K15/plas_hand,0)+IF(B15=5,$Q15/Al_hand+$R15/Fe_hand+$S15/septic_hand+$U15/plas_hand,0)+IF(
16	=IF(A16=5,$G16/Al_hand+$H16/Fe_hand+$I16/septic_hand+$K16/plas_hand,0)+IF(B16=5,$Q16/Al_hand+$R16/Fe_hand+$S16/septic_hand+$U16/plas_hand,0)+IF(
17	=IF(A17=5,$G17/Al_hand+$H17/Fe_hand+$I17/septic_hand+$K17/plas_hand,0)+IF(B17=5,$Q17/Al_hand+$R17/Fe_hand+$S17/septic_hand+$U17/plas_hand,0)+IF(
18	=IF(A18=5,$G18/Al_hand+$H18/Fe_hand+$I18/septic_hand+$K18/plas_hand,0)+IF(B18=5,$Q18/Al_hand+$R18/Fe_hand+$S18/septic_hand+$U18/plas_hand,0)+IF(
19	=IF(A19=5,$G19/Al_hand+$H19/Fe_hand+$I19/septic_hand+$K19/plas_hand,0)+IF(B19=5,$Q19/Al_hand+$R19/Fe_hand+$S19/septic_hand+$U19/plas_hand,0)+IF(
20	=IF(A20=5,$G20/Al_hand+$H20/Fe_hand+$I20/septic_hand+$K20/plas_hand,0)+IF(B20=5,$Q20/Al_hand+$R20/Fe_hand+$S20/septic_hand+$U20/plas_hand,0)+IF(
21	=IF(A21=5,$G21/Al_hand+$H21/Fe_hand+$I21/septic_hand+$K21/plas_hand,0)+IF(B21=5,$Q21/Al_hand+$R21/Fe_hand+$S21/septic_hand+$U21/plas_hand,0)+IF(
22	=IF(A22=5,$G22/Al_hand+$H22/Fe_hand+$I22/septic_hand+$K22/plas_hand,0)+IF(B22=5,$Q22/Al_hand+$R22/Fe_hand+$S22/septic_hand+$U22/plas_hand,0)+IF(
23	=IF(A23=5,$G23/Al_hand+$H23/Fe_hand+$I23/septic_hand+$K23/plas_hand,0)+IF(B23=5,$Q23/Al_hand+$R23/Fe_hand+$S23/septic_hand+$U23/plas_hand,0)+IF(
24	=IF(A24=5,$G24/Al_hand+$H24/Fe_hand+$I24/septic_hand+$K24/plas_hand,0)+IF(B24=5,$Q24/Al_hand+$R24/Fe_hand+$S24/septic_hand+$U24/plas_hand,0)+IF(
25	=IF(A25=5,$G25/Al_hand+$H25/Fe_hand+$I25/septic_hand+$K25/plas_hand,0)+IF(B25=5,$Q25/Al_hand+$R25/Fe_hand+$S25/septic_hand+$U25/plas_hand,0)+IF(
26	=IF(A26=5,$G26/Al_hand+$H26/Fe_hand+$I26/septic_hand+$K26/plas_hand,0)+IF(B26=5,$Q26/Al_hand+$R26/Fe_hand+$S26/septic_hand+$U26/plas_hand,0)+IF(
27	=IF(A27=5,$G27/Al_hand+$H27/Fe_hand+$I27/septic_hand+$K27/plas_hand,0)+IF(B27=5,$Q27/Al_hand+$R27/Fe_hand+$S27/septic_hand+$U27/plas_hand,0)+IF(

