LIFE CYCLE ASSESSMENT OF MUNICIPAL SOLID WASTE MANAGEMENT ALTERNATIVES: AN INTEGRATED OPTIMIZATION MODEL

by

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Chair of Advisory Committee

I dedicate this thesis to all the Latin American farm-workers and laborers that help with the development of the state of North Carolina with their daily hard work.

Biography

He was born in the rural town of San Isidro del General, Costa Rica, Central America, in 1969. Later, he moved to the capital city San José and studied at the University of Costa Rica. He obtained his 5-year degree (Licenciatura) in Civil Engineering in 1991. After graduating, he worked as a junior instructor at the University of Costa Rica for two years, teaching basic courses and doing research in the Environmental Engineering field. During this period, Solano-Mora gained experience and interest in the environmental situation of his country, particularly in the area of solid waste management. He decided to continue his studies to strengthen his skills and knowledge and came to the United States to start graduate work in Fall of 1994.

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North Carolina State University

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Family and friends

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Abstract

SOLANO MORA, ERIC. Life Cycle Assessment of Municipal Solid Waste Management Alternatives: An Integrated Optimization Model. (Under the direction of Dr. S. Ranji Ranjithan)

Solid Waste Management (SWM) is a major engineering activity that has important technical, economic, social and environmental constraints. Feasible management strategies are difficult to choose due to the complexity of the SWM system. Numerous alternatives to manage solid wastes are available in the U.S., and many different combinations of these alternatives could be obtained depending on the desired goals. In this thesis, a mathematical optimization approach is developed to analyze an integrated SWM system comprising several management options for collection, separation, treatment, and disposal of waste generated in the residential, multi-family and commercial sectors. This approach facilitates the evaluation and comparison of alternative SWM strategies where each strategy is defined by a set of active process options, flow of waste items through these options, and the set of waste items recovered for recycling. The evaluation of a strategy can be carried out based on a range of criteria, including cost and Life Cycle Inventory (LCI) factors such as CO, CO_2, NO_x , VOC, and greenhouse gas emissions. The mathematical model represents all feasible SWM strategies for a given SWM system. Solution of this model using a linear programming algorithm provides a mechanism for a systematic search through these feasible alternatives. This model also allows the introduction of specific restrictions and preferences. For instance, additional equations can be specified in the model to represent a mandated minimum diversion requirement or to exclude a set of process options from consideration. The net total cost of the SWM system was defined as the objective function. The main constraints consisted of mass balance equations. The model was tested for several hypothetical scenarios to evaluate its applicability and accuracy. The scenarios were tested for different mandated overall diversion rates, and for different increments on the disposal and combustion tipping fees. The linear programming approach was found to be effective in modeling and analyzing the SWM system and captured most of the system characteristics with reasonable simplifying assumptions. The least cost SWM strategies obtained for the tested scenarios consisted of rational choices of process options and waste flow configurations. The model was tested and found to be easy to modify to represent inclusion or exclusion of specific process options. It was found to be efficient in terms of required computational time.

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Chapter 1: Introduction

1.1. Problem description

Municipal solid waste management (SWM) is a responsibility of every modern society. Improper handling or final disposal of solid wastes can have many consequences, including community health problems, landfill space shortage and prohibitive operational and maintenance costs. Solid waste management should consider not only how to collect and manage garbage but also a series of other important issues. Solid waste managers and decision makers must include technical, social, economic and environmental considerations during development of integrated solid waste management strategies.

Generally, SWM planners and decision makers have focused primarily on minimizing the total cost of a SWM system, with limited attention to the issues mentioned above, when choosing a management strategy. Industrial and academic research have made important technological improvements in the collection, separation, treatment and disposal processes which have helped achieve substantial cost reductions. This includes development of mathematical models to optimize the design of basic management components such as collection routes and technology for efficient material recovery. As the early regulations were less stringent, the development of feasible SWM strategies has been relatively easy. Landfills, for example, did not have a strict control on liquid and gaseous emissions. Cities now require additional regulations and controls on pollutants resulting from solid waste management. Landfills must have liner systems for leachate collection and landfill operators are also required to collect and treat landfill gases. Similarly, combustion facilities are required to treat gaseous emissions. Recently, most US cities are beginning to adopt the Environmental Protection Agency (EPA) suggested diversion targets. Therefore, new methods and procedures are required to develop and analyze alternative SWM strategies that comply with these environmental requirements while meeting budget and resource restrictions.

Life Cycle Assessment (LCA) has been recognized as a potentially useful technique in understanding and development of economically and environmentally efficient SWM alternatives. LCA can be used to estimate the overall environmental impact of a product during its entire life. It is a concept established by the Society of Environmental Toxicology and Chemistry (SETAC) in 1990 and its structure contains three separate but interrelated components: life cycle inventory (LCI), life cycle impact analysis and life cycle improvement analysis.

Shapiro (1993) defined life cycle inventories as the quantification of the energy and raw material inputs and environmental releases associated with each stage of production. She also defined impact analysis as the assessment of the impacts on human health and the environment associated with those inputs and outputs. The improvement analysis comprises of the evaluation of opportunities to reduce energy and material inputs or environmental impacts. This concept can be extended and applied to components of solid waste. Some researchers have applied life cycle assessments to packaging materials (Shapiro, 1993) and some specific products such as children's diaper systems (Sauer *et al.*, 1994). Rethmeyer (1993) suggested a methodology for conducting life cycle inventory studies applied to products and packaging materials. However, researchers have conducted limited research on LCAs and LCIs.

It is possible to treat each waste component of the solid waste stream as a separate material undergoing a series of processes, such as collection, separation, treatment, disposal and remanufacturing, that constitute a SWM alternative. Within each process, an LCI associated with the quantity of waste processed can be established. For instance, at a combustion facility, the net energy and raw material consumption and the associated emissions resulting from combusting a ton of waste (with known composition) can be estimated. Further, the contribution by individual waste items to the LCI can be estimated based on appropriate allocation schemes. This allows one to quantify the energy and raw material consumption and the environmental releases associated with a given SWM strategy.

In this thesis, a mathematical optimization approach is developed to analyze an integrated SWM system comprising several different management options for collection, separation, treatment, and disposal of waste generated in the residential, multi-family and commercial sectors. This approach facilitates the evaluation and comparison of alternative SWM strategies where each strategy is defined by a set of active process options, flow of waste items through these options, and the set of waste items recovered for recycling. The evaluation of a strategy can be carried out based on a range of criteria, including cost and LCI factors such as CO, CO_2, NO_x , VOC, and greenhouse gas emissions. The mathematical model represents all feasible SWM strategies for a given SWM system. Solution of this model using a Linear Programming (LP) algorithm provides a mechanism for a systematic search through these feasible alternatives. This model also allows the specification of specific restrictions and preferences. For instance, additional mathematical equations can be specified in the model to represent a mandated minimum diversion requirement or to exclude a set of process options from considerations.

1.2. Related Work

Reported work on solid waste management include studies on individual unit processes and integrated analysis. Brief summaries of studies that are closely related to the research described in this thesis are presented in this section. First, there is a mention of early research that did not use any particular algorithm to get the optimal solution. Second, models using Mixed Integer Programming (MIP) are described and compared. Third, models using Linear Programming (LP) applied to both the integrated solid waste management system and some management sub-systems are discussed. Lastly, recent work on the analysis of SWM systems using Decision Support Systems (DSS) is discussed.

In the early seventies, Esmaili (1972) proposed a haul optimization model. His objective was to minimize the total combined cost of solid waste transport, processing, and disposal for a given area over a certain period of time. He included a set of constraints to represent the capacity limitation of each disposal plant and the model was solved using an exhaustive search routine. The algorithm used to solve the model consisted of several steps, and repetitive runs were needed to obtain the optimal solution. For that reason, this model could be highly time consuming when analyzing a complex SWM system. Additionally, the model requires storage of great amounts of preliminary calculations, which can be prohibitive in terms of space consumption when analyzing a large scale SWM system.

Liebman *et al.* (1975) developed a mathematical theory related to garbage vehicle routing. They represented the waste source locations in a city as discrete nodes in a network. Links with associated transportation costs were used to connect these nodes. The objective of the garbage vehicle routing procedure was to find the least cost tour over these links. Although their work only included a theoretical discussion, they suggested different algorithms to solve these routing problems. The most important contribution of this paper was the development and incorporation of mathematical theory into procedures for manual routing of garbage trucks. Although no routing optimization analyses are included in this thesis, the mathematical theory developed by Liebman *et al.* could be applied later to help design collection routes for the collection options in the selected SWM strategy.

The Waste Resource Allocation Program (WRAP) uses Mixed Integer Programming to find the optimal solution in a SWM system. Hasit and Warner (1981) tested WRAP and compared its performance with those of other models available at that time. WRAP is a computer program introduced by the United States Environmental Protection Agency. Given a set of existing sites and waste resources, WRAP determines the type, location, and size of new facilities. It includes mass flow and capacity constraints and considers time as an additional parameter, which allows representation of temporal changes in waste generation, costs, regulations, and technology. The authors evaluated the heuristic approach developed by Esmaili (1972) and found it to be computationally prohibitive for large size problems. Instead, the WRAP model relieved the user from computing the distances between sources and facilities. A shortcoming of this method is that piecewise linearization techniques were incorporated to model non-linear cost functions which required the model to develop four different phases to find the optimal solution. After the first two phases, an LP optimal solution was found. The other phases found local and global optima when considering additional issues on the cost functions. Often, the model did not improve solutions from phase to phase and was found to be computationally time consuming. In addition to this limitation, the model could handle only up to 90 constraints and 360 variables.

Gottinger (1988) described a model for regional solid waste management as a network flow problem. The general problem was to find what facilities to build and the best way to manage wastes so that the overall cost of the system was minimized. The potential locations of intermediate processing facilities and landfills, the locations and capacities of existing landfills, the cost structures and the quantities of wastes generated at the sources were given. This mixed integer linear programming model was solved using an algorithm for network analysis. The model included mass flow and capacity constraints, and constraints to limit only one facility at a potential facility location. It considered either that the capacities of non-existent facilities were infinite, or that the capacities of already existent facilities were finite. The complexity of the algorithm used in the model could be limiting when analyzing a SWM system like the one studied in this thesis. As the system complexity increases, the algorithm would be more difficult to program and would generate a large amount of intermediate information that needs to be stored.

Another mixed integer linear programming model applied to SWM was developed by Chang *et al.* (1993). The model selected the size of and site for facilities and the level of their physical operation over several periods of time. They included the effects of recycling, estimates of facility construction and operating costs, and the residual values of new facilities. They also included location and size of new facilities, values of energy recovery, forecasts of waste generation, impacts of air pollution and tipping fee estimations. The objective function was to minimize the discounted cash flow corresponding to all the quantifiable environmental and economic benefits and costs. The authors included mass flow and capacity constraints. Additionally, constraints were added to: ensure a new facility to be built only once; determine the value for the tipping fee for each time period; and limit the air pollution emissions. Like in the models previously mentioned in this chapter, the solutions specified the mass allocation of generated waste to the potential facilities. Important differences are the consideration of benefits and costs based on a life cycle framework, and the air pollution control. An important shortcoming was that the model was found to be computationally time consuming.

The SWM models described above were developed using mixed integer linear programming (MIP). However, there are numerous SWM models developed with linear programming (LP). Hasit and Warner (1981) compared these two techniques when applied to the WRAP model. In their scenarios, the number of cost combinations increased rapidly as the number of facilities increased, resulting in higher data requirements and program handling. They noted that LP models can get offset by those effects and cannot handle discrete sizes for facilities. Instead, they added, MIP can take all those considerations into account. Gottinger (1988) analyzed some of the scenarios developed to test his model in terms of memory requirements when using an MIP model and noted the high memory requirements of the algorithm used to solve the model.

Hsieh and Ho (1993) presented a linear programming model to analyze a SWM system. The objective function was to minimize the present value of collection, recycling, treatment and disposal costs. They included mass flow and capacity constraints. The model analyzes very simplified SWM systems with a small amount of management options. Additionally, the model assumption of allowing only one connection between management options is an important limitation and cannot be used to analyze large SWM systems with multiple and complex interrelationships.

Movassaghi (1993) presented an LP model for a regionally based refuse-to-energy (RTE) facility consisting of incineration with steam recovery. The objective function was to minimize collection, transfer, RTE treatment and disposal costs. He included mass flow and capacity constraints to exclusively drive waste flows based on end-user demands of the generated steam. The author simplified his model by using an *a priori* allocation of a set of customers to a given steam generation plant. The SWM system analyzed was simplified and did not include other management options, such as recyclables separation facilities and composting plants, to divert wastes from disposal.

The different LP models reported in the literature are not developed to obtain the best strategy for an integrated solid waste management. They are formulated to analyze more simplified SWM systems than the one studied in this thesis. For example, there are models to optimize the performance of individual components of the whole system, such as recycling collection programs, MSW collection programs or Material Recovery Facilities. In the linear programming model presented by Diamadopoulos *et al.* (1995), the objective was to minimize a solid waste recycling system cost. The model was developed exclusively to analyze recycling strategies for some recyclable waste categories in the waste stream. Lund (1990) developed a LP model for scheduling of solid waste recycling. This helps identify a least-cost recycling plan by scheduling the recycling options to minimize the present value cost of providing solid waste disposal services into the future, and a least-cost lifetime for the landfill by considering the recycling costs and the benefits of deferring landfill closure and future replacement costs. Jacobs and Everett (1992) expanded Lund's formulation by considering consecutive landfills. The tipping costs, along with the costs of implementing each recycling option, were used to determine the optimal solution for each existing and possible future landfill. Lund *et al.* (1994) formulated a linear programming model for analysis of material recovery facilities (MRF) with the objective of minimizing total recyclables separation and processing costs.

The models discussed above incorporated only a limited number of process options with restrictive waste flow configurations. They still lack the capability to carry out a comprehensive analysis of an integrated SWM system. Kaneko (1994) formulated a linear programming model that facilitates an integrated analysis of a SWM system that includes: mixed waste collection, recyclable collection, yardwaste collection and co-collection of mixed waste and recyclables; mixed waste and commingled recyclables separation; combustion and yardwaste composting; and landfill disposal. The total system cost was the objective function and mass balance constraints represented feasible waste flow through the SWM system. He introduced cost coefficients developed in spreadsheet-based SWM process models that used large amounts of information on costs, demographics and solid waste characteristics. The model was demonstrated to be flexible to modify to enable analysis of different issues in the SWM system. These analyses included landfill disposal costs, landfill utilization, and management of disposal demand by economic incentives to study the effect of direct general subsidies on the overall SWM system. The model was found to be very efficient in terms of computational time requirements.

Ranjithan *et al.* (1995) described a Decision Support System (DSS) development as a computer-based design environment to integrate Kaneko's model into a interactive decision making environment. The purpose of such tool is to help local planners carry out decision-making processes concerning solid waste management. Figure 1.1, shows a schematic diagram of the DSS with its components and their inter-relationships. The DSS also integrates the spreadsheet-based SWM process models that provide the cost coefficients for the optimization model.

No existing model or procedure incorporates the LCI factors and cost in an integrated manner to allow an efficient and systematic evaluation and comparison of SWM alternatives. With increasing regulations on SWM processes and mandatory diversion requirements, escalating SWM costs, and depleting natural resources, a need for a comprehensive SWM model to facilitate efficient and effective decision making in SWM is important. The work reported in this thesis addresses this problem.

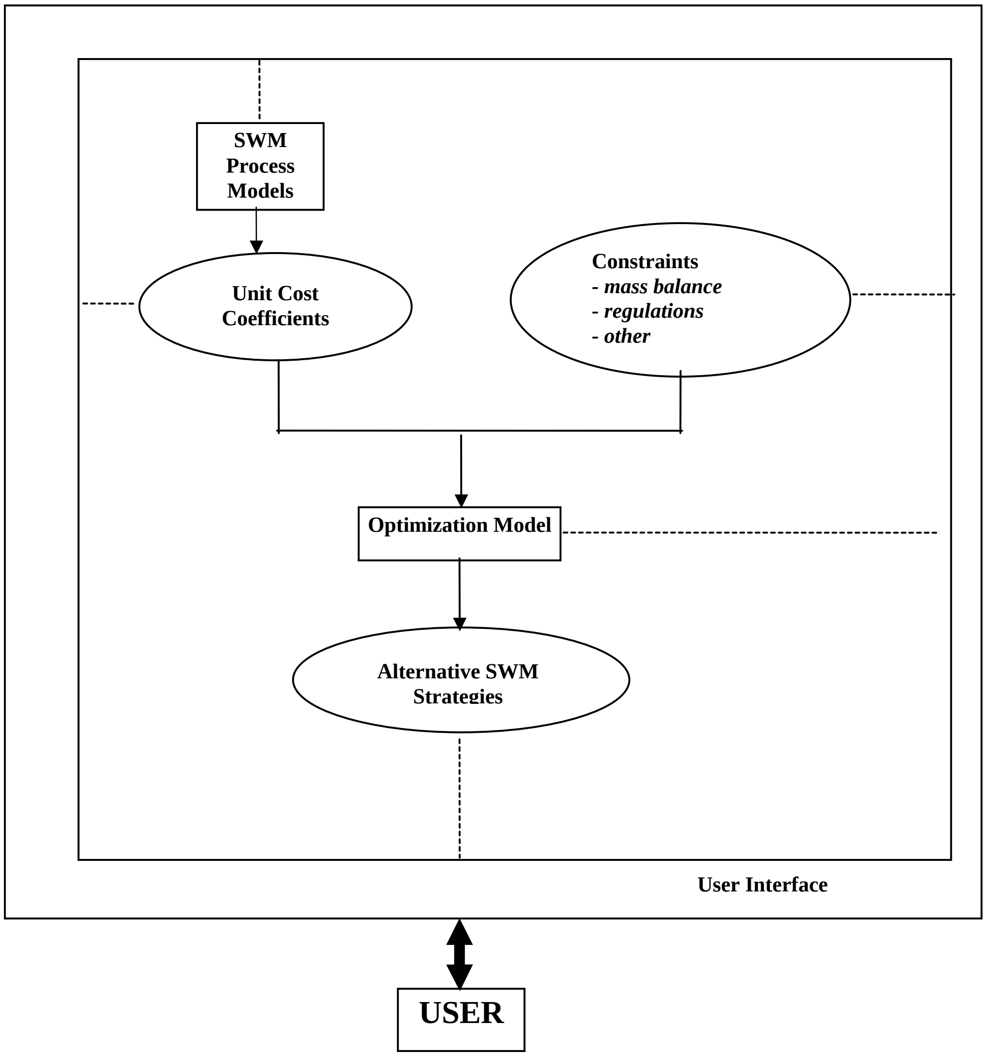


Figure 1.1: Schematic diagram of a DSS framework

1.3. Main objective and scope

1.3.1. Objective

The main objective of this thesis is to develop and test a comprehensive mathematical model that facilitates an integrated analysis of an SWM system. This analysis framework will include net management cost and several LCI parameters, including net environmental releases and energy and raw material consumptions. The integrated SWM system will include several components and the interrelationships among the components. The integrated SWM system consists of 21 collection options, 8 transfer stations, 5 Material Recovery Facilities (MRFs), 6 treatment facilities and 3 final disposal facilities. The system included 38 different waste stream items in the residential and multi-family sectors and 21 different waste stream items in the commercial sectors.

1.3.2. Scope

The linear programming model presented in this thesis is the starting point in the process of building an efficient optimization tool for the Decision Support System. It is developed using available cost information about the management options and does not include any other LCI parameter. The model takes cost coefficients from available spreadsheets models and from other sources such as textbooks and journal articles. Simplifications are made when information about management options is unknown.

Chapter 2: System Definition

2.1. System components

The waste management elements of the municipal solid waste system analyzed in this thesis are shown in Figure 2.1. This thesis uses the system definition included in Appendix D, which is the system description for a life-cycle inventory of municipal solid waste management alternatives. Figure 2.2 shows the detailed waste management alternatives and the possible flows that solid waste can take in the system. Detailed solid waste mass flow diagrams are shown in Appendix C. The following paragraphs define the system elements and their interrelationships.

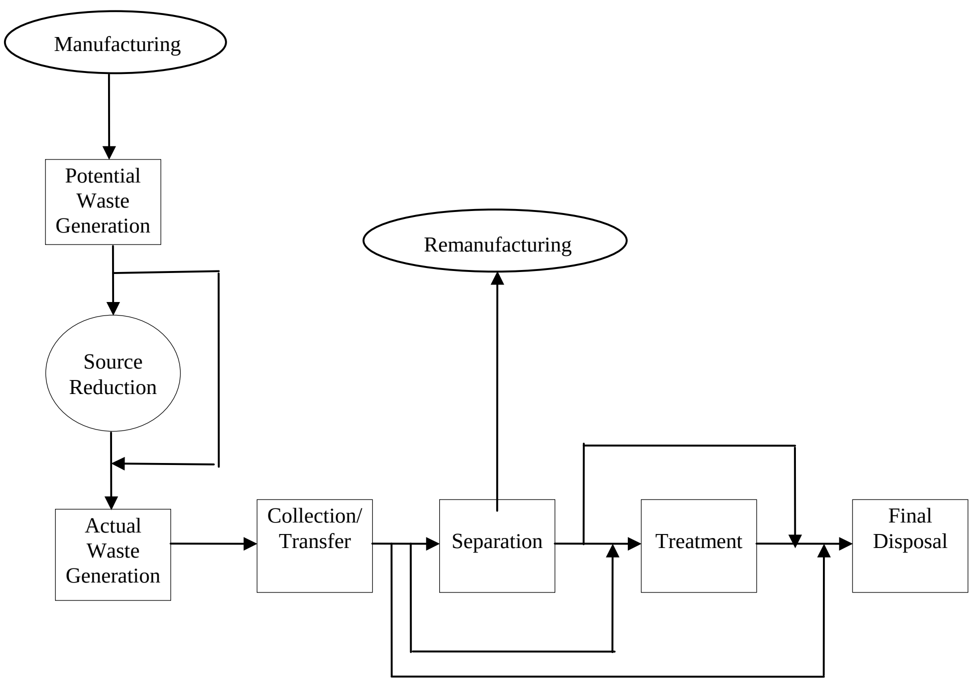


Figure 2.1: Functional Elements of the Life Cycle Analysis of Municipal Solid Waste Management Alternatives

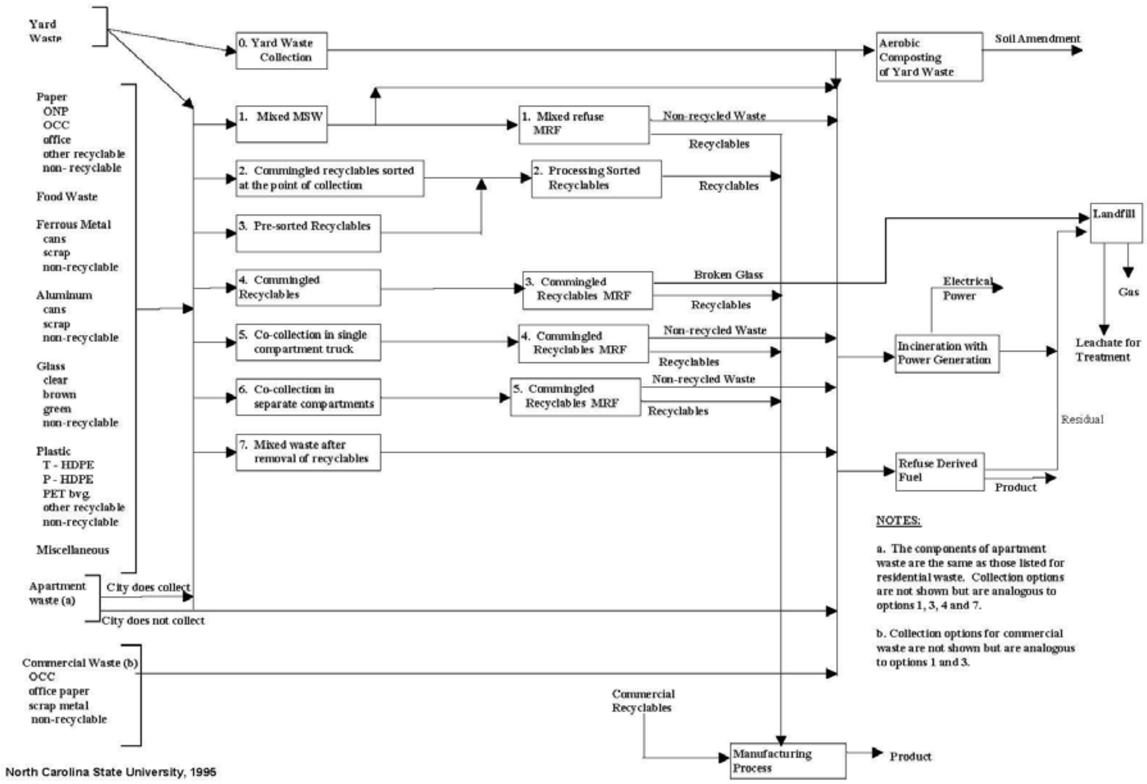


Figure 2.2: Alternatives for Integrated Solid Waste Management

2.1.1. Generation

This section describes the solid waste stream components. Figure 2.1 shows potential waste generation after product manufacturing and consumption. Source reduction is a possibility to reduce the potential generation of wastes through the application of strategies such as material reuse and container refill. The actual generation of wastes in the system is the remaining waste after applying source reduction strategies. This mass of wastes enters the management system and flows through the different management options.