	BV
1	
2	
3	in thousands
4	35
5	3
6	15
7	5
8	0.00515
9	0
10	7.5
11	
12	1st
13	=IF(A13=1,price1*PtoA,(IF(A13=2,price2*PtoA,(IF(A13=3,price3*PtoA,(IF(A13=4,price4*PtoA,(IF(A13=5,price5*hours*$BU13*52+price5c*PtoA,(IF(A13=6,price6*PtoA,"")
14	=IF(A14=1,price1*PtoA,(IF(A14=2,price2*PtoA,(IF(A14=3,price3*PtoA,(IF(A14=4,price4*PtoA,(IF(A14=5,price5*hours*$BU14*52+price5c*PtoA,(IF(A14=6,price6*PtoA,"")
15	=IF(A15=1,price1*PtoA,(IF(A15=2,price2*PtoA,(IF(A15=3,price3*PtoA,(IF(A15=4,price4*PtoA,(IF(A15=5,price5*hours*$BU15*52+price5c*PtoA,(IF(A15=6,price6*PtoA,"")
16	=IF(A16=1,price1*PtoA,(IF(A16=2,price2*PtoA,(IF(A16=3,price3*PtoA,(IF(A16=4,price4*PtoA,(IF(A16=5,price5*hours*$BU16*52+price5c*PtoA,(IF(A16=6,price6*PtoA,"")
17	=IF(A17=1,price1*PtoA,(IF(A17=2,price2*PtoA,(IF(A17=3,price3*PtoA,(IF(A17=4,price4*PtoA,(IF(A17=5,price5*hours*$BU17*52+price5c*PtoA,(IF(A17=6,price6*PtoA,"")
18	=IF(A18=1,price1*PtoA,(IF(A18=2,price2*PtoA,(IF(A18=3,price3*PtoA,(IF(A18=4,price4*PtoA,(IF(A18=5,price5*hours*$BU18*52+price5c*PtoA,(IF(A18=6,price6*PtoA,"")
19	=IF(A19=1,price1*PtoA,(IF(A19=2,price2*PtoA,(IF(A19=3,price3*PtoA,(IF(A19=4,price4*PtoA,(IF(A19=5,price5*hours*$BU19*52+price5c*PtoA,(IF(A19=6,price6*PtoA,"")
20	=IF(A20=1,price1*PtoA,(IF(A20=2,price2*PtoA,(IF(A20=3,price3*PtoA,(IF(A20=4,price4*PtoA,(IF(A20=5,price5*hours*$BU20*52+price5c*PtoA,(IF(A20=6,price6*PtoA,"")
21	=IF(A21=1,price1*PtoA,(IF(A21=2,price2*PtoA,(IF(A21=3,price3*PtoA,(IF(A21=4,price4*PtoA,(IF(A21=5,price5*hours*$BU21*52+price5c*PtoA,(IF(A21=6,price6*PtoA,"")
22	=IF(A22=1,price1*PtoA,(IF(A22=2,price2*PtoA,(IF(A22=3,price3*PtoA,(IF(A22=4,price4*PtoA,(IF(A22=5,price5*hours*$BU22*52+price5c*PtoA,(IF(A22=6,price6*PtoA,"")
23	=IF(A23=1,price1*PtoA,(IF(A23=2,price2*PtoA,(IF(A23=3,price3*PtoA,(IF(A23=4,price4*PtoA,(IF(A23=5,price5*hours*$BU23*52+price5c*PtoA,(IF(A23=6,price6*PtoA,"")
24	=IF(A24=1,price1*PtoA,(IF(A24=2,price2*PtoA,(IF(A24=3,price3*PtoA,(IF(A24=4,price4*PtoA,(IF(A24=5,price5*hours*$BU24*52+price5c*PtoA,(IF(A24=6,price6*PtoA,"")
25	=IF(A25=1,price1*PtoA,(IF(A25=2,price2*PtoA,(IF(A25=3,price3*PtoA,(IF(A25=4,price4*PtoA,(IF(A25=5,price5*hours*$BU25*52+price5c*PtoA,(IF(A25=6,price6*PtoA,"")
26	=IF(A26=1,price1*PtoA,(IF(A26=2,price2*PtoA,(IF(A26=3,price3*PtoA,(IF(A26=4,price4*PtoA,(IF(A26=5,price5*hours*$BU26*52+price5c*PtoA,(IF(A26=6,price6*PtoA,"")
27	=IF(A27=1,price1*PtoA,(IF(A27=2,price2*PtoA,(IF(A27=3,price3*PtoA,(IF(A27=4,price4*PtoA,(IF(A27=5,price5*hours*$BU27*52+price5c*PtoA,(IF(A27=6,price6*PtoA,"")

	BW
1	
2	
3	
4	1 = ECS
5	2 = Magnet
6	3 = Air classifier
7	4 = screen/tromel
8	5 = hand sort
9	5 = hand sort
10	6 = shredder
11	
12	2nd
13	
14	
15	
16	
17	
18	=IF(B18=1,price1*PtoA,(IF(B18=2,price2*PtoA,(IF(B18=3,price3*PtoA,(IF(B18=4,price4*PtoA,(IF(B18=5,price5*hours*$BU18*52+price5c*PtoA,(IF(B18=6,price6*PtoA,"")
19	=IF(B19=1,price1*PtoA,(IF(B19=2,price2*PtoA,(IF(B19=3,price3*PtoA,(IF(B19=4,price4*PtoA,(IF(B19=5,price5*hours*$BU19*52+price5c*PtoA,(IF(B19=6,price6*PtoA,"")
20	=IF(B20=1,price1*PtoA,(IF(B20=2,price2*PtoA,(IF(B20=3,price3*PtoA,(IF(B20=4,price4*PtoA,(IF(B20=5,price5*hours*$BU20*52+price5c*PtoA,(IF(B20=6,price6*PtoA,"")
21	=IF(B21=1,price1*PtoA,(IF(B21=2,price2*PtoA,(IF(B21=3,price3*PtoA,(IF(B21=4,price4*PtoA,(IF(B21=5,price5*hours*$BU21*52+price5c*PtoA,(IF(B21=6,price6*PtoA,"")
22	=IF(B22=1,price1*PtoA,(IF(B22=2,price2*PtoA,(IF(B22=3,price3*PtoA,(IF(B22=4,price4*PtoA,(IF(B22=5,price5*hours*$BU22*52+price5c*PtoA,(IF(B22=6,price6*PtoA,"")
23	=IF(B23=1,price1*PtoA,(IF(B23=2,price2*PtoA,(IF(B23=3,price3*PtoA,(IF(B23=4,price4*PtoA,(IF(B23=5,price5*hours*$BU23*52+price5c*PtoA,(IF(B23=6,price6*PtoA,"")
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25	=IF(B25=1,price1*PtoA,(IF(B25=2,price2*PtoA,(IF(B25=3,price3*PtoA,(IF(B25=4,price4*PtoA,(IF(B25=5,price5*hours*$BU25*52+price5c*PtoA,(IF(B25=6,price6*PtoA,"")
26	=IF(B26=1,price1*PtoA,(IF(B26=2,price2*PtoA,(IF(B26=3,price3*PtoA,(IF(B26=4,price4*PtoA,(IF(B26=5,price5*hours*$BU26*52+price5c*PtoA,(IF(B26=6,price6*PtoA,"")
27	=IF(B27=1,price1*PtoA,(IF(B27=2,price2*PtoA,(IF(B27=3,price3*PtoA,(IF(B27=4,price4*PtoA,(IF(B27=5,price5*hours*$BU27*52+price5c*PtoA,(IF(B27=6,price6*PtoA,"")

	BX	BY	BZ	CA	CB	CC	CD	CE
1								
2								
3		useful life, yr				Al	Fe	septic
4		30				=0.28*2000	=9	0
5		30			i="APR"=		clean steel cans	
6		30			0.06			
7		30			(P/A,i%,n)			
8		8	hrs/day		=+(CB6*(1+CB6)^30)/((1+CB			
9		30						
10		30						
11	OSTS PER				TOTAL		FIT FROM RECYCLA	
12	3rd	4th	5th	6th	COST/YR	Al	Fe	septic
13					=SUM(BV13:CA13)*1000	=+BO13*Price_Al	=+BP13*Price_Fe	=+BQ13*Price_septic
14					=SUM(BV14:CA14)*1000	=+BO14*Price_Al	=+BP14*Price_Fe	=+BQ14*Price_septic
15					=SUM(BV15:CA15)*1000	=+BO15*Price_Al	=+BP15*Price_Fe	=+BQ15*Price_septic
16					=SUM(BV16:CA16)*1000	=+BO16*Price_Al	=+BP16*Price_Fe	=+BQ16*Price_septic
17					=SUM(BV17:CA17)*1000	=+BO17*Price_Al	=+BP17*Price_Fe	=+BQ17*Price_septic
18					=SUM(BV18:CA18)*1000	=+BO18*Price_Al	=+BP18*Price_Fe	=+BQ18*Price_septic
19					=SUM(BV19:CA19)*1000	=+BO19*Price_Al	=+BP19*Price_Fe	=+BQ19*Price_septic
20					=SUM(BV20:CA20)*1000	=+BO20*Price_Al	=+BP20*Price_Fe	=+BQ20*Price_septic
21					=SUM(BV21:CA21)*1000	=+BO21*Price_Al	=+BP21*Price_Fe	=+BQ21*Price_septic
22					=SUM(BV22:CA22)*1000	=+BO22*Price_Al	=+BP22*Price_Fe	=+BQ22*Price_septic
23					=SUM(BV23:CA23)*1000	=+BO23*Price_Al	=+BP23*Price_Fe	=+BQ23*Price_septic
24					=SUM(BV24:CA24)*1000	=+BO24*Price_Al	=+BP24*Price_Fe	=+BQ24*Price_septic
25					=SUM(BV25:CA25)*1000	=+BO25*Price_Al	=+BP25*Price_Fe	=+BQ25*Price_septic
26					=SUM(BV26:CA26)*1000	=+BO26*Price_Al	=+BP26*Price_Fe	=+BQ26*Price_septic
27					=SUM(BV27:CA27)*1000	=+BO27*Price_Al	=+BP27*Price_Fe	=+BQ27*Price_septic