The three types of solid waste generation sectors considered in the model are the residential, multi-family and commercial sectors. Waste characterization studies from the U.S. Environmental Protection Agency (EPA) are used here as the main data source for waste composition. The term residential sector refers to any sector that uses individual collection containers. The term multi-family sector refers to any sector that uses containerized collection. The term commercial sector refers to the set of commercial units including stores, offices, businesses and others.

The following list includes the names and notation used to identify waste generated at the residential and multi-family sectors.

Yard trimmings - Grass	YTG
Yard trimmings - Leaves	YTL
Yard trimmings - Branches	YTB
Old newsprint	ONP
Old corrugated cardboard	OCC
Office paper	OFF
Phone Books	PBK
Books	BOOK
Old Magazines	OMG
Third Class Mail	MAIL
Other recyclable paper 1 *	PAOT1
Other recyclable paper 2 *	PAOT2
Other recyclable paper 3 *	PAOT3
Other recyclable paper 4 *	PAOT4
Other recyclable paper 5 *	PAOT5
Non-recyclable paper	PANR
Food Waste	FW
Ferrous metal cans	FCAN
Other ferrous metal	FMOT
Non-recyclable ferrous metal	FNR
Aluminum cans	ACAN
Aluminum other 1 *	ALOT1
Aluminum other 2 *	ALOT2
Non-recyclable aluminum	ANR
Clear glass	GCLR
Brown glass	GBRN
Green glass	GGRN
Non-recyclable glass	GNR
Transparent HDPE	HDT
Pigmented HDPE	HDP
PET beverage bottles	PPET

Other recyclable plastics 1 *	PLOT1
Other recyclable plastics 2 *	PLOT2
Other recyclable plastics 3 *	PLOT3
Other recyclable plastics 4 *	PLOT4
Other recyclable plastics 5 *	PLOT5
Non-recyclable plastics	PLNR
Miscellaneous	MIS

The following list includes the names and notation used to identify waste generated at the commercial sectors.

Old newsprint	ONP
Old corrugated cardboard.	OCC
Office paper	OFF
Phone Books	PBK
Third Class Mail	MAIL
Other recyclable paper 1 *	PAOT1
Other recyclable paper 2 *	PAOT2
Other recyclable paper 3 *	PAOT3
Pallets (wooden)	PAL
PET beverage bottles	PPET
Ferrous metal cans	FCAN
Aluminum cans	ACAN
Clear glass	GCLR
Brown glass	GBRN
Green glass	GGRN
Combustible compostable recyclable other *	CCRO
Combustible non-compostable recyclable other*	CNRO
Combustible compostable non-recyclable other *	CCNO
Combustible non-compostable non-recyclable other *	CNNO
Non-combustible non-compostable recyclable other *	NNRO
Non-combustible non-recyclable other *	NNNO

* The user can include recycling of additional components not specifically listed in any other category.

2.1.2. Post generation stages

Wastes generated in each generation sector can be collected by a combination of several collection options. Residential collection options include yardwaste collection, mixed waste collection, recyclables collection, co-collection of mixed waste and recyclables, residuals collection, wet/dry collection and recyclables and yardwaste drop-off. Multi-family collection options include mixed waste collection, recyclables collection, residuals collection, wet/dry collection and recyclables drop-off. Commercial collection options include mixed waste collection, recyclables collection and residuals collection. Table 2.1 shows all the collection options used in this thesis.

Table 2.1 Collection options

Collection option	Notation
1. Residential sector	
Yard trimming collection for aerobic composting	C0
Collection of mixed MSW in one truck	C1
Collection of commingled recyclables sorted at the point of collection by the collection crew	C2
Collection of pre-sorted recyclables	C3
Collection of commingled recyclables sorted at a MRF with old newsprint (ONP) in a separate compartment	C4
Collection of commingled recyclables and MSW (bagged separately) in a truck with two compartments with ONP in a third compartment	C5
Collection of commingled recyclables and MSW (bagged separately) in a truck with three compartments with ONP in a separate compartment	C6
Collection of mixed MSW after removal of recyclables or yard waste	C7
Recyclables drop-off by the generator	C8
Collection of leaves using a leaf vacuum truck	C9
Yard trimming drop-off by the generator	C10
Wet/dry/commingled recyclables collection in separate compartments	C11
Wet/dry collection in separate compartments after collection of recyclables by C2, C3 or C4	C12
2. Multi-family sector	
Collection of mixed MSW in one truck before separation of any component	C13
Collection of pre-sorted recyclables in multiple bins	C14
Collection of commingled recyclables in two bins with ONP separate	C15
Collection of MSW after removing recyclables through C14 or C15	C16
Wet/dry/commingled recyclables collection in separate compartments	C17
Wet/dry collection in separate compartments with commingled recyclables collected through C14 or C15	C18
3. Commercial sector	
Collection of pre-sorted recyclables	C19
Collection of mixed MSW before or after recyclables removal	C20

Transfer options include eight types of transfer stations, three of which are rail transfer stations. Table 2.2. shows the list of these transfer stations. The transfer stations TR3 and TR4 separate bags with MSW from the bags with recyclables. The bags then flow out of the transfer stations to different locations as appropriate. Rail transportation is another option included to transport solid waste from one management stage to another. In the process, there is one transfer station (RT1) that transfers MSW from collection vehicles to rail cars. Rail cars unload the wastes at two optional destination transfer stations (RT2 and RT3). RT2 transfers MSW from trains to haul vehicles that transport MSW to landfill D1, and RT3 transfers MSW from trains to haul vehicles that transport MSW to landfill D3.

Table 2.2: Transfer options

Transfer option	**Notation**
Transfer of mixed waste	TR1
Commingled recyclables transfer	TR2
Transfer of both MSW and sorted recyclables coming in separate bags and collected in a one compartment truck	TR3
Transfer of both MSW and sorted recyclables coming in separate bags and collected in a two compartment truck	TR4
Transfer of pre-sorted recyclables	TR5
Railroad receiving transfer station	RT1
Transfer of MSW from trains to haul vehicles that transport MSW to landfill D1	RT2
Transfer of MSW from trains to haul vehicles that transport MSW to landfill D3	RT3

Separation of materials to be recycled occurs in Material Recovery Facilities (MRF). Collection of solid waste will affect the design of a MRF. The model includes five type of MRFs. Table 2.3 shows the MRF considered in this thesis. At the S4 MRF, bags containing the recyclables are separated and sorted and the bags containing the mixed MSW are loaded back in haul trucks that transport them to the next management node. At the S5 MRF, only the bags containing the recyclables are processed and the bags containing the mixed MSW stay in the collection trucks that transport them to the next management node.

Table 2.3: Separation options

Separation option	Notation
MRF to process mixed refuse coming from mixed waste collection options (C1, C13), residual collection options (C7, C16) and wet/dry collection options (C11, C12, C17, C18)	S1
MRF to process pre-sorted recyclables collected through C2, C3, C14 or dropped off by the generator (C8)	S2
MRF to process commingled recyclables collected through commingled recyclables collection options C4, C15 or wet/dry collection options C11, C17	S3
MRF to process commingled recyclables collected by collection option C5	S4
MRF to process commingled recyclables collected by collection option C6	S5

The SWM system includes six treatment options for solid waste. Aerobic composting of yard waste may occur either in a centralized municipal facility or in the generator's backyard. Mixed waste composting occurs at a mixed waste composting facility. This facility includes preprocessing to remove materials such as white goods normally excluded from composting. Combustion of wastes occurs at a combustion facility that generates electric power. The separation of waste as fuel occurs at a refuse-derived-fuel plant (RDF). An RDF plant will also include preprocessing to remove materials normally excluded from RDF such as aluminum, ferrous metal and glass. Anaerobic digestion of MSW occurs at an anaerobic digestion reactor. The process generates compost and methane. As in RDF plants, preprocessing is required to remove materials normally excluded from digestion. Table 2.4 shows all the treatment options.

Table 2.4: Treatment options

Treatment option	Notation
Aerobic composting of yard waste in a centralized municipal facility	T1
Combustion facility that generates electric power	T3
Refuse derived fuel plant	T5
Aerobic composting of yardwaste at the generator's backyard	T6
Mixed waste composting facility	T7
Anaerobic digestion reactor	T8

The numbering sequence for treatment alternatives is discontinuous because in previous stages of this investigation the system included T2 and T4 alternatives which correspond to combustion with steam production and combustion with no energy recovery, respectively. This thesis will not include T2 and

T4 because the majority of combustion facilities constructed today include energy recovery as electricity.

There are three disposal alternatives. The first is a landfill designed to received mixed MSW. It operates as a dry landfill without leachate recycling. The second one will receive only ash from combustion processes. The third one is an enhanced bioreactor that receives mixed MSW and operates to enhance decomposition. It is also known as a wet landfill. Table 2.5 shows the list of disposal facilities.

Table 2.5: Disposal options

Treatment option	Notation
Mixed MSW dry landfill	D1
Ash mono-landfill	D2
Wet landfill	D3

The materials recovered from the waste stream are recyclables, waste as fuel and compost. The recyclables are recovered at the separation facilities or at the RDF, mixed waste compost and anaerobic digestion treatment facilities. The yardwaste compost is produced at the yard waste compost facilities and at the generator's backyard. The mixed waste compost is generated at the mixed waste composting facility. Waste as fuel is recovered at RDF facilities and at MRFs. Waste as fuel is recovered during the pre-selection processes at the mixed waste composting and the anaerobic digestion facilities too.

The system described in the previous paragraphs will be represented in a linear programming model and tested. Input data for the model will be obtained from various sources. Some of these sources are available pre-processors written as spreadsheets to gather and process data about the management options. Some other sources include databases, documented references and pre-processors under construction. These data consist of cost coefficients for the management options. Cost information includes capital, operation and maintenance costs. In future versions of the model, input data will also include LCI parameters. Life cycle parameters will include net energy and material consumption, and net release of emissions. The boundaries of the SWM system modeled in this thesis are presented in the following section.

2.2. SWM System Boundaries

The boundaries adopted for the system described in this thesis consider some of the recommendations given by Tillman *et al.* (1994). They discussed the difficulties to select the system boundaries in an LCA and explained the differences between selecting boundaries for the technological and natural systems. They defined the beginning of life cycle as the acquisition of raw materials, and the end when heat or waste in solid, liquid or gaseous form flows to receiving soil, water or air. Although the inventory does not include impacts on the technological system caused by pollutants, the authors recommended their inclusion in later steps of LCA. The authors underlined the importance of selecting the geographical area for the analysis. Various parts of a product may come from anywhere in the world, and infrastructure such as electricity production, waste management and transport systems, may differ in different regions. Regarding time boundaries, time horizon selections should be restricted to the life time during which the technology is surveyable. They recommended using the lifetime of the product when deciding the time horizon. The last type of boundaries discussed in their paper deals with boundaries between the life cycle of a product studied and the related life cycle. They emphasized the methodological difficulties when dealing with processes with multiple products, such as in waste treatment processes. Their major recommendations were to include in the system the activities relevant to the purpose of the study. They noted that the choice of system boundaries relates closely to the goal definition of the study.

As an example of selecting boundaries for life cycle inventories, Bogusky *et al.* (1993) described open-loop and closed-loop recycling. They developed a mathematical representation to analyze Life Cycle Inventory related to recycling. They defined open-loop recycling as recycling of a post-consumer product into another useful product a limited number of times. Closed-loop was defined as the process when a product is recycled into another product that can be recycled repeatedly. They presented an allocation approach to recycling of post-consumer products. The equations basically balanced all inputs and outputs associated with the entire LCI system. They included raw material inputs, energy inputs, product outputs, air emission outputs, water pollutant outputs, and both industrial and post-consumer solid waste outputs associated with all the products produced by the system. Other important equations allocated system inputs and outputs to any one product from the system. This approach can work as an approximate methodology for analyzing recycling effects in the environment. However, some of the allocation schemes, such as the endless recycling are not realistic enough for an LCI model.

The system boundaries adopted in this thesis are presented in Appendix D. The solid waste components included within the boundaries of the system are listed in Section 2.1.1. Additionally, the system will allow for the recovery of combinations of components such as the recovery of mixed paper for use as either pulp or fuel. The economic analysis includes the costs of all the solid waste management options defined previously. If an SWM facility processes a waste item, the model will include all the cost related to its treatment. For example, the cost of treating leachate generated in a landfill, and the cost of educational materials associated with source reduction or other aspects of solid waste management will be included. The economical analysis includes the revenue that the public sector receives after selling a product. This product may be the recovered recyclables from a MRF, material from RDF or electricity from a combustion facility. This revenue or incurred cost is the final level considered within the boundaries. The analysis does not include the remanufacturing costs. The costs associated with the collection and processing of waste generated in the private sector is not considered in the total system cost. The waste generators pay for this private collection service. If this waste flows to a facility in the public sector, a tipping fee is applied to reflect the cost of waste management at that facility.

The system includes all resources, energy and emissions associated with the production of a new product using virgin material. It will contrast these values with those related to the production of a new product using recycled material. It will consider life cycle parameters from the recovery of a raw material to its product conversion. The energy consumed and emissions released when manufacturing that product are also taken into account. The boundaries exclude the energy associated with the operation of a facility’s infrastructure. For example, the energy expended to operate an office used to supervise collection workers is excluded. The boundaries will include the energy associated with the treatment of any additional wastes resulting from a waste treatment option.

Chapter 3: Mass flow equations for the SWM system

3.1. Overview

The mass flow equations presented in this chapter are a mathematical representation of the mass flow diagrams (Appendix C) that describe all potential paths the different waste items could take through the SWM system. These mass flow equations serve two main purposes: 1) they require mass balance of all waste components flowing through the SWM system; and 2) represent all feasible flow paths of waste items through the different unit processes while disallowing waste components to enter infeasible unit processes.

A set of mass flow equations is written for each unit process (generation, collection, transportation, separation, treatment or disposal) in the SWM system. These equations represent mass conservation in terms of mass of waste coming into and going out of a particular unit process. The waste components are grouped into different waste stream sets based on common properties of the individual components. These set definitions are described in section 3.2.9.

The equations are shown for a waste stream set implying that all members of that set can flow in the specified path. This does not, however, imply that all items have to flow necessarily together; it is possible for an individual waste component to take any one of the feasible paths specified for a waste stream set that includes that waste component. Further, no mass accumulation is allowed in any unit process, however, physical, chemical or biological transformations, such as composting, methane generation and combustion can take place.

3.2. Notation

The following notation will be used to identify the different unit processes in the solid waste management system:

3.2.1. Generation

G : all generation sectors

3.2.2. Collection alternatives

Residential sector

C0: Collection of yard trimmings for aerobic composting

C1: Collection of mixed MSW in one truck prior to separation of any component

C2: Collection of commingled recyclables (sorted at the point of collection by the crew)

C3: Collection of pre-sorted recyclables

C4: Collection of commingled recyclables (to be sorted at a MRF) (ONP in a separate compartment)

C5: Collection of commingled recyclables and MSW (bagged separately) in a two compartment truck (ONP in a separate compartment)

C6: Collection of commingled recyclables and MSW (bagged separately) in a three compartment truck (ONP in a separate compartment)

C7: Collection of mixed MSW after removal of recyclables or yard waste

C8: Recyclables drop-off by the generator

C9: Collection of leaves using a leaf vacuum truck

C10: Yard trimmings drop-off by the generator

C11: Wet/dry/commingled recyclables collection in separate compartments

C12: Wet/dry collection in separate compartments with recyclables collected via C2, C3 or C4

Multi-family sectors

C13: Collection of mixed MSW

C14: Collection of pre-sorted recyclables (multiple bins)

C15: Collection of commingled recyclables (two bins, ONP separate)

C16: Collection of MSW after removal of recyclables via C14 or C15

C17: Wet/dry/commingled recyclables collection in separate compartments

C18: Multi-family wet/dry collection in separate compartments with commingled recyclables collected via C14 or C15.

Commercial sectors

C19: Collection of pre-sorted recyclables

C20: Collection of mixed MSW (before or after recyclables removal)

3.2.3. Transfer alternatives

TR1: Transfer of mixed MSW

TR2: Transfer of commingled recyclables (not in bags)

TR3: Transfer of MSW and sorted recyclables (in separate bags, one compartment)

TR4: Transfer of MSW and sorted recyclables (in separate bags, separate compartments)

TR5: Transfer of pre-sorted recyclables

In transfer stations TR3 and TR4, MSW (black bags) and recyclables (blue bags) will be separated and will flow out of the transfer stations to different locations as appropriate.

RT1: Rail transfer of MSW from collection vehicles

RT2: Rail transfer of MSW from trains to haul vehicles at landfill D1

RT3: Rail transfer of MSW from trains to haul vehicles at landfill D3

3.2.4. Separation alternatives

S1: Sorting of mixed refuse

S2: Processing of pre-sorted recyclables collected via C2 and C3

S3: Sorting of commingled recyclables collected via C4

S4: Sorting of commingled recyclables collected as mixed waste and recyclables in color coded bags in single compartment truck via C5

S5: Sorting of commingled recyclables collected as mixed waste and recyclables in color coded bags in a double compartment truck via C6.

Separation processes will occur at Materials Recovery Facilities (MRF). Items normally excluded from MSW (couches, white goods, etc.) are not processed at these facilities.

3.2.5. Treatment alternatives

T1: Aerobic composting of yard waste
T3: Combustion with electric power generation
T5: Refuse derived fuel (mixed MSW)
T6: Backyard composting
T7: Mixed refuse composting
T8: Anaerobic digestion

Treatment options T5, T7 and T8 would include preprocessing to remove materials such as white goods normally excluded from these processes. Previous stages of this investigation included T2 and T4 alternatives (combustion with steam production and combustion with no energy recovery, respectively). These treatment alternatives are not in common use and were excluded. Therefore, the numbering sequence for treatment alternatives is discontinuous.

3.2.6. Disposal alternatives

D1: Landfill
D2: Ash Landfill
D3: Enhanced Bioreactor

3.2.7. Product Outputs

Recyclables, Compost, Fuel, Methane, Electricity

3.2.8. Additional factors

The following definitions are used to represent factors that affect the amount of solid waste in the system.

CPR: collection participation rate
CEFF: collection efficiency
CRF: reduction factor after composting
ASHF: ash fraction after combustion

SE: separation efficiency

The collection participation rate (CPR) of a collection option is the percentage of a generation sector participating in that collection option. For example, a participation rate of 70% for the commingled recyclables collection option C2 means that only 70% of the generation sector will participate in setting out recyclable waste items in commingled recyclables bins. The remaining 30% will dispose the recyclables with the mixed waste.

The collection efficiency (CEFF) is defined for every recyclable item collected by each recyclables collection option. This factor is used to represent the fraction of a recyclable item properly separated by the household participating in a collection option. For example, a collection efficiency of 80% for old newsprint in an area served by the commingled recyclables option, means that only 80% of the old newsprint generated by those who are participating in this collection option will be set out as commingled recyclables while the remaining 20% will be disposed as mixed waste.

The total mass of a potentially recyclable material that is actually collected as a recyclable by a recyclable collection option is determined by both the collection participation rate and the collection efficiency. This mass is equal to the mass of the material collected by the collection option multiplied by the collection participation rate and by the collection efficiency.
The fraction CRF represents the mass reduction due to the composting process. The fraction ASHF is the percentage of mass for those wastes that can be reduced to ash. The fraction SE is used to indicate the material separation efficiency at a MRF.

3.2.9. Definition of Sets

In the following set definitions, the set names follow a defined pattern. Specifically, all set names will have 4 characters defined as follows:

a) First character represents the generation sector where the waste is generated:

R: residential, M: multi-family, C: commercial

b) Second character represents combustibility:

C: combustible, N: non-combustible

c) Third character represents compostability:

C: compostable, N: non-compostable

d) Fourth character represents recyclability

R: recyclable, N: non-recyclable

3.2.9.1. Residential sectors (single family housing)

Yard trimmings- leaves:	RYTL
Yard trimmings - other:	RYTO
Combustible compostable recyclable:	RCCR
Combustible non-compostable recyclable:	RCNR
Non-combustible non-compostable recyclable:	RNNR
Combustible compostable non-recyclables:	RCCN
Combustible non-compostable non-recyclable:	RCNN
Non-combustible non-compostable non-recyclables:	RNNN

3.2.9.2. Multi-family sectors (apartments, duplexes)

Yard trimmings- leaves:	MYTL
Yard trimmings - other:	MYTO
Combustible compostable recyclable:	MCCR
Combustible non-compostable recyclable:	MCNR
Non-combustible non-compostable recyclable:	MNNR
Combustible compostable non-recyclables:	MCCN
Combustible non-compostable non-recyclable:	MCNN
Non-combustible non-compostable non-recyclables:	MNNN

3.2.9.3. Commercial sectors

Combustible compostable recyclable:	CCCR
Combustible non-compostable recyclable:	CCNR

Non-combustible non-compostable recyclable:	CNNR
Combustible compostable non-recyclable:	CCCN
Combustible non-compostable non-recyclable:	CCNN
Non-combustible non-compostable non-recyclable	CNNN

The equations and coefficients in this document are shown for sets of items; however unique values for the coefficients corresponding to the different waste components will be assigned in the mathematical model. For example, $CEFF_{(RCCR,\ C2)}$ represents the collection efficiency for items in set RCCR collected by collection option C2. In the mathematical model, there will be a value for CEFF corresponding to each individual item in the RCCR set.

3.3. Generation node

The generation node includes three categories: residential, multi-family and commercial. The maximum amount of waste generated in each category is called the potentially generated amount. The amount of waste actually generated may be different if a source reduction program is in place.

Potentially generated amounts

The potentially generated amounts are the tonnage of each waste component generated before any source reduction activity. These values are given as input parameters by the user or as default values in a spreadsheet built to analyze generation information. The following variables are used to express these values. The subscript PG stands for "potentially generated."