	CF	CG	CH	CI	CJ
1					
2					
3	Plas		Tipping_Fee		
4	=0.02*2000	per ton	=+CH6/CH5	US$/ton	
5	avg of HDPE & PET		1.6515	DM$/US$	
6			=+CH7/1.1	DM$/ton	
7			165	DM$/tonne	
8					
9				Higher is	
10				Better	
11		TOTAL	Tipping $	Benefit/	
12	Plas	GAINS/YR	**Saved**/Yr	Cost	B-C
13	=+BS13*Price_plas	=SUM(CC13:CF13)*8*52	=+Tipping_Fee*(BT13)*8*52	=(CG13+CH13)/CB13	=+CG13+CH13-CB13
14	=+BS14*Price_plas	=SUM(CC14:CF14)*8*52	=+Tipping_Fee*(BT14)*8*52	=(CG14+CH14)/CB14	=+CG14+CH14-CB14
15	=+BS15*Price_plas	=SUM(CC15:CF15)*8*52	=+Tipping_Fee*(BT15)*8*52	=(CG15+CH15)/CB15	=+CG15+CH15-CB15
16	=+BS16*Price_plas	=SUM(CC16:CF16)*8*52	=+Tipping_Fee*(BT16)*8*52	=(CG16+CH16)/CB16	=+CG16+CH16-CB16
17	=+BS17*Price_plas	=SUM(CC17:CF17)*8*52	=+Tipping_Fee*(BT17)*8*52	=(CG17+CH17)/CB17	=+CG17+CH17-CB17
18	=+BS18*Price_plas	=SUM(CC18:CF18)*8*52	=+Tipping_Fee*(BT18)*8*52	=(CG18+CH18)/CB18	=+CG18+CH18-CB18
19	=+BS19*Price_plas	=SUM(CC19:CF19)*8*52	=+Tipping_Fee*(BT19)*8*52	=(CG19+CH19)/CB19	=+CG19+CH19-CB19
20	=+BS20*Price_plas	=SUM(CC20:CF20)*8*52	=+Tipping_Fee*(BT20)*8*52	=(CG20+CH20)/CB20	=+CG20+CH20-CB20
21	=+BS21*Price_plas	=SUM(CC21:CF21)*8*52	=+Tipping_Fee*(BT21)*8*52	=(CG21+CH21)/CB21	=+CG21+CH21-CB21
22	=+BS22*Price_plas	=SUM(CC22:CF22)*8*52	=+Tipping_Fee*(BT22)*8*52	=(CG22+CH22)/CB22	=+CG22+CH22-CB22
23	=+BS23*Price_plas	=SUM(CC23:CF23)*8*52	=+Tipping_Fee*(BT23)*8*52	=(CG23+CH23)/CB23	=+CG23+CH23-CB23
24	=+BS24*Price_plas	=SUM(CC24:CF24)*8*52	=+Tipping_Fee*(BT24)*8*52	=(CG24+CH24)/CB24	=+CG24+CH24-CB24
25	=+BS25*Price_plas	=SUM(CC25:CF25)*8*52	=+Tipping_Fee*(BT25)*8*52	=(CG25+CH25)/CB25	=+CG25+CH25-CB25
26	=+BS26*Price_plas	=SUM(CC26:CF26)*8*52	=+Tipping_Fee*(BT26)*8*52	=(CG26+CH26)/CB26	=+CG26+CH26-CB26
27	=+BS27*Price_plas	=SUM(CC27:CF27)*8*52	=+Tipping_Fee*(BT27)*8*52	=(CG27+CH27)/CB27	=+CG27+CH27-CB27

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13. ABSTRACT *(Maximum 200 words)*
The maximum recovery of recyclables from municipal solid waste (MSW) using material recovery facility (MRF) technologies is determined. Two waste streams at Spangdahlem AB, Germany are analyzed; stationary container wastes and commingled recyclables. Three schemes are considered, one for each waste stream, and one for both.
Multi-criteria decision making is the methodology. The criteria are recovery and annual benefit minus cost (B-C). Recovery is determined using the recovery factor transfer function of Diaz et al. (1982). Each technology, or unit operation, in a sequence is independent because particle size distribution of each waste component is considered. B-C is based on revenue from sold recyclables, tipping fees saved by not landfilling separated waste, and manual labor and amortized equipment costs.

Six unit operations are considered: eddy current separator (ECS), magnet, air classifier, screen, manual sort, and shredder. Sequences one to six operations long are considered. Three heuristics eliminate 42,179 of 55,986 potential sequences as infeasible.
The result is domination by a MRF to process both wastes and a tradeoff between 35.7% recovery of the total at an annual B-C of $0.95 million and recovery of 35.6% at an annual B-C of $1.02 million. Hand sort recovers the most, and is economical.

14. SUBJECT TERMS
materials recovery, Germany, decision making, waste recycling, solid wastes, material separation, wastes (sanitary engineering), landfills, reduction, sorting, magnetic separation, screens, shredding, eddy currents, plastic, aluminum, metal scraps, glass, paper, garbage

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