Residential sectors:

Yard trimmings, leaves :	$[RYTL]_{(PG)}$
Yard trimmings other:	$[RYTO]_{(PG)}$
Combustible recyclable compostable:	$[RCCR]_{(PG)}$
Combustible recyclable non-compostable:	$[RCNR]_{(PG)}$
Non-combustible non-compostable recyclables:	$[RNNR]_{(PG)}$
Combustible non-recyclable compostable:	$[RCCN]_{(PG)}$
Combustible non-recyclable non-compostable:	$[RCNN]_{(PG)}$
Non-combustible non-recyclable non-compostable:	$[RNNN]_{(PG)}$

Multi-family sectors:

Yard trimmings, leaves :	$[MYTL]_{(PG)}$
Yard trimmings other:	$[MYTO]_{(PG)}$
Combustible recyclable compostable:	$[MCCR]_{(PG)}$
Combustible recyclable non-compostable:	$[MCNR]_{(PG)}$
Non-combustible non-compostable recyclables:	$[MNNR]_{(PG)}$
Combustible non-recyclable compostable:	$[MCCN]_{(PG)}$
Combustible non-recyclable non-compostable:	$[MCNN]_{(PG)}$
Non-combustible non-recyclable non-compostable:	$[MNNN]_{(PG)}$

Commercial sectors:

Combustible recyclable compostable:	$[CCCR]_{(PG)}$
Combustible recyclable non-compostable:	$[CCNR]_{(PG)}$
Non-combustible non-compostable recyclables:	$[CNNR]_{(PG)}$
Combustible non-recyclable compostable:	$[CCCN]_{(PG)}$
Combustible non-recyclable non-compostable:	$[CCNN]_{(PG)}$
Non-combustible non-recyclable non-compostable:	$[CNNN]_{(PG)}$

Actually generated amounts

A source reduction factor SR for any waste item may be specified to represent the fraction of the potentially generated amount that is captured by a source reduction program. The fractions SR take a value from 0 to 1. The adjusted amount of the potentially generated waste is called the "actually generated" amount of waste. For example, a 10% source reduction (SR = 0.1) of yard waste RYTO results in an actually generated amount of 0.90 * $[RYTO]_{(PG)}$. The subscript AG stands for "actually generated." The following equations describe how the actually generated waste amounts are computed.

Residential sectors:

$$[RYTL]_{(AG)} = [RYTL]_{(PG)} * (1- SR_{[RYTL]})$$
$$[RYTO]_{(AG)} = [RYTO]_{(PG)} * (1- SR_{[RYTO]})$$
$$[RCCR]_{(AG)} = [RCCR]_{(PG)} * (1- SR_{[RCCR]})$$
$$[RCNR]_{(AG)} = [RCNR]_{(PG)} * (1- SR_{[RCNR]})$$
$$[RNNR]_{(AG)} = [RNNR]_{(PG)} * (1- SR_{[RNNR]})$$
$$[RCCN]_{(AG)} = [RCCN]_{(PG)} * (1- SR_{[RCCN]})$$
$$[RCNN]_{(AG)} = [RCNN]_{(PG)} * (1- SR_{[RCNN]})$$
$$[RNNN]_{(AG)} = [RNNN]_{(PG)} * (1- SR_{[RNNN]})$$

Multi-family sectors:

$[MYTL]_{(AG)} = [MYTL]_{(PG)} * (1- SR_{[MYTL]})$
$[MYTO]_{(AG)} = [MYTO]_{(PG)} * (1- SR_{[MYTO]})$
$[MCCR]_{(AG)} = [MCCR]_{(PG)} * (1- SR_{[MCCR]})$
$[MCNR]_{(AG)} = [MCNR]_{(PG)} * (1 - SR_{[MCNR]})$
$[MNNR]_{(AG)} = [MNNR]_{(PG)} * (1- SR_{[MNNR]})$
$[MCCN]_{(AG)} = [MCCN]_{(PG)} * (1- SR_{[MCCN]})$
$[MCNN]_{(AG)} = [MCNN]_{(PG)} * (1- SR_{[MCNN]})$
$[MNNN]_{(AG)} = [MNNN]_{(PG)} * (1- SR_{[MNNN]})$

Commercial sectors:

$[CCCR]_{(AG)} = [CCCR]_{(PG)} * (1- SR_{[CCCR]})$
$[CCNR]_{(AG)} = [CCNR]_{(PG)} * (1- SR_{[CCNR]})$
$[CNNR]_{(AG)} = [CNNR]_{(PG)} * (1- SR_{[CNNR]})$
$[CCCN]_{(AG)} = [CCCN]_{(PG)} * (1- SR_{[CCCN]})$
$[CCNN]_{(AG)} = [CCNN]_{(PG)} * (1- SR_{[CCNN]})$
$[CNNN]_{(AG)} = [CNNN]_{(PG)} * (1- SR_{[CNNN]})$

Destination of all generated wastes

All wastes actually generated must be collected by one or a number of collection options. The following subscripts are used to identify the collection options: C0, C1, C2, C3, ..., C20. Only the sets shown in the tables attached to each mass flow diagram in the Appendix C are allowed to be collected by that collection option. Therefore, all the collection options by which each set is potentially collected can be determined by identifying that particular set in all the tables.

The left hand side of the following sets of equations represents the actual amount of wastes generated, and the right hand side represents all possible ways to collect the generated waste. For example, the first equation says that all the yard waste leaves actually generated in the residential sector can be collected by the collection options C0, C1, C5, C6, C7, C9, C10, C11 and C12. The expression $[RYTL]_{(AG)(C0)}$ represents the amount of actually generated yardwaste leaves that is collected by collection option C0.

Residential sectors:

$$[RYTL]_{(AG)} = [RYTL]_{(AG)(C0)} + [RYTL]_{(AG)(C1)} + [RYTL]_{(AG)(C5)} + [RYTL]_{(AG)(C6)} + [RYTL]_{(AG)(C7)} + [RYTL]_{(AG)(C9)} + [RYTL]_{(AG)(C10)} + [RYTL]_{(AG)(C11)} + [RYTL]_{(AG)(C12)}$$

$$[RYTO]_{(AG)} = [RYTO]_{(AG)(C0)} + [RYTO]_{(AG)(C1)} + [RYTO]_{(AG)(C5)} + [RYTO]_{(AG)(C6)} + [RYTO]_{(AG)(C7)} + [RYTO]_{AG)(C10)} + [RYTO]_{(AG)(C11)} + [RYTO]_{(AG)(C12)}$$

$$[RCCR]_{(AG)} = [RCCR]_{(AG)(C1)} + [RCCR]_{(AG)(C2)} + [RCCR]_{(AG)(C3)} + [RCCR]_{(AG)(C4)} + [RCCR]_{(AG)(C5)} + [RCCR]_{(AG)(C6)} + [RCCR]_{(AG)(C7)} + [RCCR]_{(AG)(C8)} + [RCCR]_{(AG)(C11)} + [RCCR]_{(AG)(C12)}$$

$$[RCNR]_{(AG)} = [RCNR]_{(AG)(C1)} + [RCNR]_{(AG)(C2)} + [RCNR]_{(AG)(C3)} + [RCNR]_{(AG)(C4)} + [RCNR]_{(AG)(C5)} + [RCNR]_{(AG)(C6)} + [RCNR]_{(AG)(C7)} + [RCNR]_{(AG)(C8)} + [RCNR]_{(AG)(C11)} + [RCNR]_{(AG)(C12)}$$

$$[RNNR]_{(AG)} = [RNNR]_{(AG)(C1)} + [RNNR]_{(AG)(C2)} + [RNNR]_{(AG)(C3)} + [RNNR]_{(AG)(C4)} + [RNNR]_{(AG)(C5)} + [RNNR]_{(AG)(C6)} + [RNNR]_{(AG)(C7)} + [RNNR]_{(AG)(C8)} + [RNNR]_{(AG)(C11)} + [RNNR]_{(AG)(C12)}$$

$$[RCCN]_{(AG)} = [RCCN]_{(AG)(C1)} + RCCN]_{(AG)(C5)} + [RCCN]_{(AG)(C6)} \; [RCCN]_{(AG)(C7)} + [RCCN]_{(AG)(C11)} + [RCCN]_{(AG)(C12)}$$

$$[RCNN]_{(AG)} = [RCNN]_{(AG)(C1)} + [RCNN]_{(AG)(C5)} + [RCNN]_{(AG)(C6)} + [RCNN]_{(AG)(C7)} + [RCNN]_{(AG)(C11)} + [RCNN]_{(AG)(C12)}$$

$$[RNNN]_{(AG)} = [RNNN]_{(AG)(C1)} + [RNNN]_{(AG)(C5)} + [RNNN]_{(AG)(C6)} + [RNNN]_{(AG)(C7)} + [RNNN]_{(AG)(C11)} + [RNNN]_{(AG)(C12)}$$

Multi-family sectors:

$$[MYTL]_{(AG)} = [MYTL]_{(AG)(C13)} + [MYTL]_{(AG)(C16)} + [MYTL]_{(AG)(C17)} + [MYTL]_{(AG)(C18)}$$

$$[MYTO]_{(AG)} = [MYTO]_{(AG)(C13)} + [MYTO]_{(AG)(C16)} + [MYTO]_{(AG)(C17)} + [MYTO]_{(AG)(C18)}$$

$$[MCCR]_{(AG)} = [MCCR]_{(AG)(C8)} + [MCCR]_{(AG)(C13)} + [MCCR]_{(AG)(C14)} + [MCCR]_{(AG)(C15)} + [MCCR]_{(AG)(C16)} + [MCCR]_{(AG)(C17)} + [MCCR]_{(AG)(C18)}$$

$$[MCNR]_{(AG)} = [MCNR]_{(AG)(C8)} + [MCNR]_{(AG)(C13)} + [MCNR]_{(AG)(C14)} + [MCNR]_{(AG)(C15)} + [MCNR]_{(AG)(C16)} + [MCNR]_{(AG)(C17)} + [MCNR]_{(AG)(C18)}$$

$$[MNNR]_{(AG)} = [MNNR]_{(AG)(C8)} + [MNNR]_{(AG)(C13)} + [MNNR]_{(AG)(C14)}$$

$$+ [MNNR]_{(AG)(C15)} + [MNNR]_{(AG)(C16)} + [MNNR]_{(AG)(C17)} + [MNNR]_{(AG)(C18)}$$

$$[MCCN]_{(AG)} = [MCCN]_{(AG)(C13)} + [MCCN]_{(AG)(C16)} + [MCCN]_{(AG)(C17)} + [MCCN]_{(AG)(C18)}$$

$$[MCNN]_{(AG)} = [MCNN]_{(AG)(C13)} + [MCNN]_{(AG)(C16)} + [MCNN]_{(AG)(C17)} + [MCNN]_{(AG)(C18)}$$

$$[MNNN]_{(AG)} = [MNNN]_{(AG)(C13)} + [MNNN]_{(AG)(C16)} + [MNNN]_{(AG)(C17)} + [MNNN]_{(AG)(C18)}$$

Commercial sectors:

$$[CCCR]_{(AG)} = [CCCR]_{(AG)(C19)} + [CCCR]_{(AG)(C20)}$$

$$[CNNR]_{(AG)} = [CNNR]_{(AG)(C19)} + [CNNR]_{(AG)(C20)}$$

$$[CCNR]_{(AG)} = [CCNR]_{(AG)(C19)} + [CCNR]_{(AG)(C20)}$$

$$[CCCN]_{(AG)} = [CCCN]_{(AG)(C20)}$$

$$[CCNN]_{(AG)} = [CCNN]_{(AG)(C20)}$$

$$[CNNN]_{(AG)} = [CNNN]_{(AG)(C20)}$$

3.4. General Equation Format

The waste flow equations presented here are written using the following format. For each unit process option, a table is used to summarize and present the potential mass flow through that option. Each waste stream set that could enter that option is shown in the first row of that table. The second row shows all the potential process options from where those waste stream sets can come. The third row shows all the potential process options to which these waste stream sets can flow after leaving the current process option. For example, Table 3.1 shows that waste components in waste stream sets RCCR, RCNR and RNNR (WS1) can enter the collection option C5 from the generation node, and flow out to process options TR3 and S4. Also, waste stream sets RYTL, RYTO, RCCN, RCNN and RNNN (WS2) can flow in from the generation node and flow out to TR3 and S4 options.

Table 3. 1: Sample Table: Mass flow through collection option C5

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}	WS2 = {RYTL, RYTO, RCCN, RCNN, RNNN}
Origin nodes	Generation: G	Generation: G
Potential destination nodes	TR3, S4 (in black and blue bags)	TR3, S4 (in black bags)

The corresponding mass flow equations for this process option (C5) are written as follows. Each set of equations relates the amount of waste component in a waste stream entering and leaving that option. For example, the mass balance corresponding to the second column in Table 3.1 is

$$[WS1]_{(AG)\,(C5)} = [WS1]_{(C5)\,(TR3)} + [WS1]_{(C5)\,(S4)}$$

where the left-hand side of the equation represents the amount of each waste stream set included in WS_1 entering collection option C5 from the generation node, and the right-hand side represents the sum of amounts flowing out to options TR3 and S4. This equation set is applicable to each member of WS1, i.e., waste stream sets RCCR, RCNR and RNNR. Therefore, the term WS1 in that equation set may be replaced by the sets RCCR, RCNR or RNNR. For example, for waste stream set RCCR, this equation will become

$$[RCCR]_{(AG)\,(C5)} = [RCCR]_{(C5)\,(TR3)} + [RCCR]_{(C5)\,(S4)}$$

and this equation is applicable to each waste component in the waste stream set RCCR.

3.5. Collection nodes

There are 21 different collection options in the SWM system: 13 for residential sectors, 6 for multi-family sectors and 2 for commercial sectors. For each one of these collection nodes, a mass flow diagram with its attached table has been established in the 'Mass Flow Diagrams' document (Appendix C). Every collection option collects a specific type or types of wastes and transports them to different destinations. The equations represent the total mass of waste collected by a collection option and delivered to a set of feasible destinations. In some equations, the fraction CPR (the collection participation rate) is used to adjust the mass of a particular waste component actually set out for collection by a certain collection option. Where CPR is not incorporated, it is assumed to take a value of one. Also, in some equations the fraction CEFF is incorporated to represent the fraction of a recyclable item properly separated by the household participating in a collection option. The mass flow equations for all collection options are presented in the following sections.

3.5.1. Collection of yard waste from residential sectors for aerobic composting (C0)

Table 3. 2: Mass flow through collection option C0

Waste stream sets (WS)	WS1 = {RYTL, RYTO}
Origin nodes	Generation
Potential destination nodes	T1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C0)} * CPR_{(C0)} = [WS1]_{(C0)(T1)} + [WS1]_{(C0)(T3)} + [WS1]_{(C0)(T5)} + [WS1]_{(C0)(T7)} + [WS1]_{(C0)(T8)} + [WS1]_{(C0)(D1)} + [WS1]_{(C0)(D3)}$$

$[WS1]_{(AG)(C0)} * CPR_{(C0)}$ represents the amount of waste actually collected by the collection option C0. The coefficient $CPR_{(C0)}$ represents the participation rate factor for C0 (see section 3.2.8).

3.5.2. Collection of mixed MSW from residential sectors in a single compartment truck (C1)

Table 3. 3: Mass flow through collection option C1

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}
Origin nodes	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C1)} = [WS1]_{(C1)(TR1)} + [WS1]_{(C1)(RT1)} + [WS1]_{(C1)(S1)} + [WS1]_{(C1)(T3)} + [WS1]_{(C1)(T5)} + [WS1]_{(C1)(T7)} + [WS1]_{(C1)(T8)} + [WS1]_{(C1)(D1)} + [WS1]_{(C1)(D3)}$$

3.5.3. Collection of residential commingled recyclables sorted at point of collection by the crew (C2)

Table 3. 4: Mass flow through collection option C2

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}
Origin nodes	Generation
Potential destination nodes	TR5, S2 (sorted by the crew)

Mass flow equations:

$$[WS1]_{(AG)(C2)} * CPR_{(C2)} * CEFF_{(WS1, C2)} = [WS1]_{(C2)(TR5)} + [WS1]_{(C2)(S2)}$$

$[WS1]_{(AG)(C2)} * CPR_{(C2)} * CEFF_{(WS1, C2)}$ represents the amount of waste actually collected by the collection option C2. The coefficient $CPR_{(C2)}$ represents the participation rate factor for C2 and the coefficient $CEFF_{(WS1)(C2)}$ represents the collection efficiency for C2 and WS1 (see section 3.2.8).

3.5.4. Collection of residential pre-sorted recyclables (C3)

Table 3. 5: Mass flow through collection option C3

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}
Origin nodes	Generation
Potential destination nodes	TR5, S2 (pre-sorted)

Mass flow equations:

$$[WS1]_{(AG)\,(C3)} \;*\; CPR_{(C3)} * CEFF_{(WS1,\,C3)} \;=\; [WS1]_{(C3)\,(TR5)} + [WS1]_{(C3)\,(S2)}$$

$[WS1]_{(AG)\,(C3)} * CPR_{(C3)} * CEFF_{(WS1,\,C3)}$ represents the amount of waste actually collected by the collection option C3. The coefficient $CPR_{(C3)}$ represents the participation rate factor for C3 and the coefficient $CEFF_{(WS1,\,C3)}$ represents the collection efficiency for C3 and WS1 (see section 3.2.8).

3.5.5. Collection of residential commingled recyclables sorted at a MRF (C4)

Table 3. 6: Mass flow through collection option C4

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}
Origin nodes	Generation
Potential destination nodes	TR2, S3 (commingled)

Mass flow equations:

$$[WS1]_{(AG)\,(C4)} \;*\; CPR_{(C4)} * CEFF_{(WS1,\,C4)} \;=\; [WS1]_{(C4)\,(TR2)} + [WS1]_{(C4)\,(S3)}$$

$[WS1]_{(AG)\,(C4)} * CPR_{(C4)} * CEFF_{(WS1,\,C4)}$ represents the amount of waste actually collected by the collection option C4. The coefficient $CPR_{(C4)}$ represents the participation rate factor for C4 and the coefficient $CEFF_{(WS1,\,C4)}$ represents the collection efficiency for C4 and WS1 (see section 3.2.8).

3.5.6. Collection of residential commingled recyclables and MSW in one single compartment truck, with newspaper in a separate compartment (C5)

Table 3. 7: Mass flow through collection option C5

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}	WS2 = {RYTL, RYTO, RCCN, RCNN, RNNN}
Origin nodes	Generation	Generation
Potential destination nodes	TR3, S4 (in both black and blue bags) (1)	TR3, S4 (in black bags) (2)

(1) The recyclable bags will never contain non-recyclable items.
(2) Black bags are unloaded at S4 and then flow out of S4 as is.

Mass flow equations:

$$[WS1]_{(AG)\,(C5)} = [WS1]_{(C5)\,(TR3)} + [WS1]_{(C5)\,(S4)}$$

where:

$$[WS1]_{(AG)\,(C5)} = [WS1(blue)]_{(AG)\,(C5)} + [WS1(black)]_{(AG)\,(C5)}$$

The amounts of recyclables in each bag are determined based on the collection participation rate (CPR) and the collection efficiency (CEFF) as follows:

$$[WS1(blue)]_{(AG)\,(C5)} = [WS1]_{(AG)\,(C5)} * CPR_{(C5)} * CEFF_{(WS1,\,C5)}$$

$$[WS1(black)]_{(AG)\,(C5)} = [WS1]_{(AG)\,(C5)} * (1 - CPR_{(C5)}) + [WS1]_{(AG)\,(C5)} * CPR_{(C5)} * (1 - CEFF_{(WS1,\,C5)})$$

The term $[WS1(blue)]_{(AG)\,(C5)}$ represents the recyclable waste components in the blue bags and the term $[WS1(black)]_{(AG)\,(C5)}$ represents the recyclable waste components in the black bags.

$$[WS2]_{(AG)\,(C5)} = [WS2]_{(C5)\,(TR3)} + [WS2]_{(C5)\,(S4)}$$

3.5.7. Collection of residential commingled recyclables and MSW in a double compartment truck, with newspaper in a separate compartment (C6)

Table 3. 8: Mass flow through collection option C6

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}	WS2 = {RYTL, RYTO, RCCN, RCNN, RNNN}
Origin nodes	Generation	Generation
Potential destination nodes	TR4, S5 (in both black and blue bags) (1)	TR4, S5 (in black bags) (2)

(1) The recyclable bags will never contain non-recyclable items.
(2) Black bags stay on the truck and will not be unloaded at S5.

Mass flow equations:

$$[WS1]_{(AG)(C6)} = [WS1]_{(C6)(TR4)} + [WS1]_{(C6)(S5)}$$

where:

$$[WS1]_{(AG)(C6)} = [WS1\ (blue)]_{(AG)(C6)} + [WS1\ (black)]_{(AG)(C6)}$$

The amounts of recyclables in each bag are determined based on the collection participation rate (CPR) and the collection efficiency (CEFF) as follows:

$$[WS1(blue)]_{(AG)(C6)} = [WS1]_{(AG)(C5)} * CPR_{(C6)} * CEFF_{(WS1,\ C6)}$$

$$[WS1(black)]_{(AG)(C6)} = [WS1]_{(AG)(C6)} * (1 - CPR_{(C6)}) + [WS1]_{(AG)(C6)} * CPR_{(C6)} * (1 - CEFF_{(WS1,\ C6)})$$

The term $[WS1(blue)]_{(AG)(C6)}$ represents the recyclable waste components in the blue bags and the term $[WS1(black)]_{(AG)(C6)}$ represents the recyclable waste components in the black bags.

$$[WS2]_{(AG)(C6)} = [WS2]_{(C6)(TR4)} + [WS2]_{(C6)(S5)}$$

3.5.8. Collection of residential mixed MSW after removal of recyclables (C7)

Table 3. 9: Mass flow through collection option C7

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}
Origin nodes	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C7)} = [WS1]_{(C7)(TR1)} + [WS1]_{(C7)(RT1)} + [WS1]_{(C7)(S1)} + [WS1]_{(C7)(T3)} + [WS1]_{(C7)(T5)} + [WS1]_{(C7)(T7)} + [WS1]_{(C7)(T8)} + [WS1]_{(C7)(D1)} + [WS1]_{(C7)(D3)}$$

3.5.9. Recyclables drop-off from residential and multi-family sectors (C8)

Table 3. 10: Mass flow through collection option C8

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}	WS2 = {MCCR, MCNR, MNNR}
Origin nodes	Generation	Generation
Potential destination nodes	TR5, S2 (pre-sorted)	TR5, S2 (pre-sorted)

Mass flow equations:

$$[WS1]_{(AG)(C8)} * CPR_{(C8)} = [WS1]_{(C8)(TR5)} + [WS1]_{(C8)(S2)}$$

$$[WS2]_{(AG)(C8)} * CPR_{(C8)} = [WS2]_{(C8)(TR5)} + [WS2]_{(C8)(S2)}$$

$[WS1]_{(AG)(C8)} * CPR_{(C8)}$ and $[WS2]_{(AG)(C8)} * CPR_{(C8)}$ represent the amount of waste actually collected by the collection option C8 in the residential and multi-family sectors respectively. The coefficient $CPR_{(C8)}$ represents the participation rate factor for C8 (see section 3.2.8).

3.5.10. Leaf collection from residential sectors in a vacuum truck (C9)

Table 3. 11: Mass flow through collection option C9

Waste stream sets (WS)	WS 1 = {RYTL}
Origin nodes	Generation
Potential destination nodes	T1, T3, T5, T7, T8, D1, D3, FUEL

Mass flow equations:

$$[WS1]_{(AG)\,(C9)} = [WS1]_{(C9)\,(T1)} + [WS1]_{(C9)\,(T3)} + [WS1]_{(C9)\,(T5)} + [WS1]_{(C9)\,(T7)} + [WS1]_{(C9)\,(T8)} + [WS1]_{(C9)\,(D1)} + [WS1]_{(C9)\,(D3)} + [WS1]_{(C9)\,FUEL}$$

3.5.11. Yard trimmings drop-off from residential sectors (C10)

Table 3. 12: Mass flow through collection option C10

Waste stream sets (WS)	WS 1 = {RYTL, RYTO}
Origin nodes	Generation
Potential destination nodes	T1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)\,(C10)} * CPR_{(C10)} = [WS1]_{(C10)\,(T1)} + [WS1]_{(C10)\,(T3)} + [WS1]_{(C10)\,(T5)} + [WS1]_{(C10)\,(T7)} + [WS1]_{(C10)\,(T8)} + [WS1]_{(C10)\,(D1)} + [WS1]_{(C10)\,(D3)}$$

$[WS1]_{(AG)\,(C10)} * CPR_{(C10)}$ represents the amount of waste actually collected by the collection option C10. The coefficient $CPR_{(C10)}$ represents the participation rate factor for C10 (see section 3.2.8).

3.5.12. Wet/dry/commingled recyclables collection in separate compartments from residential sectors (C11)

All waste components may be collected by this collection option. However, the user can specify the fraction of each item that is allowed to go in each of the three different compartments. A simplified equation below describes the allocation:

Total amount of waste component w collected by C11 =
amount of waste component w in wet compartment +
amount of waste component w in dry compartment +
amount of waste component w in recyclable compartment

where

amount of waste component w in wet compartment =
$F_{wet,\ C11,\ w}$ * (Total amount of waste component w collected by C11)

amount of waste component w in dry compartment =
$F_{dry,\ C11,\ w}$ * (Total amount of waste component w collected by C11)

amount of waste component w in recyclable compartment =
$F_{rec,\ C11,\ w}$ * (Total amount of waste component w collected by C11)

The user defined fractions $F_{wet,\ C11,\ w}$, $F_{dry,\ C11,\ w}$, $F_{rec,\ C11,\ w}$ are set such that

$$F_{wet,\ C11,\ w} + F_{dry,\ C11,\ w} + F_{rec,\ C11,\ w} = 1.$$

Certain waste components will be blocked from entering a particular compartment. For instance, food waste will not be allowed in the dry compartment and that fraction will be forced to zero.

Table 3. 13: Mass flow through collection option C11

Waste stream sets (WS)	Wet compartment: WS1 = {RYTL, RYTO, RCNR, RCCN}	Dry compartment: WS2 = {RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}	Recyclables compartment: WS3 = {RCCR, RCNR, RNNR}
Origin nodes	Generation	Generation	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, TR2, RT1, S1, S3, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)\,(C11)} = [WS1]_{(C11)\,(TR1)} + [WS1]_{(C11)\,(RT1)} + [WS1]_{(C11)\,(S1)} + [WS1]_{(C11)\,(T3)} + [WS1]_{(C11)\,(T5)} + [WS1]_{(C11)\,(T7)} + [WS1]_{(C11)\,(T8)} + [WS1]_{(C11)\,(D1)} + [WS1]_{(C11)\,(D3)}$$

$$[WS2]_{(AG)\,(C11)} = [WS2]_{(C11)\,(TR1)} + [WS2]_{(C11)\,(RT1)} + [WS2]_{(C11)\,(S1)} + [WS2]_{(C11)\,(T3)} + [WS2]_{(C11)\,(T5)} + [WS2]_{(C11)\,(T7)} + [WS2]_{(C11)\,(T8)} + [WS2]_{(C11)\,(D1)} + [WS2]_{(C11)\,(D3)}$$

$$[WS3]_{(AG)\,(C11)} = [WS3]_{(C11)\,(TR1)} + [WS3]_{(C11)\,(TR2)} + [WS3]_{(C11)\,(RT1)} + [WS3]_{(C11)\,(S1)} + [WS3]_{(C11)\,(S3)} + [WS3]_{(C11)\,(T3)} + [WS3]_{(C11)\,(T5)} + [WS3]_{(C11)\,(T7)} + [WS3]_{(C11)\,(T8)} + [WS3]_{(C11)\,(D1)} + [WS3]_{(C11)\,(D3)}$$

It would be desirable to send the wet fraction to T7, T8 or D3; the dry fraction to RT1, TR1, S1, T3, T5, T7, D1 or D3; and the recyclables to TR2, S3 or T5. However, the equations are written to represent all potential flow paths available for each set of components.

3.5.13. Wet/dry collection from residential sectors in separate compartments with commingled recyclables collected via C2, C3 or C4 (C12)

All residential waste components may be collected by this collection option. However, the user can specify the fraction of each item that is allowed to go in each of the two different compartments. The following simplified equation describes the allocation:

Total amount of waste component w collected by C12 =
amount of waste component w in wet compartment +
amount of waste component w in dry compartment

where

amount of waste component w in wet compartment =
$F_{wet, C12, w}$ * (Total amount of waste component w collected by C12)

amount of waste component w in dry compartment =
$F_{dry, C12, w}$ * (Total amount of waste component w collected by C12)

The user defined fractions $F_{wet, C12, w}$, $F_{dry, C12, w}$ are set such that

$$F_{wet, C12, w} + F_{dry, C12, w} = 1.$$

Certain waste components will be blocked from entering a particular compartment. For instance, food waste will not be allowed in the dry compartment and that fraction will be set to zero.

Table 3. 14: Mass flow through collection option C12

Waste stream sets (WS)	Wet compartment: WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}	Dry compartment: WS2 = {RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}
Origin nodes	Generation	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C12)} = [WS1]_{(C12)(TR1)} + [WS1]_{(C12)(RT1)} + [WS1]_{(C12)(S1)} + [WS1]_{(C12)(T3)} + [WS1]_{(C12)(T5)} + [WS1]_{(C12)(T7)} + [WS1]_{(C12)(T8)} + [WS1]_{(C12)(D1)} + [WS1]_{(C12)(D3)}$$

$$[WS2]_{(AG)(C12)} = [WS2]_{(C12)(TR1)} + [WS2]_{(C12)(RT1)} + [WS2]_{(C12)(S1)} + [WS2]_{(C12)(T3)} + [WS2]_{(C12)(T5)} + [WS2]_{(C12)(T7)} + [WS2]_{(C12)(T8)} + [WS2]_{(C12)(D1)} + [WS2]_{(C12)(D3)}$$

It would be desirable to send the wet fraction to T7, T8 or D3; and the dry fraction to RT1, TR1, S1, T3, T5, T7, D1 or D3. However, the equations are written to represent all potential flow paths available for each set of components.

3.5.14. Collection of mixed MSW from multi-family sectors where containerized collection is required in a single compartment truck (hauled or stationary container) (C13)

Table 3. 15: Mass flow through collection option C13

Waste stream sets (WS)	WS 1 = {MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}
Origin nodes	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)\,(C13)} = [WS1]_{(C13)\,(TR1)} + [WS1]_{(C13)\,(RT1)} + [WS1]_{(C13)\,(S1)} + [WS1]_{(C13)\,(T3)} + [WS1]_{(C13)\,(T5)} + [WS1]_{(C13)\,(T7)} + [WS1]_{(C13)\,(T8)} + [WS1]_{(C13)\,(D1)} + [WS1]_{(C13)\,(D3)}$$

3.5.15. Collection of pre-sorted recyclables in container quantities from multi-family sectors (multi-compartment bin) (C14)

Table 3. 16: Mass flow through collection option C14

Waste stream sets (WS)	WS 1= {MCCR, MCNR, MNNR}
Origin nodes	Generation
Potential destination nodes	TR5, S2 (pre-sorted)

Mass flow equations:

$$[WS1]_{(AG)\,(C14)} * CPR_{(C14)} * CEFF_{(WS1,\,C14)} = [WS1]_{(C14)\,(TR5)} + [WS1]_{(C14)\,(S2)}$$

$[WS1]_{(AG)\,(C14)} * CPR_{(C14)} * CEFF_{(WS1,\,C14)}$ represents the amount of waste actually collected by the collection option C14. The coefficient $CPR_{(C14)}$ represents the participation rate factor for C14 and the coefficient $CEFF_{(WS1,\,C14)}$ represents the collection efficiency for C14 and WS1 (see section 3.2.8).

3.5.16. Collection of commingled recyclables in container quantities from multi-family sectors, in two compartments, with newspaper in a separate compartment (C15)

Table 3. 17: Mass flow through collection option C15

Waste stream sets (WS)	WS1 = {MCCR, MCNR, MNNR}
Origin nodes	Generation
Potential destination nodes	TR2, S3 (commingled)

Mass flow equations:

$$[WS1]_{(AG)(C15)} * CPR_{(C15)} * CEFF_{(WS1, C15)} = [WS1]_{(C15)(TR2)} + [WS1]_{(C15)(S3)}$$

$[WS1]_{(AG)(C15)} * CPR_{(C15)} * CEFF_{(WS1, C15)}$ represents the amount of waste actually collected by the collection option C15. The coefficient $CPR_{(C15)}$ represents the participation rate factor for C15 and the coefficient $CEFF_{(WS1, C15)}$ represents the collection efficiency for C15 and WS1 (see section 3.2.8).

3.5.17. Collection of MSW from multi-family dwellings where containerized collection is required after removal of recyclables via C14 or C15 (hauled or stationary) (C16)

Table 3. 18: Mass flow through collection option C16

Waste stream sets (WS)	WS1 = {MYTL, MYTO, MCCN, MCNN, MNNN}	WS2 = {MCCR, MCNR, MNNR}
Origin nodes	Generation	Generation: residuals from C14 and C15
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C16)} = [WS1]_{(C16)(TR1)} + [WS1]_{(C16)(RT1)} + [WS1]_{(C16)(S1)} + [WS1]_{(C16)(T3)} + [WS1]_{(C16)(T5)} + [WS1]_{(C16)(T7)} + [WS1]_{(C16)(T8)} + [WS1]_{(C16)(D1)} + [WS1]_{(C16)(D3)}$$

$$[WS2]_{(AG)(C16)} = [WS2]_{(C16)(TR1)} + [WS2]_{(C16)(RT1)} + [WS2]_{(C16)(S1)} + [WS2]_{(C16)(T3)} + [WS2]_{(C16)(T5)} + [WS21]_{(C16)(T7)} + [WS2]_{(C16)(T8)} + [WS2]_{(C16)(D1)} + [WS2]_{(C16)(D3)}$$

3.5.18. Multi-family wet/dry/commingled recyclables collection in separate compartments (C17)

All multi-family waste components may be collected by this collection option. However, the user can specify the fraction of each item that is allowed to go in each of the three different compartments. A simplified equation below describes the allocation:

Total amount of waste component w collected by C17 =
amount of waste component w in wet compartment +
amount of waste component w in dry compartment +
amount of waste component w in recyclable compartment

where

amount of waste component w in wet compartment =
$F_{wet, C17, w}$ * (Total amount of waste component w collected by C17)

amount of waste component w in dry compartment =
$F_{dry, C17, w}$ * (Total amount of waste component w collected by C17)

amount of waste component w in recyclable compartment =
$F_{rec, C17, w}$ * (Total amount of waste component w collected by C17)

The user defined fractions $F_{wet, C17, w}$, $F_{dry, C17, w}$, $F_{rec, C17, w}$ are set such that

$$F_{wet, C17, w} + F_{dry, C17, w} + F_{rec, C17, w} = 1.$$

Certain waste components will be blocked from entering a particular compartment. For instance, food waste will not be allowed in the dry compartment and that fraction will be set to zero.

Table 3. 19: Mass flow through collection option C17

Waste stream sets (WS)	Waste sets in the wet compartment: WS1 = {MYTL, MYTO, MCNR, MCCN}	Waste sets in the dry compartment: WS2 = {MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}	Waste sets in the recyclables compartment: WS3 = {MCCR, MCNR, MNNR}
Origin nodes	Generation	Generation	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, TR2, RT1, S1, S3, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C17)} = [WS1]_{(C17)(TR1)} + [WS1]_{(C17)(RT1)} + [WS1]_{(C17)(S1)} + [WS1]_{(C17)(T3)} + [WS1]_{(C17)(T5)} + [WS1]_{(C17)(T7)} + [WS1]_{(C17)(T8)} + [WS1]_{(C17)(D1)} + [WS1]_{(C17)(D3)}$$

$$[WS2]_{(AG)(C17)} = [WS2]_{(C17)(TR1)} + [WS2]_{(C17)(RT1)} + [WS2]_{(C17)(S1)} + [WS2]_{(C17)(T3)} + [WS2]_{(C17)(T5)} + [WS2]_{(C17)(T7)} + [WS2]_{(C17)(T8)} + [WS2]_{(C17)(D1)} + [WS2]_{(C17)(D3)}$$

$$[WS3]_{(AG)(C17)} = [WS3]_{(C17)(TR1)} + [WS3]_{(C17)(TR2)} + [WS3]_{(C17)(RT1)} + [WS3]_{(C17)(S1)} + [WS3]_{(C17)(S3)} + [WS3]_{(C17)(T3)} + [WS3]_{(C17)(T5)} + [WS3]_{(C17)(T7)} + [WS3]_{(C17)(T8)} + [WS3]_{(C17)(D1)} + [WS3]_{(C17)(D3)}$$

It would be desirable to send the wet fraction to T7, T8 or D3; the dry fraction to RT1, TR1, S1, T3, T5, T7, D1 or D3; and the recyclables to TR2, S3 or T5. However, the equations are written to represent all potential flow paths available for each set of components.

3.5.19. Multi-family wet/dry collection in separate compartments with commingled recyclables collected via C14 or C15 (C18)

This collection option collects the residual mass after removal of recyclables in collection options C14 and C15. All multi-family waste components may be collected by this collection option. However, the user can specify the fraction of each item that is allowed to go in each of the two different compartments. A simplified equation below describes the allocation:

Total amount of waste component w collected by C18 =
amount of waste component w in wet compartment +
amount of waste component w in dry compartment

where

amount of waste component w in wet compartment =
$F_{wet, C18, w}$ * (Total amount of waste component w collected by C18)

amount of waste component w in dry compartment =
$F_{dry, C18, w}$ * (Total amount of waste component w collected by C18)

The user defined fractions $F_{wet, C18, w}$, $F_{dry, C18, w}$ are set such that

$$F_{wet, C18, w} + F_{dry, C18, w} = 1.$$

Certain waste components will be blocked from entering a particular compartment. For instance, food waste will not be allowed in the dry compartment and that fraction will be set to zero.

Table 3. 20: Mass flow through collection option C18

Waste stream sets (WS)	Waste stream sets in wet compartment: WS1 = {MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}	Waste stream sets in dry compartment: WS2 = {MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}
Origin nodes	Generation	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)(C18)} = [WS1]_{(C18)(TR1)} + [WS1]_{(C18)(RT1)} + [WS1]_{(C18)(S1)} + [WS1]_{(C18)(T3)} + [WS1]_{(C18)(T5)} + [WS1]_{(C18)(T7)} + [WS1]_{(C18)(T8)} + [WS1]_{(C18)(D1)} + [WS1]_{(C18)(D3)}$$

$$[WS2]_{(AG)(C18)} = [WS2]_{(C18)(TR1)} + [WS2]_{(C18)(RT1)} + [WS2]_{(C18)(S1)} + [WS2]_{(C18)(T3)} + [WS2]_{(C18)(T5)} + [WS2]_{(C18)(T7)} + [WS2]_{(C18)(T8)} + [WS2]_{(C18)(D1)} + [WS2]_{(C18)(D3)}$$

It would be desirable to send the wet fraction to T7, T8 or D3; and the dry fraction to RT1, TR1, S1, T3, T5, T7, D1 or D3. However, the equations are written to represent all potential flow paths available for each set of components.

3.5.20. Collection of pre-sorted commercial recyclables (C19)

Table 3. 21: Mass flow through collection option C19

Waste stream sets (WS)	WS1 = {CCCR, CCNR, CNNR}
Origin nodes	Generation
Potential destination nodes	TR5, S2 (pre-sorted)

Mass flow equations:

$$[WS1]_{(AG)\,(C19)} * CPR_{(C19)} * CEFF_{(WS1,\,C19)} = [WS1]_{(C19)\,(TR5)} + [WS1]_{(C19)\,(S2)}$$

$[WS1]_{(AG)\,(C19)} * CPR_{(C19)} * CEFF_{(WS1,\,C19)}$ represents the amount of waste actually collected by the collection option C19. The coefficient $CPR_{(C19)}$ represents the participation rate factor for C19 and the fraction $CEFF_{(WS1,\,C19)}$ represents the collection efficiency for C19 and WS1 (see section 3.2.8).

3.5.21. Collection of containerized commercial waste before or after removal of recyclables (C20)

Table 3. 22: Mass flow through collection option C20

Waste stream sets (WS)	WS1 = {CCCR, CCNR, CNNR}	WS2 = {CCCN, CCNN, CNNN}
Origin nodes	Generation: residuals from C19 if selected or total generation	Generation
Potential destination nodes	TR1, RT1, S1, T3, T5, T7, T8, D1, D3	TR1, RT1, S1, T3, T5, T7, T8, D1, D3

Mass flow equations:

$$[WS1]_{(AG)\,(C20)} = [WS1]_{(C20)\,(TR1)} + [WS1]_{(C20)\,(RT1)} + [WS1]_{(C20)\,(S1)} + [WS1]_{(C20)\,(T3)} + [WS1]_{(C20)\,(T5)} + [WS1]_{(C20)\,(T7)} + [WS1]_{(C20)\,(T8)} + [WS1]_{(C20)\,(D1)} + [WS1]_{(C20)\,(D3)}$$

$$[WS2]_{(AG)\,(C20)} = [WS2]_{(C20)\,(TR1)} + [WS2]_{(C20)\,(RT1)} + [WS2]_{(C20)\,(S1)} + [WS2]_{(C20)\,(T3)} + [WS2]_{(C20)\,(T5)} + [WS2]_{(C20)\,(T7)} + [WS2]_{(C20)\,(T8)} + [WS2]_{(C20)\,(D1)} + [WS2]_{(C20)\,(D3)}$$

3.5.22. Collection of residuals

All collection options dedicated for recyclables collection may not capture all of the recyclable waste generated. The residual amount will depend on the level of participation (represented by the collection participation factor, CPR) by the people in each sector and the collection efficiency (CEFF) that represents how well the material is separated and set out by those who participate. For example, a participation factor of $CPR_{(C2)} = 0.9$ means that 90 % of the people covered by the collection option C2 will presort the recyclables and set out in appropriate bins. The remaining 10% of the people will throw their recyclables with the mixed waste. Further, a collection efficiency of $CEFF_{(RCCR,\ C2)} = 0.7$ means that all the people who participate in the collection option C2 will properly separate the waste components in the set RCCR with the mixed waste only 70% of the time, i.e., they will mistakenly throw away 30% of the recyclables in the set RCCR with the mixed waste.

Several mixed waste collection options to be used in conjunction with the different recyclables collection options are defined. These collection options are similar to the MSW collection option C1, but will collect only the residual MSW after removal of recyclables by another collection option. In the residential sector, the residual waste can be collected by options C7 and C12. Options C13 and C18 can collect the residual waste in the multi-family sector. The residual waste in the commercial sector can be collected by option C20.

The following expression represents the residual amount of a waste stream WS after collection by a dedicated recyclables or yardwaste collection option i:

$$[WS]_{(AG)\,(i)} * (1 - CPR_{(i)}) + [WS]_{(AG)\,(i)} * CPR_{(i)} * (1 - CEFF_{(WS,\,i)})$$

where i = {C0, C2, C3, C4, C8, C9, C10} for residential sectors
i = {C14, C15} for multi-family sectors
i = {C19} for commercial sectors.

The sum of these residual amounts will be collected by: collection options C7 and C12 for the residential sectors; collection options C16 and C18 for the multi family sectors; and C20 for the commercial sectors.

3.6. Transfer nodes

There are 8 transfer options: 5 transfer stations for road transportation (TR1, TR2, TR3, TR4 and TR5) and 3 for rail (RT1, RT2 and RT3). A transfer station receives waste from local collection and then prepares it for long haul to one of the potential destination nodes. Transfer stations TR1, TR2, TR3, TR4, TR5 and RT1 can receive waste from some of the collection options. Rail transfer stations RT2 and RT3 can only receive mass from RT1. In the transfer stations for road transportation, all materials are unloaded from the trucks at the transfer station, and then reloaded into bigger vehicles.

Transfer station TR3 receives waste from the collection option C5. The black bags that contain non-recyclable material and misdirected recyclables, and the blue bags with the recyclable material from collection option C5 are unloaded at this transfer station. The blue and black bags are then separated at the transfer station. All bags are loaded again in bigger vehicles. Similarly, transfer station TR4 receives waste from the collection option C6. The black bags that contain non-recyclable material and misdirected recyclables, and the blue bags with the recyclable material from collection option C6 are unloaded at this transfer station. The blue and black bags are already separated from the truck. Blue and black bags are reloaded into separate, bigger vehicles.

3.6.1. Transfer of mixed MSW (TR1)

Table 3. 23: Mass flow through transfer option TR1

Waste stream sets (WS)	Residential waste stream sets: WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}	Multi-family waste stream sets: WS2 = {MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}	Commercial waste stream sets: WS3 = {CCCR, CCNR, CNNR, CCCN, CCNN, CNNN}
Potential origin nodes	C1, C7; C11, C12 (1)	C13, C16; C17, C18 (1)	C20
Potential destination nodes	S1, T3, T5, D1, D3	S1, T3, T5, D1, D3	S1, T3, T5, D1, D3

(1) Enter in all compartments

Mass flow equations:

$$[WS1]_{(C1)\,(TR1)} + [WS1]_{(C7)\,(TR1)} + [WS1]_{(C11)\,(TR1)} + [WS1]_{(C12)\,(TR1)} = [WS1]_{(TR1)\,(S1)} + [WS1]_{(TR1)\,(T3)} + [WS1]_{(TR1)\,(T5)} + [WS1]_{(TR1)\,(D1)} + [WS1]_{(TR1)\,(D3)}$$

$$[WS2]_{(C13)\,(TR1)} + [WS2]_{(C16)\,(TR1)} + [WS2]_{(C17)\,(TR1)} + [WS2]_{(C18)\,(TR1)} = [WS2]_{(TR1)\,(S1)} + [WS2]_{(TR1)\,(T3)} + [WS2]_{(TR1)\,(T5)} + [WS2]_{(TR1)\,(D1)} + [WS2]_{(TR1)\,(D3)}$$

$[WS3]_{(C20)(TR1)} = [WS3]_{(TR1)(S1)} + [WS3]_{(TR1)(T3)} + [WS3]_{(TR1)(T5)} + [WS3]_{(TR1)(D1)} + [WS3]_{(TR1)(D3)}$

3.6.2. Transfer of commingled recyclables (not in bags) (TR2)

Table 3. 24: Mass flow through transfer option TR2

Waste stream sets (WS)	Residential waste stream sets: WS1 = {RCCR, RCNR, RNNR}	Multi-family waste stream sets: WS2 = {MCCR, MCNR, MNNR}
Potential origin nodes	C4; C11 (1)	C15; C17 (1)
Potential destination nodes	S3	S3

(1) Enter in recyclables compartment only.

Mass flow equations:

$[WS1]_{(C4)(TR2)} + [WS1]_{(C11)(TR2)} = [WS1]_{(TR2)(S3)}$

$[WS2]_{(C15)(TR2)} + [WS2]_{(C17)(TR2)} = [WS2]_{(TR2)(S3)}$

3.6.3. Transfer of MSW and sorted recyclables (in separate bags in a single compartment) (TR3)

Table 3. 25: Mass flow through transfer option TR3

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCN, RCNN, RNNN}	WS2 = {RCCR, RCNR, RNNR}
Potential origin nodes	C5 (1)	C5 (2)
Potential destination nodes	S4, T3, T5, T7, T8, D1, D3 (1)	S3 (3), S4 (4) T3, T5, T7, T8, D1, D3 (5)

(1) Enter and leave in black bags
(2) Enter in black and blue bags
(3) Leave only in blue bags
(4) Leave in both blue and black bags
(5) Leave only in black bags

Mass flow equations:

$[WS1]_{(C5)(TR3)} = [WS1]_{(TR3)(S4)} + [WS1]_{(TR3)(T3)} + [WS1]_{(TR3)(T5)} + [WS1]_{(TR3)(T7)} + [WS1]_{(TR3)(T8)} + [WS1]_{(TR3)(D1)} + [WS1]_{(TR3)(D3)}$

$[WS2]_{(C5)(TR3)} = [WS2]_{(TR3)(S3)} + [WS2]_{(TR3)(S4)} + [WS2]_{(TR3)(T3)} + [WS2]_{(TR3)(T5)} + [WS2]_{(TR3)(T7)} + [WS2]_{(TR3)(T8)} + [WS2]_{(TR3)(D1)} + [WS2]_{(TR3)(D3)}$

3.6.4. Transfer of MSW and sorted recyclables (in separate bags in separate compartments) (TR4)

Table 3. 26: Mass flow through transfer option TR4

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCN, RCNN, RNNN}	WS2 = {RCCR, RCNR, RNNR}
Potential origin nodes	C6 (1)	C6 (2)
Potential destination nodes	T3, T5, T7, T8, D1, D3 (1)	S3 (3); T3, T5, T7, T8, D1, D3 (4)

(1) Enter and leave in black bags
(2) Enter in black and blue bags
(3) Leave only in blue bags
(4) Leave only in black bags

Mass flow equations:

$$[WS1]_{(C6)\,(TR4)} = [WS1]_{(TR4)\,(T3)} + [WS1]_{(TR4)\,(T5)} + [WS1]_{(TR4)\,(T7)} + [WS1]_{(TR4)\,(T8)} + [WS1]_{(TR4)\,(D1)} + [WS1]_{(TR4)\,(D3)}$$

$$[WS1]_{(C6)\,(TR4)} = [WS1]_{(TR4)\,(S3)} + [WS1]_{(TR4)\,(T3)} + [WS1]_{(TR4)\,(T5)} + [WS1]_{(TR4)\,(T7)} + [WS1]_{(TR4)\,(T8)} + [WS1]_{(TR4)\,(D1)} + [WS1]_{(TR4)\,(D3)}$$

3.6.5. Pre-sorted recyclables transfer station (TR5)

Table 3. 27: Mass flow through transfer option TR5

Waste stream sets (WS)	WS1 = {RCCR, RCNR, RNNR}	WS2 = {MCCR, MCNR, MNNR}	WS3 = {CCCR, CCNR, CNNR}
Potential origin nodes	C2, C3, C8	C8, C14	C19
Potential destination nodes	S2	S2	S2

Mass flow equations:

$$[WS1]_{(C2)\,(TR5)} + [WS1]_{(C3)\,(TR5)} + [WS1]_{(C8)\,(TR5)} = [WS1]_{(TR5)\,(S2)}$$

$$[WS2]_{(C8)\,(TR5)} + [WS2]_{(C14)\,(TR5)} = [WS2]_{(TR5)\,(S2)}$$

$$[WS3]_{(C19)\,(TR5)} = [WS3]_{(TR5)\,(S2)}$$

3.6.6. Rail transfer of MSW from collection vehicles (RT1)

Table 3. 28: Mass flow through transfer option RT1

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN}	WS2 = {MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN}	WS3 = {CCCR, CCNR, CNNR, CCCN, CCNN, CNNN}
Potential origin nodes	C1, C7; C11, C12 [(1)]	C13, C16; C17, C18 [(1)]	C20
Potential destination nodes	RT2, RT3	RT2, RT3	RT2, RT3

(1) Enter inside any compartment

Mass flow equations:

$$[WS1]_{(C1)\,(RT1)} + [WS1]_{(C7)\,(RT1)} + [WS1]_{(C11)\,(RT1)} + [WS1]_{(C12)\,(RT1)} = [WS1]_{(RT1)\,(RT2)} + [WS1]_{(RT1)\,(RT3)}$$

$$[WS2]_{(C13)\,(RT1)} + [WS2]_{(C16)\,(RT1)} + [WS2]_{(C17)\,(RT1)} + [WS2]_{(C18)\,(RT1)} = [WS2]_{(RT1)\,(RT2)} + [WS2]_{(RT1)\,(RT3)}$$

$$[WS3]_{(C20)\,(RT1)} = [WS3]_{(RT1)\,(RT2)} + [WS3]_{(RT1)\,(RT3)}$$

3.6.7. Rail transfer of MSW from trains to haul vehicles at landfill D1 (RT2)

Table 3. 29: Mass flow through transfer option RT2

Waste stream sets (WS)	WS1 = { RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN, MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN, CCCR, CCNR, CNNR, CCCN, CCNN, CNNN }
Potential origin nodes	RT1
Potential destination nodes	D1

Mass flow equations:

$$[WS1]_{(RT1)\,(RT2)} = [WS1]_{(RT2)\,(D1)}$$

3.6.8. Rail transfer of MSW from trains to haul vehicles at landfill D3 (RT3)

Table 3. 30: Mass flow through transfer option RT3

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN, MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN, CCCR, CCNR, CNNR, CCCN, CCNN, CNNN }
Potential origin nodes	RT1
Potential destination nodes	D3

Mass flow equations:

$$[WS1]_{(RT1)\,(RT3)} = [WS1]_{(RT3)\,(D3)}$$

3.7. Separation nodes

There are 5 separation options: mixed refuse MRF (S1), pre-sorted recyclables MRF (S2), commingled recyclables MRF (S3), and co-collected waste MRF (S4 and S5). The fraction SE is used to indicate the material separation efficiency at the MRF. This fraction can take values from 0 to 1. For example, if the separation efficiency at MRF S1 for waste set RCNR is 90% ($SE_{(RCNR,S1)} = 0.9$), then the actual recovered amount is $SE_{(RCNR,\ S1)}$ * (total mass of [RCNR] entering S1). The resulting residuals generated during the sorting process at the S1 MRF are calculated as: (1 - $SE_{(RCNR,\ S1)}$ * (total mass of [RCNR] entering S1).

Separation option S1 can separate all recyclable materials from the three generation sectors: residential, multi-family and commercial. The S1 MRF residuals can potentially go to the combustion facility T3 or to the landfills D1 or D3. Separation option S2 does not generate any residuals during the sorting process. Separation option S3 can separate all recyclable materials from only two generation sectors: residential and multi-family sectors. The residuals at this facility consist mostly of broken glass. Very small amounts of residuals from other waste items are generated. These residuals are calculated as a percentage of the incoming mass to the MRF. The users have to input only one value for the separation efficiency of glass and another for the separation efficiencies of all other waste items sorted at the S3. The S3 MRF residuals can potentially go to the landfills D1 and D3.

The separation options S4 and S5 can separate recyclables from only the residential sectors. The recyclables entering in the blue bags are sorted at this facility. The residuals handling is similar as in the S3 MRF. Residuals from the sorting process can go to the landfills D1 and D3.

3.7.1. Sorting of mixed refuse MRF (S1)

Table 3. 31: Mass flow through separation option S1

Waste stream sets (WS)	WS1 = {RYTL, RYTO}	WS2 = {RCCR, RCNR}	WS3 = {RNNR}	WS4 = {RCCN, RCNN}	WS5 = {RNNN}
Potential origin nodes	C11, C12 (1); C1, C7, TR1	C11, C12 (1); C1, C7, TR1	C11, C12 (1); C1, C7, TR1	C11, C12 (1); C1, C7, TR1	C11, C12 (1); C1, C7, TR1
Potential destination nodes	T3, D1, D3 as residuals	FUEL, RECY; T3, D1, D3 as residuals	RECY; T3, D1, D3 as residuals	FUEL; T3, D1, D3 as residuals	T3, D1, D3 as residuals

(1) Enter in any compartment

Mass flow equations:

$$[WS1]_{(C1)(S1)} + [WS1]_{(C7)(S1)} + [WS1]_{(C11)(S1)} + [WS1]_{(C12)(S1)} + [WS1]_{(TR1)(S1)} = [WS1]_{(S1)(T3)} + [WS1]_{(S1)(D1)} + [WS1]_{(S1)(D3)}$$

$$[WS2]_{(C1)(S1)} + [WS2]_{(C7)(S1)} + [WS2]_{(C11)(S1)} + [WS2]_{(C12)(S1)} + [WS2]_{(TR1)(S1)} = [WS2]_{(S1)\ FUEL} + [WS2]_{(S1)\ REC} + [WS2]_{(S1)(T3)} + [WS2]_{(S1)(D1)} + [WS2]_{(S1)(D3)}$$

where:

$$[WS2]_{(S1)\ FUEL} + [WS2]_{(S1)\ REC} = SE_{(WS2,S1)} * ([WS2]_{(C1)(S1)} + [WS2]_{(C7)(S1)} + [WS2]_{(C11)(S1)} + [WS2]_{(C12)(S1)} + [WS2]_{(TR1)(S1)})$$

and:

$$[WS2]_{(S1)(T3)} + [WS2]_{(S1)(D1)} + [WS2]_{(S1)(D3)} = (1 - SE_{(WS2,S1)}) * ([WS2]_{(C1)(S1)} + [WS2]_{(C7)(S1)} + [WS2]_{(C11)(S1)} + [WS2]_{(C12)(S1)} + [WS2]_{(TR1)(S1)})$$

Note: The equations above state that part of the waste stream may be recovered as either recyclables or waste as fuel with a separation efficiency of SE at the facility. The residual waste stream may flow to the treatment or the disposal nodes.

$$[WS3]_{(C1)(S1)} + [WS3]_{(C7)(S1)} + [WS3]_{(C11)(S1)} + [WS3]_{(C12)(S1)} + [WS3]_{(TR1)(S1)} = [WS3]_{(S1)\ REC} + [WS3]_{(S1)(T3)} + [WS3]_{(S1)(D1)} + [WS3]_{(S1)(D3)}$$

where:

$$[WS3]_{(S1)\ REC} = SE_{(WS3,S1)} * ([WS3]_{(C1)(S1)} + [WS3]_{(C7)(S1)} + [WS3]_{(C11)(S1)} + [WS3]_{(C12)(S1)} + [WS3]_{(TR1)(S1)})$$

and:

$[WS3]_{(S1)(T3)} + [WS3]_{(S1)(D1)} + [WS3]_{(S1)(D3)} = (1 - SE_{(WS3,S1)}) * ([WS3]_{(C1)(S1)} + [WS3]_{(C7)(S1)} + [WS3]_{(C11)(S1)} + [WS3]_{(C12)(S1)} + [WS3]_{(TR1)(S1)})$

See note above.

$[WS4]_{(C1)(S1)} + [WS4]_{(C7)(S1)} + [WS4]_{(C11)(S1)} + [WS4]_{(C12)(S1)} + [WS4]_{(TR1)(S1)} = [WS4]_{(S1)\,FUEL} + [WS4]_{(S1)(T3)} + [WS4]_{(S1)(D1)} + [WS4]_{(S1)(D3)}$

where:

$[WS4]_{(S1)\,FUEL} = SE_{(WS4,S1)} * ([WS4]_{(C1)(S1)} + [WS4]_{(C7)(S1)} + [WS4]_{(C11)(S1)} + [WS4]_{(C12)(S1)} + [WS4]_{(TR1)(S1)})$

and:

$[WS4]_{(S1)(T3)} + [WS4]_{(S1)(D1)} + [WS4]_{(S1)(D3)} = (1 - SE_{(WS4,S1)}) * ([WS4]_{(C1)(S1)} + [WS4]_{(C7)(S1)} + [WS4]_{(C11)(S1)} + [WS4]_{(C12)(S1)} + [WS4]_{(TR1)(S1)})$

See note above.

$[WS5]_{(C1)(S1)} + [WS5]_{(C7)(S1)} + [WS5]_{(C11)(S1)} + [WS5]_{(C12)(S1)} + [WS5]_{(TR1)(S1)} = [WS5]_{(S1)(T3)} + [WS5]_{(S1)(D1)} + [WS5]_{(S1)(D3)}$

Table 3.31 (continued)

Waste stream sets (WS)	WS6 = {MYTL, MYTO}	WS7 = {MCCR, MCNR}	WS8 = {MNNR}	WS9 = {MCCN, MCNN}	WS10 = {MNNN}
Potential origin nodes	C17, C18 (1); C13, C16, TR1	C17, C18 (1); C13, C16, TR1	C17, C18 (1); C13, C16, TR1	C17, C18 (1); C13, C16, TR1	C17, C18 (1); C13, C16, TR1
Potential destination nodes	T3, D1, D3 as residuals	FUEL, RECY; T3, D1, D3 as residuals	RECY; T3, D1, D3 as residuals	FUEL; T3, D1, D3 as residuals	T3, D1, D3 as residuals

(1) Enter in any compartment

Mass flow equations:

$[WS6]_{(C13)(S1)} + [WS6]_{(C16)(S1)} + [WS6]_{(C17)(S1)} + [WS6]_{(C18)(S1)} + [WS6]_{(TR1)(S1)} = [WS6]_{(S1)(T3)} + [WS6]_{(S1)(D1)} + [WS6]_{(S1)(D3)}$

$[WS7]_{(C13)(S1)} + [WS7]_{(C16)(S1)} + [WS7]_{(C17)(S1)} + [WS7]_{(C18)(S1)} + [WS7]_{(TR1)(S1)} = [WS7]_{(S1)\,REC} + [WS7]_{(S1)\,FUEL} + [WS7]_{(S1)(T3)} + [WS7]_{(S1)(D1)} + [WS7]_{(S1)(D3)}$

where:

$[WS7]_{(S1)\,REC} + [WS7]_{(S1)\,FUEL} = SE_{(WS2,S1)} * ([WS7]_{(C13)(S1)} + [WS7]_{(C16)(S1)} + [WS7]_{(C17)(S1)} + [WS7]_{(C18)(S1)} + [WS7]_{(TR1)(S1)})$

and:

$[WS7]_{(S1)(T3)} + [WS7]_{(S1)(D1)} + [WS7]_{(S1)(D3)} = (1- SE_{(WS2,S1)}) * ([WS7]_{(C13)(S1)} + [WS7]_{(C16)(S1)} + [WS7]_{(C17)(S1)} + [WS7]_{(C18)(S1)} + [WS7]_{(TR1)(S1)})$

See note above.

$$[WS8]_{(C13)\,(S1)} + [WS8]_{(C16)\,(S1)} + [WS8]_{(C17)\,(S1)} + [WS8]_{(C18)\,(S1)} + [WS8]_{(TR1)\,(S1)} = [WS8]_{(S1)\ REC} + [WS8]_{(S1)\,(T3)} + [WS8]_{(S1)\,(D1)} + [WS8]_{(S1)\,(D3)}$$

where:

$$[WS8]_{(S1)\ REC} = SE_{(WS3,S1)} * ([WS8]_{(C13)\,(S1)} + [WS8]_{(C16)\,(S1)} + [WS8]_{(C17)\,(S1)} + [WS8]_{(C18)\,(S1)} + [WS8]_{(TR1)\,(S1)})$$

and:

$$[WS8]_{(S1)\,(T3)} + [WS8]_{(S1)\,(D1)} + [WS8]_{(S1)\,(D3)} = (1 - SE_{(WS3,S1)}) * ([WS8]_{(C13)\,(S1)} + [WS8]_{(C16)\,(S1)} + [WS8]_{(C17)\,(S1)} + [WS8]_{(C18)\,(S1)} + [WS8]_{(TR1)\,(S1)})$$

See note above.

$$[WS9]_{(C13)\,(S1)} + [WS9]_{(C16)\,(S1)} + [WS9]_{(C17)\,(S1)} + [WS9]_{(C18)\,(S1)} + [WS9]_{(TR1)\,(S1)} = [WS9]_{(S1)\ FUEL} + [WS9]_{(S1)\,(T3)} + [WS9]_{(S1)\,(D1)} + [WS9]_{(S1)\,(D3)}$$

where:

$$[WS9]_{(S1)\ FUEL} = SE_{(WS9,S1)} * ([WS9]_{(C13)\,(S1)} + [WS9]_{(C16)\,(S1)} + [WS9]_{(C17)\,(S1)} + [WS9]_{(C18)\,(S1)} + [WS9]_{(TR1)\,(S1)})$$

and:

$$[WS9]_{(S1)\,(T3)} + [WS9]_{(S1)\,(D1)} + [WS9]_{(S1)\,(D3)} = (1 - SE_{(WS9,S1)}) * ([WS9]_{(C13)\,(S1)} + [WS9]_{(C16)\,(S1)} + [WS9]_{(C17)\,(S1)} + [WS9]_{(C18)\,(S1)} + [WS9]_{(TR1)\,(S1)})$$

See note above.

$$[WS10]_{(C13)\,(S1)} + [WS10]_{(C16)\,(S1)} + [WS10]_{(C17)\,(S1)} + [WS10]_{(C18)\,(S1)} + [WS10]_{(TR1)\,(S1)} = [WS10]_{(S1)\,(T3)} + [WS10]_{(S1)\,(D1)} + [WS10]_{(S1)\,(D3)}$$

Table 3.31 (continued)

Waste stream sets (WS)	WS11 = {CCCR, CCNR}	WS12 = {CNNR}	WS13 = {CCCN, CCNN}	WS14 = {CNNN}
Potential origin nodes	C20, TR1	C20, TR1	C20, TR1	C20, TR1
Potential destination nodes	FUEL , RECY; T3, D1, D3 as residuals	RECY; T3, D1, D3 as residuals	FUEL; T3, D1, D3 as residuals	T3, D1, D3 as residuals

Mass flow equations:

$$[WS11]_{(C20)(S1)} + [WS11]_{(TR1)(S1)} = [WS11]_{(S1)\ REC} + [WS11]_{(S1)\ FUEL} + [WS11]_{(S1)(T3)} + [WS11]_{(S1)(D1)} + [WS11]_{(S1)(D3)}$$

where:

$$[WS11]_{(S1)\ REC} + [WS11]_{(S1)\ FUEL} = SE_{(WS11,\ S1)} * ([WS11]_{(C20)(S1)} + [WS11]_{(TR1)(S1)})$$

and:

$$[WS11]_{(S1)(T3)} + [WS11]_{(S1)(D1)} + [WS11]_{(S1)(D3)} = (1 - SE_{(WS11,\ S1)}) * ([WS11]_{(C20)(S1)} + [WS11]_{(TR1)(S1)})$$

See note above.

$$[WS12]_{(C20)(S1)} + [WS12]_{(TR1)(S1)} = [WS12]_{(S1)\ REC} + [WS12]_{(S1)(T3)} + [WS12]_{(S1)(D1)} + [WS12]_{(S1)(D3)}$$

where:

$$[WS12]_{(S1)\ REC} = SE_{(WS12,S1)} * ([WS12]_{(C20)(S1)} + [WS12]_{(TR1)(S1)})$$

and:

$$[WS12]_{(S1)(T3)} + [WS12]_{(S1)(D1)} + [WS12]_{(S1)(D3)} = (1 - SE_{(WS12,S1)}) * ([WS12]_{(C20)(S1)} + [WS12]_{(TR1)(S1)})$$

See note above.

$$[WS13]_{(C20)(S1)} + [WS13]_{(TR1)(S1)} = [WS13]_{(S1)\ FUEL} + [WS13]_{(S1)(T3)} + [WS13]_{(S1)(D1)} + [WS13]_{(S1)(D3)}$$

where:

$$[WS13]_{(S1)\ FUEL} = SE_{(WS13,S1)} * ([WS13]_{(C20)(S1)} + [WS13]_{(TR1)(S1)})$$

and:

$$[WS13]_{(S1)(T3)} + [WS13]_{(S1)(D1)} + [WS13]_{(S1)(D3)} = (1 - SE_{(WS13,S1)}) * ([WS13]_{(C20)(S1)} + [WS13]_{(TR1)(S1)})$$

See note above.

$$[WS14]_{(C20)(S1)} + [WS14]_{(TR1)(S1)} = [WS14]_{(S1)(T3)} + [WS14]_{(S1)(D1)} + [WS14]_{(S1)(D3)}$$

3.7.2. Processing of pre-sorted recyclables in a MRF (S2)

Table 3. 32: Mass flow through separation option S2

Waste stream sets (WS)	WS1 = {RCCR, RCNR}	WS2 = {RNNR}	WS3 = {MCCR, MCNR}	WS4 = {MNNR}	WS5 = {CCCR, CCNR}	WS6 = {CNNR}
Potential origin nodes	C2, C3, C8, TR5	C2, C3, C8, TR5	C8, C14, TR5	C8, C14, TR5	C19, TR5	C19, TR5
Potential destination nodes	FUEL , RECY	RECY	FUEL , RECY	RECY	FUEL , RECY	RECY

Mass flow equations:

$$[WS1]_{(C2)\,(S2)} + [WS1]_{(C3)\,(S2)} + [WS1]_{(C8)\,(S2)} + [WS1]_{(TR5)\,(S2)} = [WS1]_{(S2)\ REC} + [WS1]_{(S2)\ FUEL}$$

$$[WS2]_{(C2)\,(S2)} + [WS2]_{(C3)\,(S2)} + [WS2]_{(C8)\,(S2)} + [WS2]_{(TR5)\,(S2)} = [WS2]_{(S2)\ REC}$$

$$[WS3]_{(C8)\,(S2)} + [WS3]_{(C14)\,(S2)} + [WS3]_{(TR5)\,(S2)} = [WS3]_{(S2)\ REC} + [WS3]_{(S2)\ FUEL}$$

$$[WS4]_{(C8)\,(S2)} + [WS4]_{(C14)\,(S2)} + [WS4]_{(TR5)\,(S2)} = [WS4]_{(S2)\ REC}$$

$$[WS5]_{(C19)\,(S2)} + [WS5]_{(TR5)\,(S2)} = [WS5]_{(S2)\ REC} + [WS5]_{(S2)\ FUEL}$$

$$[WS6]_{(C19)\,(S2)} + [WS6]_{(TR5)\,(S2)} = [WS6]_{(S2)\ REC}$$

3.7.3. Sorting of commingled recyclables in a MRF (S3)

Table 3. 33: Mass flow through separation option S3

Waste stream sets (WS)	WS1 = {RCCR, RCNR}	WS2 = {RNNR}	WS3 = {MCCR, MCNR}	WS4 = {MNNR}
Potential origin nodes	C4, C11 (1) ; TR2; TR3, TR4 (2)	C4, C11 (1) ; TR2; TR3, TR4 (2)	C15, C17 (1); TR2	C15, C17 (1); TR2
Potential destination nodes	FUEL, RECY; D1, D3 as residuals	RECY; D1, D3 as residuals	FUEL, RECY; D1, D3 as residuals	RECY; D1, D3 as residuals

(1) Only waste from the recyclables compartment
(2) Only waste in the blue bags

Mass flow equations:

$$[WS1]_{(C4)\,(S3)} + [WS1]_{(C11)\,(S3)} + [WS1]_{(TR2)\,(S3)} + [WS1]_{(TR3)\,(S3)} + [WS1]_{(TR4)\,(S3)} = [WS1]_{(S3)\,FUEL} + [WS1]_{(S3)\,REC} + [WS1]_{(S3)\,(D1)} + [WS1]_{(S3)\,(D3)}$$

where:

$$[WS1]_{(S3)\,FUEL} + [WS1]_{(S3)\,REC} = SE_{(WS1,\,S3)} * ([WS1]_{(C4)\,(S3)} + [WS1]_{(C11)\,(S3)} + [WS1]_{(TR2)\,(S3)} + [WS1]_{(TR3)\,(S3)} + [WS1]_{(TR4)\,(S3)})$$

and:

$$[WS1]_{(S3)\,(D1)} + [WS1]_{(S3)\,(D3)} = (1 - SE_{(WS1,\,S3)}) * ([WS1]_{(C4)\,(S3)} + [WS1]_{(C11)\,(S3)} + [WS1]_{(TR2)\,(S3)} + [WS1]_{(TR3)\,(S3)} + [WS1]_{(TR4)\,(S3)})$$

See note in section 3.7.1.

$$[WS2]_{(C4)\,(S3)} + [WS2]_{(C11)\,(S3)} + [WS2]_{(TR2)\,(S3)} + [WS2]_{(TR3)\,(S3)} + [WS2]_{(TR4)\,(S3)} = [WS2]_{(S3)\,REC} + [WS2]_{(S3)\,(D1)} + [WS2]_{(S3)\,(D3)}$$

where:

$$[WS2]_{(S3)\,REC} = SE_{(WS2,S3)} * ([WS2]_{(C4)\,(S3)} + [WS2]_{(C11)\,(S3)} + [WS2]_{(TR2)\,(S3)} + [WS2]_{(TR3)\,(S3)} + [WS2]_{(TR4)\,(S3)})$$

and:

$$[WS2]_{(S3)\,(D1)} + [WS2]_{(S3)\,(D3)} = (1 - SE_{(WS2,S3)}) * ([WS2]_{(C4)\,(S3)} + [WS2]_{(C11)\,(S3)} + [WS2]_{(TR2)\,(S3)} + [WS2]_{(TR3)\,(S3)} + [WS2]_{(TR4)\,(S3)})$$

See note in section 3.7.1.

$$[WS3]_{(C15)\,(S3)} + [WS3]_{(C17)\,(S3)} + [WS3]_{(TR2)\,(S3)} = [WS3]_{(S3)\,FUEL} + [WS3]_{(S3)\,REC} + [WS3]_{(S3)\,(D1)} + [WS3]_{(S3)\,(D3)}$$

where:

$$[WS3]_{(S3)\,FUEL} + [WS3]_{(S3)\,REC} = SE_{(WS3,S3)} * ([WS3]_{(C15)\,(S3)} + [WS3]_{(C17)\,(S3)} + [WS3]_{(TR2)\,(S3)})$$

and:

$[WS3]_{(S3)(D1)} + [WS3]_{(S3)(D3)} = (1 - SE_{(WS3,S3)}) * ([WS3]_{(C15)(S3)} + [WS3]_{(C17)(S3)} + [WS3]_{(TR2)(S3)})$

See note in section 3.7.1.

$[WS4]_{(C15)(S3)} + [WS4]_{(C17)(S3)} + [WS4]_{(TR2)(S3)} = [WS4]_{(S3)\,REC} + [WS4]_{(S3)(D1)} + [WS4]_{(S3)(D3)}$

where:

$[WS4]_{(S3)\,REC} = SE_{(WS4,S3)} * ([WS4]_{(C15)(S3)} + [WS4]_{(C17)(S3)} + [WS4]_{(TR2)(S3)})$

and:

$[WS4]_{(S3)(D1)} + [WS4]_{(S3)(D3)} = (1 - SE_{(WS4,S3)}) * ([WS4]_{(C15)(S3)} + [WS4]_{(C17)(S3)} + [WS4]_{(TR2)(S3)})$

See note in section 3.7.1.

3.7.4. Sorting recyclables (collected using co-collection option C5) in a commingled recyclables MRF (S4)

Table 3. 34: Mass flow through separation option S4

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCN, RCNN, RNNN}(1)	WS2 = {RCCR, RCNR, RNNR}(2)
Potential origin nodes	C5, TR3	C5, TR3
Potential destination nodes	T3, T5, T7, T8, D1, D3	T3, T5, T7, T8, D1, D3; RECY, FUEL

(1) These items enter in black bags, which are unloaded and then flow out as is

(2) These items enter in both blue and black bags but only the blue bags are sorted in S4

Both black bags and blue bags will enter the S4 MRF facility. The black bags are first unloaded at this facility and then reloaded back into another vehicle that will carry them to one of the potential destination nodes. Blue bags contain commingled recyclables which are sorted at this facility. The recyclables in waste stream set WS2 may arrive at this facility in both blue and black bags. The portion of recyclables in the black bags is the amount that is thrown away with the mixed waste stream by the household. Equations to estimate this portion are described in section 3.5.6.

Mass flow equations:

$[WS1]_{(C5)(S4)} + [WS1]_{(TR3)(S4)} = [WS1]_{(S4)(T3)} + [WS1]_{(S4)(T5)} + [WS1]_{(S4)(T7)} + [WS1]_{(S4)(T8)} + [WS1]_{(S4)(D1)} + [WS1]_{(S4)(D3)}$

$[WS2(black)]_{(C5)(S4)} + [WS2(black)]_{(TR3)(S4)} = [WS2(black)]_{(S4)(T3)}$

$$+ [WS2(black)]_{(S4)\,(T5)} + [WS2(black)]_{(S4)\,(T7)} + [WS2(black)]_{(S4)\,(T8)} + [WS2(black)]_{(S4)\,(D1)} + [WS2(black)]_{(S4)\,(D3)}$$

$$[WS2(blue)]_{(C5)\,(S4)} + [WS2(blue)]_{(TR3)\,(S4)} = [WS2(blue)]_{(S4)\,RECY} + [WS2(blue)]_{(S4)\,FUEL} + [WS2(blue)]_{(S4)\,(D1)} + [WS2(blue)]_{(S4)\,(D3)}$$

where:

$$[WS2(blue)]_{(S4)\,RECY} + [WS2(blue)]_{(S4)\,FUEL} = SE_{(WS2,S4)} * ([WS2(blue)]_{(C5)\,(S4)} + [WS2(blue)]_{(TR3)\,(S4)})$$

and:

$$[WS2(blue)]_{(S4)\,(D1)} + [WS2(blue)]_{(S4)\,(D3)} = (1 - SE_{(WS2,S4)}) * ([WS2(blue)]_{(C5)\,(S4)} + [WS2(blue)]_{(TR3)\,(S4)})$$

See note in section 3.7.1.

3.7.5. Sorting in a MRF of commingled recyclables collected as mixed waste and recyclables in color coded bags in a double compartment truck (S5)

Table 3. 35: Mass flow through separation option S5

Waste stream sets (WS)	WS1 = {RYTL, RYTO, RCCN, RCNN, RNNN}(1)	WS2 = {RCCR, RCNR, RNNR}(2)
Potential origin nodes	C6	C6
Potential destination nodes	T3, T5, T7, T8, D1, D3	T3, T5, T7, T8, D1, D3 RECY, FUEL

(1) These items are inside black bags, which are not unloaded from the truck
(2) These items are inside both blue and black bags but only the blue bags are sorted in S5

Only blue bags will enter this facility. The black bags remain in the truck that will carry them to one of the potential destination nodes. Blue bags contain commingled recyclables that are sorted at this facility. The recyclables in waste stream set WS2 may be contained in both blue and black bags. The portion of recyclables in the black bags is the amount that is thrown away with the mixed waste stream by the household. Equations to estimate this portion are described in section 3.5.7.

Mass flow equations:

$$[WS1]_{(C6)\,(S5)} = [WS1]_{(S5)\,(T3)} + [WS1]_{(S5)\,(T5)} + [WS1]_{(S5)\,(T7)} + [WS1]_{(S5)\,(T8)} + [WS1]_{(S5)\,(D1)} + [WS1]_{(S5)\,(D3)}$$

$$[WS2(black)]_{(C6)\,(S5)} = [WS2(black)]_{(S5)\,(T3)} + [WS2(black)]_{(S5)\,(T5)} + [WS2(black)]_{(S5)\,(T7)} + [WS2(black)]_{(S5)\,(T8)} + [WS2(black)]_{(S5)\,(D1)} + [WS2(black)]_{(S5)\,(D3)}$$

$[WS2(blue)]_{(C6)(S5)} = [WS2(blue)]_{(S5) RECY} + [WS2(blue)]_{(S5) FUEL} + [WS2(blue)]_{(S5)(D1)} + [WS2(blue)]_{(S5)(D3)}$

where:
$[WS2(blue)]_{(S5) RECY} + [WS2(blue)]_{(S5) FUEL} = SE_{(WS2,S5)} * [WS2(blue)]_{(C6)(S5)}$

and:
$[WS2(blue)]_{(S5)(D1)} + [WS2(blue)]_{(S5)(D3)} = (1 - SE_{(WS2,S5)}) * [WS2(blue)]_{(C6)(S5)}$
See note in section 3.7.1.

3.8. Treatment nodes

There are 6 treatment options: aerobic composting of yard waste, waste-to-energy, refuse derived fuel, backyard composting, mixed refuse composting and anaerobic digestion.

The aerobic composting of yardwaste treatment option T1, receives mass flow from the yardwaste collection options C0, C9 and C10 only. At waste to energy treatment option T3, waste is combusted to recover energy as electricity. The ash generated at this facility is computed using the ash fraction $ASHF_{(WS, T3)}$. At Refuse Derived Fuel (RDF) treatment option T5, mixed waste composting treatment option T7, and anaerobic digestion treatment option T8, waste is first sorted to remove some recyclables and non-typical waste items.

Treatment option T6, backyard composting, is not a central facility. It is introduced to account for the amount of yardwaste that may be diverted before the waste stream enters any collection option. The only implication to mass flow is the amount of yardwaste that is diverted or reduced at the source. A source reduction coefficient SR is used to compute the mass diverted from the potentially generated amount of yardwaste in the residential sectors.

The amount of compost produced at treatment options T1, T6 and T7 is estimated using the fraction CRF that represents the mass reduction during the composting process. For example, $CRF_{(WS, T)}$ is the ratio of mass of compost produced at facility T to the mass of waste stream WS treated at T.

3.8.1. Aerobic composting of yard waste (T1)

Table 3. 36: Mass flow through treatment option T1

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}
Potential origin nodes	C0, C9, C10	C0, C10
Potential destination nodes	Compost	Compost

Mass flow equations:

$$[WS1]_{(C0)\,(T1)} + [WS1]_{(C9)\,(T1)} + [WS1]_{(C10)\,(T1)} = [WS1(COMP)]_{(T1)\,COMP} / CRF_{(WS1,\,T1)}$$

$$[WS2]_{(C0)\,(T1)} + [WS2]_{(C10)\,(T1)} = [WS2(COMP)]_{(T1)\,COMP} / CRF_{(WS2,\,T1)}$$

3.8.2. Waste-to-energy (T3)

Table 3. 37: Mass flow through treatment option T3

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR, RCNR, RNNR}	WS4 = {RCCN, RCNN, RNNN}
Potential origin nodes	C0, C1, C9, C10; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3) ; S1 as residuals	C0, C1, C10; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3) ; S1 as residuals	C1 ; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3) ; S1 as residuals	C1 ; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3) ; S1 as residuals
Potential destination nodes	D2 (as ash)	D2 (as ash)	D2 (as ash)	D2 (as ash)

(1) Enter in any compartment
(2) Enter in black bags
(3) Enter in black bags unloaded from collection option C6 truck

Mass flow equations:

$$[WS1]_{(C0)\,(T3)} + [WS1]_{(C1)\,(T3)} + [WS1]_{(C7)\,(T3)} + [WS1]_{(C9)\,(T3)} + [WS1]_{(C10)\,(T3)} + [WS1]_{(C11)\,(T3)} + [WS1]_{(C12)\,(T3)} + [WS1]_{(S1)\,(T3)} + [WS1]_{(S4)\,(T3)} + [WS1]_{(S5)\,(T3)} + [WS1]_{(TR1)\,(T3)} + [WS1]_{(TR3)\,(T3)} + [WS1]_{(TR4)\,(T3)} = [WS1(ASH)]_{(T3)\,(D2)} / ASHF_{(WS1,\,T3)}$$

$$[WS2]_{(C0)\,(T3)} + [WS2]_{(C1)\,(T3)} + [WS2]_{(C7)\,(T3)} + [WS2]_{(C10)\,(T3)} + [WS2]_{(C11)\,(T3)} + [WS2]_{(C12)\,(T3)} + [WS2]_{(S1)\,(T3)} + [WS2]_{(S4)\,(T3)} + [WS2]_{(S5)\,(T3)} + [WS2]_{(TR1)\,(T3)} + [WS2]_{(TR3)\,(T3)} + [WS2]_{(TR4)\,(T3)} = [WS2(ASH)]_{(T3)\,(D2)} / ASHF_{(WS2,\,T3)}$$

$$[WS3]_{(C1)(T3)} + [WS3]_{(C7)(T3)} + [WS3]_{(C11)(T3)} + [WS3]_{(C12)(T3)} + [WS3]_{(S1)(T3)} + [WS3]_{(S4)(T3)} + [WS3]_{(S5)(T3)} + [WS3]_{(TR1)(T3)} + [WS3]_{(TR3)(T3)} + [WS3]_{(TR4)(T3)} = [WS3(ASH)]_{(T3)(D2)} / ASHF_{(WS3,\ T3)}$$

$$[WS4]_{(C1)(T3)} + [WS4]_{(C7)(T3)} + [WS4]_{(C11)(T3)} + [WS4]_{(C12)(T3)} + [WS4]_{(S1)(T3)} + [WS4]_{(S4)(T3)} + [WS4]_{(S5)(T3)} + [WS4]_{(TR1)(T3)} + [WS4]_{(TR3)(T3)} + [WS4]_{(TR4)(T3)} = [WS4(ASH)]_{(T3)(D2)} / ASHF_{(WS4,\ T3)}$$

Table 3.37 (continued)

Waste stream sets (WS)	WS6 = {MYTL, MYTO, MCCR, MCNR, MNNR MCCN, MCNN, MNNN}	WS7 = {CCCR, CCNR, CCCN, CCNN, CNNN, CNNR}
Potential origin nodes	C13, C16; C17, C18 (1); TR1; S1 as residuals	C20; TR1, S1 as residuals
Potential destination nodes	D2	D2

(1) Enter in any of wet or dry compartments

Mass flow equations:

$$[WS6]_{(C13)(T3)} + [WS6]_{(C16)(T3)} + [WS6]_{(C17)(T3)} + [WS6]_{(C18)(T3)} + [WS6]_{(S1)(T3)} + [WS6]_{(TR1)(T3)} = [WS6(ASH)]_{(T3)(D2)} / ASHF_{(WS6,\ T3)}$$

$$[WS7]_{(C20)(T3)} + [WS7]_{(TR1)(T3)} + [WS7]_{(S1)(T3)} = [WS7(ASH)]_{(T3)(D2)} / ASHF_{(WS7,\ T3)}$$

3.8.3. Refuse Derived Fuel (RDF) (T5)

Table 3. 38: Mass flow through treatment option T5

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR, RCNR}	WS4 = {RNNR}	WS5 = {RCCN, RCNN}	WS6 = {RNNN}
Potential origin nodes	C0, C1, C9, C10; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)	C0, C1, C10; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)	C1; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)	C1; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)	C1; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)	C1; C11, C12 (1); C7, TR1; TR3, TR4, S4 (2); S5 (3)
Potential destination nodes	FUEL; D1, D3 as residuals	D1, D3 as residuals	FUEL, REC; D1, D3 as residuals	RECY; D1, D3 as residuals	FUEL; D1, D3 as residuals	D1, D3 as residuals

(1) Enter in any of wet or dry compartments
(2) Enter in black bags
(3) Enter in black bags unloaded from collection option C6 truck

Mass flow equations:

$$[WS1]_{(C0)\,(T5)} + [WS1]_{(C1)\,(T5)} + [WS1]_{(C7)\,(T5)} + [WS1]_{(C9)\,(T5)} + [WS1]_{(C10)\,(T5)} + [WS1]_{(C11)\,(T5)} + [WS1]_{(C12)\,(T5)} + [WS1]_{(TR1)\,(T5)} + [WS1]_{(TR3)\,(T5)} + [WS1]_{(TR4)\,(T5)} + [WS1]_{(S4)\,(T5)} + [WS1]_{(S5)\,(T5)} = [WS1]_{(T5)\,FUEL} + [WS1]_{(T5)\,(D1)} + [WS1]_{(T5)\,(D3)}$$

where:

$$[WS1]_{(T5)\,FUEL} = SE_{(WS1,\,T5)} * ([WS1]_{(C0)\,(T5)} + [WS1]_{(C1)\,(T5)} + [WS1]_{(C7)\,(T5)} + [WS1]_{(C9)\,(T5)} + [WS1]_{(C10)\,(T5)} + [WS1]_{(C11)\,(T5)} + [WS1]_{(C12)\,(T5)} + [WS1]_{(TR1)\,(T5)} + [WS1]_{(TR3)\,(T5)} + [WS1]_{(TR4)\,(T5)} + [WS1]_{(S4)\,(T5)} + [WS1]_{(S5)\,(T5)})$$

and:

$$[WS1]_{(T5)\,(D1)} + [WS1]_{(T5)\,(D3)} = (1 - SE_{(WS1,\,T5)}) * ([WS1]_{(C0)\,(T5)} + [WS1]_{(C1)\,(T5)} + [WS1]_{(C7)\,(T5)} + [WS1]_{(C9)\,(T5)} + [WS1]_{(C10)\,(T5)} + [WS1]_{(C11)\,(T5)} + [WS1]_{(C12)\,(T5)} + [WS1]_{(TR1)\,(T5)} + [WS1]_{(TR3)\,(T5)} + [WS1]_{(TR4)\,(T5)} + [WS1]_{(S4)\,(T5)} + [WS1]_{(S5)\,(T5)})$$

$$[WS2]_{(C0)\,(T5)} + [WS2]_{(C1)\,(T5)} + [WS2]_{(C7)\,(T5)} + [WS2]_{(C10)\,(T5)} + [WS2]_{(C11)\,(T5)} + [WS2]_{(C12)\,(T5)} + [WS2]_{(TR1)\,(T5)} + [WS2]_{(TR3)\,(T5)} + [WS2]_{(TR4)\,(T5)} + [WS2]_{(S4)\,(T5)} + [WS2]_{(S5)\,(T5)} = [WS2]_{(T5)\,(D1)} + [WS2]_{(T5)\,(D3)}$$

$$[WS3]_{(C1)\,(T5)} + [WS3]_{(C7)\,(T5)} + [WS3]_{(C11)\,(T5)} + [WS3]_{(C12)\,(T5)} + [WS3]_{(TR1)\,(T5)} + [WS3]_{(TR3)\,(T5)} + [WS3]_{(TR4)\,(T5)} + [WS3]_{(S4)\,(T5)} + [WS3]_{(S5)\,(T5)} = [WS3]_{(T5)\,FUEL} + [WS3]_{(T5)\,REC} + [WS3]_{(T5)\,(D1)} + [WS3]_{(T5)\,(D3)}$$

where:

$$[WS3]_{(T5)\,FUEL} + [WS3]_{(T5)\,REC} = SE_{(WS3,\,T5)} * ([WS3]_{(C1)\,(T5)} + [WS3]_{(C7)\,(T5)}$$

$$+ [WS3]_{(C11)(T5)} + [WS3]_{(C12)(T5)} + [WS3]_{(TR1)(T5)} + [WS3]_{(TR3)(T5)} + [WS3]_{(TR4)(T5)} + [WS3]_{(S4)(T5)} + [WS3]_{(S5)(T5)})$$

and:

$$[WS3]_{(T5)(D1)} + [WS3]_{(T5)(D3)} = (1 - SE_{(WS3,\ T5)}) * ([WS3]_{(C1)(T5)} + [WS3]_{(C7)(T5)} + [WS3]_{(C11)(T5)} + [WS3]_{(C12)(T5)} + [WS3]_{(TR1)(T5)} + [WS3]_{(TR3)(T5)} + [WS3]_{(TR4)(T5)} + [WS3]_{(S4)(T5)} + [WS3]_{(S5)(T5)})$$

$$[WS4]_{(C1)(T5)} + [WS4]_{(C7)(T5)} + [WS4]_{(C11)(T5)} + [WS4]_{(C12)(T5)} + [WS4]_{(TR1)(T5)} + [WS4]_{(TR3)(T5)} + [WS4]_{(TR4)(T5)} + [WS4]_{(S4)(T5)} + [WS4]_{(S5)(T5)} = [WS4]_{(T5)\ REC} + [WS4]_{(T5)(D1)} + [WS4]_{(T5)(D3)}$$

where:

$$[WS4]_{(T5)\ REC} = SE_{(WS4,\ T5)} * ([WS4]_{(C1)(T5)} + [WS4]_{(C7)(T5)} + [WS4]_{(C11)(T5)} + [WS4]_{(C12)(T5)} + [WS4]_{(TR1)(T5)} + [WS4]_{(TR3)(T5)} + [WS4]_{(TR4)(T5)} + [WS4]_{(S4)(T5)} + [WS4]_{(S5)(T5)})$$

and:

$$[WS4]_{(T5)(D1)} + [WS4]_{(T5)(D3)} = (1 - SE_{(WS4,\ T5)}) * ([WS4]_{(C1)(T5)} + [WS4]_{(C7)(T5)} + [WS4]_{(C11)(T5)} + [WS4]_{(C12)(T5)} + [WS4]_{(TR1)(T5)} + [WS4]_{(TR3)(T5)} + [WS4]_{(TR4)(T5)} + [WS4]_{(S4)(T5)} + [WS4]_{(S5)(T5)})$$

$$[WS5]_{(C1)(T5)} + [WS5]_{(C7)(T5)} + [WS5]_{(C11)(T5)} + [WS5]_{(C12)(T5)} + [WS5]_{(TR1)(T5)} + [WS5]_{(TR3)(T5)} + [WS5]_{(TR4)(T5)} + [WS5]_{(S4)(T5)} + [WS5]_{(S5)(T5)} = [WS5]_{(T5)(D1)} + [WS5]_{(T5)(D3)} + [WS5]_{(T5)\ FUEL}$$

where:

$$[WS5]_{(T5)\ FUEL} = SE_{(WS5,\ T5)} * ([WS5]_{(C1)(T5)} + [WS5]_{(C7)(T5)} + [WS5]_{(C11)(T5)} + [WS5]_{(C12)(T5)} + [WS5]_{(TR1)(T5)} + [WS5]_{(TR3)(T5)} + [WS5]_{(TR4)(T5)} + [WS5]_{(S4)(T5)} + [WS5]_{(S5)(T5)})$$

and:

$$[WS5]_{(T5)(D1)} + [WS5]_{(T5)(D3)} = (1- SE_{(WS5,\ T5)}) * ([WS5]_{(C1)(T5)} + [WS5]_{(C7)(T5)} + [WS5]_{(C11)(T5)} + [WS5]_{(C12)(T5)} + [WS5]_{(TR1)(T5)} + [WS5]_{(TR3)(T5)} + [WS5]_{(TR4)(T5)} + [WS5]_{(S4)(T5)} + [WS5]_{(S5)(T5)})$$

$$[WS6]_{(C1)(T5)} + [WS6]_{(C7)(T5)} + [WS6]_{(C11)(T5)} + [WS6]_{(C12)(T5)} + [WS6]_{(TR1)(T5)} + [WS6]_{(TR3)(T5)} + [WS6]_{(TR4)(T5)} + [WS6]_{(S4)(T5)} + [WS6]_{(S5)(T5)} = [WS6]_{(T5)(D1)} + [WS6]_{(T5)(D3)}$$

Table 3.38 (continued)

Waste stream sets (WS)	WS7 = {MYTL}	WS8 = {MYTO}	WS9 = {MCCR, MCNR}	WS10 = {MNNR}	WS11 = {MCCN, MCNN}	WS12 = {MNNN}
Potential origin nodes	C13, C16; C17, C18 (1) ; TR1	C13, C16; C17, C18 (1) ; TR1	C13, C16; C17, C18 (1) ; TR1	C13, C16; C17, C18 (1) ; TR1	C13, C16; C17, C18 (1) ; TR1	C13, C16; C17, C18 (1) ; TR1
Potential destination nodes	FUEL; D1, D3 as residuals	D1, D3 as residuals	FUEL, REC; D1, D3 as residuals	RECY; D1, D3 as residuals	FUEL; D1, D3 as residuals	D1, D3 as residuals

(1) Enter in any compartment

Mass flow equations:

$$[WS7]_{(C13)\,(T5)} + [WS7]_{(C16)\,(T5)} + [WS7]_{(C17)\,(T5)} + [WS7]_{(C18)\,(T5)} + [WS7]_{(TR1)\,(T5)} = [WS7]_{(T5)\,FUEL} + [WS7]_{(T5)\,(D1)} + [WS7]_{(T5)\,(D3)}$$

where:

$$[WS7]_{(T5)\,FUEL} = SE_{(WS7,\,T7)} * ([WS7]_{(C13)\,(T5)} + [WS7]_{(C16)\,(T5)} + [WS7]_{(C17)\,(T5)} + [WS7]_{(C18)\,(T5)} + [WS7]_{(TR1)\,(T5)})$$

and:

$$[WS7]_{(T5)\,(D1)} + [WS7]_{(T5)\,(D3)} = (1- SE_{(WS7,\,T7)}) * ([WS7]_{(C13)\,(T5)} + [WS7]_{(C16)\,(T5)} + [WS7]_{(C17)\,(T5)} + [WS7]_{(C18)\,(T5)} + [WS7]_{(TR1)\,(T5)})$$

$$[WS8]_{(C13)\,(T5)} + [WS8]_{(C16)\,(T5)} + [WS8]_{(C17)\,(T5)} + [WS8]_{(C18)\,(T5)} + [WS8]_{(TR1)\,(T5)} = [WS8]_{(T5)\,(D1)} + [WS8]_{(T5)\,(D3)}$$

$$[WS9]_{(C13)\,(T5)} + [WS9]_{(C16)\,(T5)} + [WS9]_{(C17)\,(T5)} + [WS9]_{(C18)\,(T5)} + [WS9]_{(TR1)\,(T5)} = [WS9]_{(T5)\,FUEL} + [WS9]_{(T5)\,REC} + [WS9]_{(T5)\,(D1)} + [WS9]_{(T5)\,(D3)}$$

where:

$$[WS9]_{(T5)\,FUEL} + [WS9]_{(T5)\,REC} = SE_{(WS9,\,T5)} * ([WS9]_{(C13)\,(T5)} + [WS9]_{(C16)\,(T5)} + [WS9]_{(C17)\,(T5)} + [WS9]_{(C18)\,(T5)} + [WS9]_{(TR1)\,(T5)})$$

and:

$$[WS9]_{(T5)\,(D1)} + [WS9]_{(T5)\,(D3)} = (1 - SE_{(WS9,\,T5)}) * ([WS9]_{(C13)\,(T5)} + [WS9]_{(C16)\,(T5)} + [WS9]_{(C17)\,(T5)} + [WS9]_{(C18)\,(T5)} + [WS9]_{(TR1)\,(T5)})$$

$$[WS10]_{(C13)\,(T5)} + [WS10]_{(C16)\,(T5)} + [WS10]_{(C17)\,(T5)} + [WS10]_{(C18)\,(T5)} + [WS10]_{(TR1)\,(T5)} = [WS10]_{(T5)\,REC} + [WS10]_{(T5)\,(D1)} + [WS10]_{(T5)\,(D3)}$$

where:

$$[WS10]_{(T5)\,REC} = SE_{(WS10,\,T5)} * ([WS10]_{(C13)\,(T5)} + [WS10]_{(C16)\,(T5)} + [WS10]_{(C17)\,(T5)} + [WS10]_{(C18)\,(T5)} + [WS10]_{(TR1)\,(T5)})$$

and:
$[WS10]_{(T5)(D1)} + [WS10]_{(T5)(D3)} = (1- SE_{(WS10, T5)}) * ([WS10]_{(C13)(T5)} + [WS10]_{(C16)(T5)} + [WS10]_{(C17)(T5)} + [WS10]_{(C18)(T5)} + [WS10]_{(TR1)(T5)})$

$[WS11]_{(C13)(T5)} + [WS11]_{(C16)(T5)} + [WS11]_{(C17)(T5)} + [WS11]_{(C18)(T5)} + [WS11]_{(TR1)(T5)} = [WS11]_{(T5) FUEL} + [WS11]_{(T5)(D1)} + [WS11]_{(T5)(D3)}$

where:
$[WS11]_{(T5) FUEL} = SE_{(WS11, T5)} * ([WS11]_{(C13)(T5)} + [WS11]_{(C16)(T5)} + [WS11]_{(C17)(T5)} + [WS11]_{(C18)(T5)} + [WS11]_{(TR1)(T5)})$

and:
$[WS11]_{(T5)(D1)} + [WS11]_{(T5)(D3)} = (1- SE_{(WS11, T5)}) * ([WS11]_{(C13)(T5)} + [WS11]_{(C16)(T5)} + [WS11]_{(C17)(T5)} + [WS11]_{(C18)(T5)} + [WS11]_{(TR1)(T5)})$

$[WS12]_{(C13)(T5)} + [WS12]_{(C16)(T5)} + [WS12]_{(C17)(T5)} + [WS12]_{(C18)(T5)} + [WS12]_{(TR1)(T5)} = [WS12]_{(T5)(D1)} + [WS12]_{(T5)(D3)}$

Table 3.38 (continued)

Waste stream sets (WS)	WS13 = {CCCR, CCNR}	WS14 = {CNNR}	WS15 = {CCCN, CCNN}	WS16 = {CNNN}
Potential origin nodes	C20, TR1	C20, TR1	C20, TR1	C20, TR1
Potential destination nodes	FUEL, RECY, D1, D3 as residuals	RECY; D1, D3 as residuals	FUEL; D1, D3 as residuals	D1, D3 as residuals

Mass flow equations:

$[WS13]_{(C20)(T5)} + [WS13]_{(TR1)(T5)} = [WS13]_{(T5) FUEL} + [WS13]_{(T5) REC} + [WS13]_{(T5)(D1)} + [WS13]_{(T5)(D3)} +$

where:
$[WS13]_{(T5) FUEL} + [WS13]_{(T5) REC} = SE_{(WS13, T5)} * ([WS13]_{(C20)(T5)} + [WS13]_{(TR1)(T5)})$

and:
$[WS13]_{(T5)(D1)} + [WS13]_{(T5)(D3)} = (1- SE_{(WS13, T5)}) * ([WS13]_{(C20)(T5)} + [WS13]_{(TR1)(T5)})$

$[WS14]_{(C20)(T5)} + [WS14]_{(TR1)(T5)} = [WS14]_{(T5) REC} + [WS14]_{(T5)(D1)} + [WS14]_{(T5)(D3)}$

where:

$[WS14]_{(T5)\ REC} = SE_{(WS14,\ T5)} * ([WS14]_{(C20)\ (T5)} + [WS14]_{(TR1)\ (T5)})$

and:
$[WS14]_{(T5)\ (D1)} + [WS14]_{(T5)\ (D3)} = (1 - SE_{(WS14,\ T5)}) * ([WS14]_{(C20)\ (T5)} + [WS14]_{(TR1)\ (T5)})$

$[WS15]_{(C20)\ (T5)} + [WS15]_{(TR1)\ (T5)} = [WS15]_{(T5)\ FUEL} + [WS15]_{(T5)\ (D1)} + [WS15]_{(T5)\ (D3)}$

where:
$[WS15]_{(T5)\ FUEL} = SE_{(WS15,\ T5)} * ([WS15]_{(C20)\ (T5)} + [WS15]_{(TR1)\ (T5)})$

and:
$[WS15]_{(T5)\ (D1)} + [WS15]_{(T5)\ (D3)} = (1 - SE_{(WS15,\ T5)}) * ([WS15]_{(C20)\ (T5)} + [WS15]_{(TR1)\ (T5)})$

$[WS16]_{(C20)\ (T5)} + [WS16]_{(TR1)\ (T5)} = [WS16]_{(T5)\ (D1)} + [WS16]_{(T5)\ (D3)}$

3.8.4. Backyard composting (T6)

This treatment option is applicable to yardwaste generated in the residential sectors. The amount of yardwaste diverted through backyard composting is determined based on a source reduction factor, SR; SR is the fraction of yardwaste composted in the backyard of single family homes.

$[WS1]_{(AG)\ (T6)} = [WS1]_{(PG)} * SR_{[WS1]}$
where:
WS1 = {RYTL, RYTO}

The actual amount of compost produced is then given by the following expression:
$[WS1(COMP)]_{(AG)\ (T6)} = CRF_{(WS1,\ T6)} * [WS1]_{(AG)\ (T6)}$

3.8.5. Mixed refuse composting (T7)

Table 3. 39: Mass flow through treatment option T7

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR}	WS4 = {RCNR}	WS5 = {RNNR}	WS6 = {RCCN}	WS7 = {RCNN}	WS8 = {RNNN}
Potential origin nodes	C0, C1, C9, C10; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C0, C1, C10; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)
Potential destination nodes	MSW Compost	MSW Compost	FUEL, RECY (4) ; MSW Compost	FUEL, RECY (4) ; D1, D3 as residuals	RECY (4) ; D1, D3 as residuals	FUEL (4) ; MSW Compost	FUEL (4) ; D1, D3 as residuals	D1, D3 as residuals

(1) Enter in any compartment
(2) Enter in black bags
(3) Enter in black bags unloaded from collection C6 truck
(4) Obtained in pre-processing stage

Mass flow equations:

$$[WS1]_{(C0)\,(T7)} + [WS1]_{(C1)\,(T7)} + [WS1]_{(C7)\,(T7)} + [WS1]_{(C9)\,(T7)} + [WS1]_{(C10)\,(T7)} + [WS1]_{(C11)\,(T7)} + [WS1]_{(C12)\,(T7)} + [WS1]_{(TR3)\,(T7)} + [WS1]_{(TR4)\,(T7)} + [WS1]_{(S4)\,(T7)} + [WS1]_{(S5)\,(T7)} = [WS1(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS1,\,T7)}$$

$$[WS2]_{(C0)\,(T7)} + [WS2]_{(C1)\,(T7)} + [WS2]_{(C7)\,(T7)} + [WS2]_{(C10)\,(T7)} + [WS2]_{(C11)\,(T7)} + [WS2]_{(C12)\,(T7)} + [WS2]_{(TR3)\,(T7)} + [WS2]_{(TR4)\,(T7)} + [WS2]_{(S4)\,(T7)} + [WS2]_{(S5)\,(T7)} = [WS2(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS2,\,T7)}$$

$$[WS3]_{(C1)\,(T7)} + [WS3]_{(C7)\,(T7)} + [WS3]_{(C11)\,(T7)} + [WS3]_{(C12)\,(T7)} + [WS3]_{(TR3)\,(T7)} + [WS3]_{(TR4)\,(T7)} + [WS3]_{(S4)\,(T7)} + [WS3]_{(S5)\,(T7)} = [WS3(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS3,\,T7)} + [WS3]_{(T7)\,FUEL} + [WS3]_{(T7)\,REC}$$

where:

$$[WS3]_{(T7)\,FUEL} + [WS3]_{(T7)\,REC} = SE_{(WS3,\,T7)} * ([WS3]_{(C1)\,(T7)} + [WS3]_{(C7)\,(T7)} + [WS3]_{(C11)(T7)} + [WS3]_{(C12)\,(T7)} + [WS3]_{(TR3)\,(T7)} + [WS3]_{(TR4)\,(T7)} + [WS3]_{(S4)\,(T7)} + [WS3]_{(S5)\,(T7)})$$

and:

$$[WS3(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS3,\ T7)} = (1 - SE_{(WS3,\ T7)}) * ([WS3]_{(C1)\ (T7)} + [WS3]_{(C7)\ (T7)} + [WS3]_{(C11)\ (T7)} + [WS3]_{(C12)\ (T7)} + [WS3]_{(TR3)\ (T7)} + [WS3]_{(TR4)\ (T7)} + [WS3]_{(S4)\ (T7)} + [WS3]_{(S5)\ (T7)})$$

$$[WS4]_{(C1)\ (T7)} + [WS4]_{(C7)\ (T7)} + [WS4]_{(C11)\ (T7)} + [WS4]_{(C12)\ (T7)} + [WS4]_{(TR3)\ (T7)} + [WS4]_{(TR4)\ (T7)} + [WS4]_{(S4)\ (T7)} + [WS4]_{(S5)\ (T7)} = [WS4]_{(T7)\ FUEL} + [WS4]_{(T7)\ REC} + [WS4]_{(T7)\ (D1)} + [WS4]_{(T7)\ (D3)}$$

where:

$$[WS4]_{(T7)\ FUEL} + [WS4]_{(T7)\ REC} = SE_{(WS4,\ T7)} * ([WS4]_{(C1)\ (T7)} + [WS4]_{(C7)\ (T7)} + [WS4]_{(C11)\ (T7)} + [WS4]_{(C12)\ (T7)} + [WS4]_{(TR3)\ (T7)} + [WS4]_{(TR4)\ (T7)} + [WS4]_{(S4)\ (T7)} + [WS4]_{(S5)\ (T7)})$$

and:

$$[WS4]_{(T7)\ (D1)} + [WS4]_{(T7)\ (D3)} = (1 - SE_{(WS4,\ T7)}) * ([WS4]_{(C1)\ (T7)} + [WS4]_{(C7)\ (T7)} + [WS4]_{(C11)\ (T7)} + [WS4]_{(C12)\ (T7)} + [WS4]_{(TR3)\ (T7)} + [WS4]_{(TR4)\ (T7)} + [WS4]_{(S4)\ (T7)} + [WS4]_{(S5)\ (T7)})$$

$$[WS5]_{(C1)\ (T7)} + [WS5]_{(C7)\ (T7)} + [WS5]_{(C11)\ (T7)} + [WS5]_{(C12)\ (T7)} + [WS5]_{(TR3)\ (T7)} + [WS5]_{(TR4)\ (T7)} + [WS5]_{(S4)\ (T7)} + [WS5]_{(S5)\ (T7)} = [WS5]_{(T7)\ REC} + [WS5]_{(T7)\ (D1)} + [WS5]_{(T7)\ (D3)}$$

where:

$$[WS5]_{(T7)\ REC} = SE_{(WS5,\ T7)} * ([WS5]_{(C1)\ (T7)} + [WS5]_{(C7)\ (T7)} + [WS5]_{(C11)\ (T7)} + [WS5]_{(C12)\ (T7)} + [WS5]_{(TR3)\ (T7)} + [WS5]_{(TR4)\ (T7)} + [WS5]_{(S4)\ (T7)} + [WS5]_{(S5)\ (T7)})$$

and:

$$[WS5]_{(T7)\ (D1)} + [WS5]_{(T7)\ (D3)} = (1 - SE_{(WS5,\ T7)}) * ([WS5]_{(C1)\ (T7)} + [WS5]_{(C7)\ (T7)} + [WS5]_{(C11)\ (T7)} + [WS5]_{(C12)\ (T7)} + [WS5]_{(TR3)\ (T7)} + [WS5]_{(TR4)\ (T7)} + [WS5]_{(S4)\ (T7)} + [WS5]_{(S5)\ (T7)})$$

$$[WS6]_{(C1)\ (T7)} + [WS6]_{(C7)\ (T7)} + [WS6]_{(C11)\ (T7)} + [WS6]_{(C12)\ (T7)} + [WS6]_{(TR3)\ (T7)} + [WS6]_{(TR4)\ (T7)} + [WS6]_{(S4)\ (T7)} + [WS6]_{(S5)\ (T7)} = [WS6(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS6,\ T7)} + [WS6]_{(T7)\ FUEL}$$

where:

$$[WS6]_{(T7)\ FUEL} = SE_{(WS6,\ T7)} * ([WS6]_{(C1)\ (T7)} + [WS6]_{(C7)\ (T7)} + [WS6]_{(C11)\ (T7)} + [WS6]_{(C12)\ (T7)} + [WS6]_{(TR3)\ (T7)} + [WS6]_{(TR4)\ (T7)} + [WS6]_{(S4)\ (T7)} + [WS6]_{(S5)\ (T7)})$$

and:

$$[WS6(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS6,\ T7)} = (1 - SE_{(WS6,\ T7)}) * ([WS6]_{(C1)\ (T7)}$$

$+ [WS6]_{(C7)(T7)} + [WS6]_{(C11)(T7)} + [WS6]_{(C12)(T7)} + [WS6]_{(TR3)(T7)} + [WS6]_{(TR4)(T7)} + [WS6]_{(S4)(T7)} + [WS6]_{(S5)(T7)})$

$$[WS7]_{(C1)(T7)} + [WS7]_{(C7)(T7)} + [WS7]_{(C11)(T7)} + [WS7]_{(C12)(T7)} + [WS7]_{(TR3)(T7)} + [WS7]_{(TR4)(T7)} + [WS7]_{(S4)(T7)} + [WS7]_{(S5)(T7)} = [WS7]_{(T7)\ FUEL} + [WS7]_{(T7)(D1)} + [WS7]_{(T7)(D3)}$$

where:

$$[WS7]_{(T7)\ FUEL} = SE_{(WS7,\ T7)} * ([WS7]_{(C1)(T7)} + [WS7]_{(C7)(T7)} + [WS7]_{(C11)(T7)} + [WS7]_{(C12)(T7)} + [WS7]_{(TR3)(T7)} + [WS7]_{(TR4)(T7)} + [WS7]_{(S4)(T7)} + [WS7]_{(S5)(T7)})$$

and:

$$[WS7]_{(T7)(D1)} + [WS7]_{(T7)(D3)} = (1- SE_{(WS7,\ T7)}) * ([WS7]_{(C1)(T7)} + [WS7]_{(C7)(T7)} + [WS7]_{(C11)(T7)} + [WS7]_{(C12)(T7)} + [WS7]_{(TR3)(T7)} + [WS7]_{(TR4)(T7)} + [WS7]_{(S4)(T7)} + [WS7]_{(S5)(T7)})$$

$$[WS8]_{(C1)(T7)} + [WS8]_{(C7)(T7)} + [WS8]_{(C11)(T7)} + [WS8]_{(C12)(T7)} + [WS8]_{(TR3)(T7)} + [WS8]_{(TR4)(T7)} + [WS8]_{(S4)(T7)} + [WS8]_{(S5)(T7)} = [WS8]_{(T7)(D1)} + [WS8]_{(T7)(D3)}$$

Table 3.39 (continued)

Waste stream sets (WS)	WS9 = {MYTL, MYTO}	WS10 = {MCCR}	WS11 = {MCNR}	WS12 = {MNNR}	WS13 = {MCCN}	WS14 = {MCNN}	WS15 = {MNNN}
Potential origin nodes	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)
Potential destination nodes	MSW Compost	FUEL, RECY (2) ; MSW Compost	FUEL, RECY (2); D1, D3 as residuals	RECY (2); D1, D3 as residuals	FUEL (2) ; MSW Compost	FUEL(2); D1, D3 as residuals	D1 and D3 as residuals

(1) Enter in any compartment
(2) Obtained in pre-processing stage

Mass flow equations:

$$[WS9]_{(C13)(T7)} + [WS9]_{(C16)(T7)} + [WS9]_{(C17)(T7)} + [WS9]_{(C18)(T7)} = [WS9(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS9,\ T7)}$$

$$[WS10]_{(C13)(T7)} + [WS10]_{(C16)(T7)} + [WS10]_{(C17)(T7)} + [WS10]_{(C18)(T7)} = [WS10(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS10,\ T7)} + [WS10]_{(T7)\ FUEL} + [WS10]_{(T7)\ REC}$$

where:
$[WS10]_{(T7)\ FUEL} + [WS10]_{(T7)\ REC} = SE_{(WS10,\ T7)} * ([WS10]_{(C13)\ (T7)} + [WS10]_{(C16)\ (T7)} + [WS10]_{(C17)\ (T7)} + [WS10]_{(C18)\ (T7)})$

and:
$[WS10(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS10,\ T7)} = (1 - SE_{(WS10,\ T7)}) * ([WS10]_{(C13)\ (T7)} + [WS10]_{(C16)\ (T7)} + [WS10]_{(C17)\ (T7)} + [WS10]_{(C18)\ (T7)})$

$[WS11]_{(C13)\ (T7)} + [WS11]_{(C16)\ (T7)} + [WS11]_{(C17)\ (T7)} + [WS11]_{(C18)\ (T7)} = [WS11]_{(T7)\ FUEL} + [WS11]_{(T7)\ REC} + [WS11]_{(T7)\ (D1)} + [WS11]_{(T7)\ (D3)}$

where:
$[WS11]_{(T7)\ FUEL} + [WS11]_{(T7)\ REC} = SE_{(WS11,\ T7)} * ([WS11]_{(C13)\ (T7)} + [WS11]_{(C16)\ (T7)} + [WS11]_{(C17)\ (T7)} + [WS11]_{(C18)\ (T7)})$

and:
$[WS11]_{(T7)\ (D1)} + [WS11]_{(T7)\ (D3)} = (1 - SE_{(WS11,\ T7)}) * ([WS11]_{(C13)\ (T7)} + [WS11]_{(C16)\ (T7)} + [WS11]_{(C17)\ (T7)} + [WS11]_{(C18)\ (T7)})$

$[WS12]_{(C13)\ (T7)} + [WS12]_{(C16)\ (T7)} + [WS12]_{(C17)\ (T7)} + [WS12]_{(C18)\ (T7)} = [WS12]_{(T7)\ REC} + [WS12]_{(T7)\ (D1)} + [WS12]_{(T7)\ (D3)}$

where:
$[WS12]_{(T7)\ REC} = SE_{(WS12,\ T7)} * ([WS12]_{(C13)\ (T7)} + [WS12]_{(C16)\ (T7)} + [WS12]_{(C17)\ (T7)} + [WS12]_{(C18)\ (T7)})$

and:
$[WS12]_{(T7)\ (D1)} + [WS12]_{(T7)\ (D3)} = (1 - SE_{(WS12,\ T7)}) * ([WS12]_{(C13)\ (T7)} + [WS12]_{(C16)\ (T7)} + [WS12]_{(C17)\ (T7)} + [WS12]_{(C18)\ (T7)})$

$[WS13]_{(C13)\ (T7)} + [WS13]_{(C16)\ (T7)} + [WS13]_{(C17)\ (T7)} + [WS13]_{(C18)\ (T7)} = [WS13(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS13,\ T7)} + [WS13]_{(T7)\ FUEL}$

where:
$[WS13]_{(T7)\ FUEL)} = SE_{(WS13,\ T7)} * ([WS13]_{(C13)\ (T7)} + [WS13]_{(C16)\ (T7)} + [WS13]_{(C17)\ (T7)} + [WS13]_{(C18)\ (T7)})$

and:
$[WS13(MSWCOMP)]_{(T7)\ MSWCOMP} / CRF_{(WS13,\ T7)} = (1 - SE_{(WS13,\ T7)}) * ([WS13]_{(C13)\ (T7)} + [WS13]_{(C16)\ (T7)} + [WS13]_{(C17)\ (T7)} + [WS13]_{(C18)\ (T7)})$

$[WS14]_{(C13)\,(T7)} + [WS14]_{(C16)\,(T7)} + [WS14]_{(C17)\,(T7)} + [WS14]_{(C18)\,(T7)} = [WS14]_{(T7)\,FUEL} + [WS14]_{(T7)\,(D1)} + [WS14]_{(T7)\,(D3)}$

where:

$[WS14]_{(T7)\,FUEL} = SE_{(WS14,\,T7)} * ([WS14]_{(C13)\,(T7)} + [WS14]_{(C16)\,(T7)} + [WS14]_{(C17)\,(T7)} + [WS14]_{(C18)\,(T7)})$

and:

$[WS14]_{(T7)\,(D1)} + [WS14]_{(T7)\,(D3)} = (1 - SE_{(WS14,\,T7)}) * ([WS14]_{(C13)\,(T7)} + [WS14]_{(C16)\,(T7)} + [WS14]_{(C17)\,(T7)} + [WS14]_{(C18)\,(T7)})$

$[WS15]_{(C13)\,(T7)} + [WS15]_{(C16)\,(T7)} + [WS15]_{(C17)\,(T7)} + [WS15]_{(C18)\,(T7)} = [WS15]_{(T7)\,(D1)} + [WS15]_{(T7)\,(D3)}$

Table 3.39 (continued)

Waste stream sets (WS)	WS16 = {CCCR}	WS17 = {CCNR}	WS18 = {CNNR}	WS19 = {CCCN}	WS20 = {CCNN}	WS21 = {CNNN}
Potential origin nodes	C20	C20	C20	C20	C20	C20
Potential destination nodes	FUEL, RECY(1) ; MSW Compost	FUEL, RECY (1) ; D1, D3 as residuals	RECY (1) ; D1, D3 as residuals	FUEL (1) ; MSW Compost	FUEL(1) ; D1, D3 as residuals	D1, D3 as residuals

(1) Obtained in pre-processing stage

Mass flow equations:

$[WS16]_{(C20)\,(T7)} = [WS16(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS16,\,T7)} + [WS16]_{(T7)\,FUEL} + [WS16]_{(T7)\,REC}$

where:

$[WS16]_{(T7)\,FUEL} + [WS16]_{(T7)\,REC} = SE_{(WS16,\,T7)} * [WS16]_{(C20)\,(T7)}$

and:

$[WS16(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS16,\,T7)} = (1 - SE_{(WS16,\,T7)}) * [WS16]_{(C20)\,(T7)}$

$[WS17]_{(C20)\,(T7)} = [WS17]_{(T7)\,FUEL} + [WS17]_{(T7)\,REC} + [WS17]_{(T7)\,(D1)} + [WS17]_{(T7)\,(D3)}$

where:

$[WS17]_{(T7)\,FUEL} + [WS17]_{(T7)\,REC} = SE_{(WS17,\,T7)} * [WS17]_{(C20)\,(T7)}$

and:

$[WS17]_{(T7)\,(D1)} + [WS17]_{(T7)\,(D3)} = (1 - SE_{(WS17,\,T7)}) * [WS17]_{(C20)\,(T7)}$

$$[WS18]_{(C20)\,(T7)} = [WS18]_{(T7)\,(D1)} + [WS18]_{(T7)\,(D3)} + [WS18]_{(T7)\,REC}$$

where:

$$[WS18]_{(T7)\,REC} = SE_{(WS18,\,T7)} * [WS18]_{(C20)\,(T7)}$$

and:

$$[WS18]_{(T7)\,(D1)} + [WS18]_{(T7)\,(D3)} = (1 - SE_{(WS18,\,T7)}) * [WS18]_{(C20)\,(T7)}$$

$$[WS19]_{(C20)\,(T7)} = [WS19(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS19,\,T7)} + [WS19]_{(T7)\,FUEL}$$

where:

$$[WS19]_{(T7)\,FUEL} = SE_{(WS19,\,T7)} * [WS19]_{(C20)\,(T7)}$$

and:

$$[WS19(MSWCOMP)]_{(T7)\,MSWCOMP} / CRF_{(WS19,\,T7)} = (1 - SE_{(WS19,\,T7)}) * [WS19]_{(C20)\,(T7)}$$

$$[WS20]_{(C20)\,(T7)} = [WS20]_{(T7)\,FUEL} + [WS20]_{(T7)\,(D1)} + [WS20]_{(T7)\,(D3)}$$

where:

$$[WS20]_{(T7)\,FUEL} = SE_{(WS20,\,T7)} * [WS20]_{(C20)\,(T7)}$$

and:

$$[WS20]_{(T7)\,(D1)} + [WS20]_{(T7)\,(D3)} = (1 - SE_{(WS20,\,T7)}) * [WS20]_{(C20)\,(T7)}$$

$$[WS21]_{(C20)\,(T7)} = [WS21]_{(T7)\,(D1)} + [WS21]_{(T7)\,(D3)}$$

3.8.6. Anaerobic digestion (T8)

Table 3. 40: Mass flow through treatment option T8

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR}	WS4 = {RCNR}	WS5 = {RNNR}	WS6 = {RCCN}	WS7 = {RCNN}	WS8 = {RNNN}
Potential origin nodes	C0, C1, C9, C10; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C0, C1, C10; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)	C1; C11, C12 (1) ; C7; TR3, TR4, S4 (2) ; S5 (3)
Potential destination nodes	MSW Compost	MSW Compost	FUEL, RECY (4) ; MSW Compost	FUEL, RECY (4) ; D1, D3 as residuals	RECY (4) ; D1, D3 as residuals	FUEL (4) ; MSW Compost	FUEL (4) ; D1, D3 as residuals	D1, D3 as residuals

(1) Enter in any compartment
(2) Enter in black bags
(3) Enter in black bags unloaded from collection C6 truck
(4) Obtained in pre-processing stage

Mass flow equations:

$$[WS1]_{(C0)\,(T8)} + [WS1]_{(C1)\,(T8)} + [WS1]_{(C7)\,(T8)} + [WS1]_{(C9)\,(T8)} + [WS1]_{(C10)\,(T8)} + [WS1]_{(C11)\,(T8)} + [WS1]_{(C12)\,(T8)} + [WS1]_{(TR3)\,(T8)} + [WS1]_{(TR4)\,(T8)} + [WS1]_{(S4)\,(T8)} + [WS1]_{(S5)\,(T8)} = [WS1(MSWCOMP)]_{(T8)\,MSWCOMP} / CRF_{(WS1,\,T8)}$$

$$[WS2]_{(C0)\,(T8)} + [WS2]_{(C1)\,(T8)} + [WS2]_{(C7)\,(T8)} + [WS2]_{(C10)\,(T8)} + [WS2]_{(C11)\,(T8)} + [WS2]_{(C12)\,(T8)} + [WS2]_{(TR3)\,(T8)} + [WS2]_{(TR4)\,(T8)} + [WS2]_{(S4)\,(T8)} + [WS2]_{(S5)\,(T8)} = [WS2(MSWCOMP)]_{(T8)\,MSWCOMP} / CRF_{(WS2,\,T8)}$$

$$[WS3]_{(C1)\,(T8)} + [WS3]_{(C7)\,(T8)} + [WS3]_{(C11)\,(T8)} + [WS3]_{(C12)\,(T8)} + [WS3]_{(TR3)\,(T8)} + [WS3]_{(TR4)\,(T8)} + [WS3]_{(S4)\,(T8)} + [WS3]_{(S5)\,(T8)} = [WS3(MSWCOMP)]_{(T8)\,MSWCOMP} / CRF_{(WS3,\,T8)} + [WS3]_{(T8)\,FUEL} + [WS3]_{(T8)\,REC}$$

where:

$$[WS3]_{(T8)\,FUEL} + [WS3]_{(T8)\,REC} = SE_{(WS3,\,T8)} * ([WS3]_{(C1)\,(T8)} + [WS3]_{(C7)\,(T8)} + [WS3]_{(C11)(T8)} + [WS3]_{(C12)\,(T8)} + [WS3]_{(TR3)\,(T8)} + [WS3]_{(TR4)\,(T8)} + [WS3]_{(S4)\,(T8)} + [WS3]_{(S5)\,(T8)})$$

and:

$$[WS3(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS3,\ T8)} = (1 - SE_{(WS3,\ T8)}) * ([WS3]_{(C1)\ (T8)} + [WS3]_{(C7)\ (T8)} + [WS3]_{(C11)\ (T8)} + [WS3]_{(C12)\ (T8)} + [WS3]_{(TR3)\ (T8)} + [WS3]_{(TR4)\ (T8)} + [WS3]_{(S4)\ (T8)} + [WS3]_{(S5)\ (T8)})$$

$$[WS4]_{(C1)\ (T8)} + [WS4]_{(C7)\ (T8)} + [WS4]_{(C11)\ (T8)} + [WS4]_{(C12)\ (T8)} + [WS4]_{(TR3)\ (T8)} + [WS4]_{(TR4)\ (T8)} + [WS4]_{(S4)\ (T8)} + [WS4]_{(S5)\ (T8)} = [WS4]_{(T8)\ FUEL} + [WS4]_{(T8)\ REC} + [WS4]_{(T8)\ (D1)} + [WS4]_{(T8)\ (D3)}$$

where:

$$[WS4]_{(T8)\ FUEL} + [WS4]_{(T8)\ REC} = SE_{(WS4,\ T8)} * ([WS4]_{(C1)\ (T8)} + [WS4]_{(C7)\ (T8)} + [WS4]_{(C11)\ (T8)} + [WS4]_{(C12)\ (T8)} + [WS4]_{(TR3)\ (T8)} + [WS4]_{(TR4)\ (T8)} + [WS4]_{(S4)\ (T8)} + [WS4]_{(S5)\ (T8)})$$

and:

$$[WS4]_{(T8)\ (D1)} + [WS4]_{(T8)\ (D3)} = (1 - SE_{(WS4,\ T8)}) * ([WS4]_{(C1)\ (T8)} + [WS4]_{(C7)\ (T8)} + [WS4]_{(C11)\ (T8)} + [WS4]_{(C12)\ (T8)} + [WS4]_{(TR3)\ (T8)} + [WS4]_{(TR4)\ (T8)} + [WS4]_{(S4)\ (T8)} + [WS4]_{(S5)\ (T8)})$$

$$[WS5]_{(C1)\ (T8)} + [WS5]_{(C7)\ (T8)} + [WS5]_{(C11)\ (T8)} + [WS5]_{(C12)\ (T8)} + [WS5]_{(TR3)\ (T8)} + [WS5]_{(TR4)\ (T8)} + [WS5]_{(S4)\ (T8)} + [WS5]_{(S5)\ (T8)} = [WS5]_{(T8)\ REC} + [WS5]_{(T8)\ (D1)} + [WS5]_{(T8)\ (D3)}$$

where:

$$[WS5]_{(T8)\ REC} = SE_{(WS5,\ T8)} * ([WS5]_{(C1)\ (T8)} + [WS5]_{(C7)\ (T8)} + [WS5]_{(C11)\ (T8)} + [WS5]_{(C12)\ (T8)} + [WS5]_{(TR3)\ (T8)} + [WS5]_{(TR4)\ (T8)} + [WS5]_{(S4)\ (T8)} + [WS5]_{(S5)\ (T8)})$$

and:

$$[WS5]_{(T8)\ (D1)} + [WS5]_{(T8)\ (D3)} = (1 - SE_{(WS5,\ T8)}) * ([WS5]_{(C1)\ (T8)} + [WS5]_{(C7)\ (T8)} + [WS5]_{(C11)\ (T8)} + [WS5]_{(C12)\ (T8)} + [WS5]_{(TR3)\ (T8)} + [WS5]_{(TR4)\ (T8)} + [WS5]_{(S4)\ (T8)} + [WS5]_{(S5)\ (T8)})$$

$$[WS6]_{(C1)\ (T8)} + [WS6]_{(C7)\ (T8)} + [WS6]_{(C11)\ (T8)} + [WS6]_{(C12)\ (T8)} + [WS6]_{(TR3)\ (T8)} + [WS6]_{(TR4)\ (T8)} + [WS6]_{(S4)\ (T8)} + [WS6]_{(S5)\ (T8)} = [WS6(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS6,\ T8)} + [WS6]_{(T8)\ FUEL}$$

where:

$$[WS6]_{(T8)\ FUEL} = SE_{(WS6,\ T8)} * ([WS6]_{(C1)\ (T8)} + [WS6]_{(C7)\ (T8)} + [WS6]_{(C11)\ (T8)} + [WS6]_{(C12)\ (T8)} + [WS6]_{(TR3)\ (T8)} + [WS6]_{(TR4)\ (T8)} + [WS6]_{(S4)\ (T8)} + [WS6]_{(S5)\ (T8)})$$

and:

$[WS6(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS6,\ T8)} = (1 - SE_{(WS6,\ T8)}) * ([WS6]_{(C1)\ (T8)} + [WS6]_{(C7)\ (T8)} + [WS6]_{(C11)\ (T8)} + [WS6]_{(C12)\ (T8)} + [WS6]_{(TR3)\ (T8)} + [WS6]_{(TR4)\ (T8)} + [WS6]_{(S4)\ (T8)} + [WS6]_{(S5)\ (T8)})$

$[WS7]_{(C1)\ (T8)} + [WS7]_{(C7)\ (T8)} + [WS7]_{(C11)\ (T8)} + [WS7]_{(C12)\ (T8)} + [WS7]_{(TR3)\ (T8)} + [WS7]_{(TR4)\ (T8)} + [WS7]_{(S4)\ (T8)} + [WS7]_{(S5)\ (T8)} = [WS7]_{(T8)\ FUEL} + [WS7]_{(T8)\ (D1)} + [WS7]_{(T8)\ (D3)}$

where:

$[WS7]_{(T8)\ FUEL} = SE_{(WS7,\ T8)} * ([WS7]_{(C1)\ (T8)} + [WS7]_{(C7)\ (T8)} + [WS7]_{(C11)\ (T8)} + [WS7]_{(C12)\ (T8)} + [WS7]_{(TR3)\ (T8)} + [WS7]_{(TR4)\ (T8)} + [WS7]_{(S4)\ (T8)} + [WS7]_{(S5)\ (T8)})$

and:

$[WS7]_{(T8)\ (D1)} + [WS7]_{(T8)\ (D3)} = (1 - SE_{(WS7,\ T8)}) * ([WS7]_{(C1)\ (T8)} + [WS7]_{(C7)\ (T8)} + [WS7]_{(C11)\ (T8)} + [WS7]_{(C12)\ (T8)} + [WS7]_{(TR3)\ (T8)} + [WS7]_{(TR4)\ (T8)} + [WS7]_{(S4)\ (T8)} + [WS7]_{(S5)\ (T8)})$

$[WS8]_{(C1)\ (T8)} + [WS8]_{(C7)\ (T8)} + [WS8]_{(C11)\ (T8)} + [WS8]_{(C12)\ (T8)} + [WS8]_{(TR3)\ (T8)} + [WS8]_{(TR4)\ (T8)} + [WS8]_{(S4)\ (T8)} + [WS8]_{(S5)\ (T8)} = [WS8]_{(T8)\ (D1)} + [WS8]_{(T8)\ (D3)}$

Table 3.40 (continued)

Waste stream sets (WS)	WS9 = {MYTL, MYTO}	WS10 = {MCCR}	WS11 = {MCNR}	WS12 = {MNNR}	WS13 = {MCCN}	WS14 = {MCNN}	WS15 = {MNNN}
Potential origin nodes	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)	C13, C16, C17, C18 (1)
Potential destination nodes	MSW Compost	FUEL, RECY (2) ; MSW Compost	FUEL, RECY (2); D1, D3 as residuals	RECY (2); D1, D3 as residuals	FUEL (2) ; MSW Compost	FUEL(2); D1, D3 as residuals	D1 and D3 as residuals

(1) Enter in any compartment
(2) Obtained in pre-processing stage

Mass flow equations:

$[WS9]_{(C13)\ (T8)} + [WS9]_{(C16)\ (T8)} + [WS9]_{(C17)\ (T8)} + [WS9]_{(C18)\ (T8)} = [WS9(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS9,\ T8)}$

$[WS10]_{(C13)\ (T8)} + [WS10]_{(C16)\ (T8)} + [WS10]_{(C17)\ (T8)} + [WS10]_{(C18)\ (T8)} = [WS10(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS10,\ T8)} + [WS10]_{(T8)\ FUEL} + [WS10]_{(T8)\ REC}$

where:

$$[WS10]_{(T8)\ FUEL} + [WS10]_{(T8)\ REC} = SE_{(WS10,\ T8)} * ([WS10]_{(C13)\ (T8)} + [WS10]_{(C16)\ (T8)} + [WS10]_{(C17)\ (T8)} + [WS10]_{(C18)\ (T8)})$$

and:

$$[WS10(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS10,\ T8)} = (1 - SE_{(WS10,\ T8)}) * ([WS10]_{(C13)\ (T8)} + [WS10]_{(C16)\ (T8)} + [WS10]_{(C17)\ (T8)} + [WS10]_{(C18)\ (T8)})$$

$$[WS11]_{(C13)\ (T8)} + [WS11]_{(C16)\ (T8)} + [WS11]_{(C17)\ (T8)} + [WS11]_{(C18)\ (T8)} = [WS11]_{(T8)\ FUEL} + [WS11]_{(T8)\ REC} + [WS11]_{(T8)\ (D1)} + [WS11]_{(T8)\ (D3)}$$

where:

$$[WS11]_{(T8)\ FUEL} + [WS11]_{(T8)\ REC} = SE_{(WS11,\ T8)} * ([WS11]_{(C13)\ (T8)} + [WS11]_{(C16)\ (T8)} + [WS11]_{(C17)\ (T8)} + [WS11]_{(C18)\ (T8)})$$

and:

$$[WS11]_{(T8)\ (D1)} + [WS11]_{(T8)\ (D3)} = (1 - SE_{(WS11,\ T8)}) * ([WS11]_{(C13)\ (T8)} + [WS11]_{(C16)\ (T8)} + [WS11]_{(C17)\ (T8)} + [WS11]_{(C18)\ (T8)})$$

$$[WS12]_{(C13)\ (T8)} + [WS12]_{(C16)\ (T8)} + [WS12]_{(C17)\ (T8)} + [WS12]_{(C18)\ (T8)} = [WS12]_{(T8)\ REC} + [WS12]_{(T8)\ (D1)} + [WS12]_{(T8)\ (D3)}$$

where:

$$[WS12]_{(T8)\ REC} = SE_{(WS12,\ T8)} * ([WS12]_{(C13)\ (T8)} + [WS12]_{(C16)\ (T8)} + [WS12]_{(C17)\ (T8)} + [WS12]_{(C18)\ (T8)})$$

and:

$$[WS12]_{(T8)\ (D1)} + [WS12]_{(T8)\ (D3)} = (1 - SE_{(WS12,\ T8)}) * ([WS12]_{(C13)\ (T8)} + [WS12]_{(C16)\ (T8)} + [WS12]_{(C17)\ (T8)} + [WS12]_{(C18)\ (T8)})$$

$$[WS13]_{(C13)\ (T8)} + [WS13]_{(C16)\ (T8)} + [WS13]_{(C17)\ (T8)} + [WS13]_{(C18)\ (T8)} = [WS13(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS13,\ T8)} + [WS13]_{(T8)\ FUEL}$$

where:

$$[WS13]_{(T8)\ FUEL)} = SE_{(WS13,\ T8)} * ([WS13]_{(C13)\ (T8)} + [WS13]_{(C16)\ (T8)} + [WS13]_{(C17)\ (T8)} + [WS13]_{(C18)\ (T8)})$$

and:

$$[WS13(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS13,\ T8)} = (1 - SE_{(WS13,\ T8)}) * ([WS13]_{(C13)\ (T8)} + [WS13]_{(C16)\ (T8)} + [WS13]_{(C17)\ (T8)} + [WS13]_{(C18)\ (T8)})$$

$[WS14]_{(C13)(T8)} + [WS14]_{(C16)(T8)} + [WS14]_{(C17)(T8)} + [WS14]_{(C18)(T8)} = [WS14]_{(T8)\,FUEL} + [WS14]_{(T8)(D1)} + [WS14]_{(T8)(D3)}$

where:

$[WS14]_{(T8)\,FUEL} = SE_{(WS14,\,T8)} * ([WS14]_{(C13)(T8)} + [WS14]_{(C16)(T8)} + [WS14]_{(C17)(T8)} + [WS14]_{(C18)(T8)})$

and:

$[WS14]_{(T8)(D1)} + [WS14]_{(T8)(D3)} = (1 - SE_{(WS14,\,T8)}) * ([WS14]_{(C13)(T8)} + [WS14]_{(C16)(T8)} + [WS14]_{(C17)(T8)} + [WS14]_{(C18)(T8)})$

$[WS15]_{(C13)(T8)} + [WS15]_{(C16)(T8)} + [WS15]_{(C17)(T8)} + [WS15]_{(C18)(T8)} = [WS15]_{(T8)(D1)} + [WS15]_{(T8)(D3)}$

Table 3.40 (continued)

Waste stream sets (WS)	WS16 = {CCCR}	WS17 = {CCNR}	WS18 = {CNNR}	WS19 = {CCCN}	WS20 = {CCNN}	WS21 = {CNNN}
Potential origin nodes	C20	C20	C20	C20	C20	C20
Potential destination nodes	FUEL, RECY(1) ; MSW Compost	FUEL, RECY (1) ; D1, D3 as residuals	RECY (1) ; D1, D3 as residuals	FUEL (1) ; MSW Compost	FUEL(1) ; D1, D3 as residuals	D1, D3 as residuals

(1) Obtained in pre-processing stage

Mass flow equations:

$[WS16]_{(C20)(T8)} = [WS16(MSWCOMP)]_{(T8)\,MSWCOMP} / CRF_{(WS16,\,T8)} + [WS16]_{(T8)\,FUEL} + [WS16]_{(T8)\,REC}$

where:

$[WS16]_{(T8)\,FUEL} + [WS16]_{(T8)\,REC} = SE_{(WS16,\,T8)} * [WS16]_{(C20)(T8)}$

and:

$[WS16(MSWCOMP)]_{(T8)\,MSWCOMP} / CRF_{(WS16,\,T8)} = (1 - SE_{(WS16,\,T8)}) * [WS16]_{(C20)(T8)}$

$[WS17]_{(C20)(T8)} = [WS17]_{(T8)\,FUEL} + [WS17]_{(T8)\,REC} + [WS17]_{(T8)(D1)} + [WS17]_{(T8)(D3)}$

where:

$[WS17]_{(T8)\,FUEL} + [WS17]_{(T8)\,REC} = SE_{(WS17,\,T8)} * [WS17]_{(C20)(T8)}$

and:

$[WS17]_{(T8)(D1)} + [WS17]_{(T8)(D3)} = (1 - SE_{(WS17,\,T8)}) * [WS17]_{(C20)(T8)}$

$[WS18]_{(C20)(T8)} = [WS18]_{(T8)(D1)} + [WS18]_{(T8)(D3)} + [WS18]_{(T8)\,REC}$

where:
$[WS18]_{(T8)\ REC} = SE_{(WS18,\ T8)} * [WS18]_{(C20)\ (T8)}$

and:
$[WS18]_{(T8)\ (D1)} + [WS18]_{(T8)\ (D3)} = (1- SE_{(WS18,\ T8)}) * [WS18]_{(C20)\ (T8)}$

$[WS19]_{(C20)\ (T8)} = [WS19(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS19,\ T8)} + [WS19]_{(T8)\ FUEL}$

where:
$[WS19]_{(T8)\ FUEL} = SE_{(WS19,\ T8)} * [WS19]_{(C20)\ (T8)}$

and:
$[WS19(MSWCOMP)]_{(T8)\ MSWCOMP} / CRF_{(WS19,\ T8)} = (1 - SE_{(WS19,\ T8)}) * [WS19]_{(C20)\ (T8)}$

$[WS20]_{(C20)\ (T8)} = [WS20]_{(T8)\ FUEL} + [WS20]_{(T8)\ (D1)} + [WS20]_{(T8)\ (D3)}$

where:
$[WS20]_{(T8)\ FUEL} = SE_{(WS20,\ T8)} * [WS20]_{(C20)\ (T8)}$

and:
$[WS20]_{(T8)\ (D1)} + [WS20]_{(T8)\ (D3)} = (1- SE_{(WS20,\ T8)}) * [WS20]_{(C20)\ (T8)}$

$[WS21]_{(C20)\ (T8)} = [WS21]_{(T8)\ (D1)} + [WS21]_{(T8)\ (D3)}$

3.9. Disposal nodes

There are three disposal options: landfill, ash mono-landfill and enhanced bioreactor. Solid wastes are disposed of at these facilities, and no solid waste flows out of them. Wastes only flow out the disposal options as leachate or landfill gases due to decomposition, but these waste transformations are not represented in the mass flow equations.

3.9.1. Landfill (D1)

Table 3. 41: Mass flow through disposal option D1

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR}	WS4 = {RCNR, RNNR}	WS5 = {RCCN}	WS6 = {RCNN, RNNN}
Potential origin nodes	C0, C1, C7, C9, C10, C11, C12, TR1, TR3, TR4, RT2, S1, S4, S5, T5	C0, C1, C7, C10, C11, C12, TR1, TR3, TR4, RT2 S1, S4, S5 T5	C1, C7, C11, C12, TR1, TR3, TR4, RT2, S1, S3, S4, S5, T5	C1, C7, C11, C12, TR1,TR3, TR4, RT2, S1, S3, S4, S5, T5, T7, T8	C1, C7, C11, C12, TR1, TR3, TR4, RT2, S1, S4, S5, T5	C1, C7, C11, C12, TR1, TR3, TR4, RT2, S1, S4, S5, T5, T7, T8

Mass flow equations:

$$[WS1]_{(TOTAL)\,(D1)} = [WS1]_{(C0)\,(D1)} + [WS1]_{(C1)\,(D1)} + [WS1]_{(C7)\,(D1)} + [WS1]_{(C9)\,(D1)} + [WS1]_{(C10)\,(D1)} + [WS1]_{(C11)\,(D1)} + [WS1]_{(C12)\,(D1)} + [WS1]_{(TR1)\,(D1)} + [WS1]_{(TR3)\,(D1)} + [WS1]_{(TR4)\,(D1)} + [WS1]_{(RT2)\,(D1)} + [WS1]_{(S1)\,(D1)} + [WS1]_{(S4)\,(D1)} + [WS1]_{(S5)\,(D1)} + [WS1]_{(T5)\,(D1)}$$

$$[WS2]_{(TOTAL)\,(D1)} = [WS2]_{(C0)\,(D1)} + [WS2]_{(C1)\,(D1)} + [WS2]_{(C7)\,(D1)} + [WS2]_{(C10)\,(D1)} + [WS2]_{(C11)\,(D1)} + [WS2]_{(C12)\,(D1)} + [WS2]_{(TR1)\,(D1)} + [WS2]_{(TR3)\,(D1)} + [WS2]_{(TR4)\,(D1)} + [WS2]_{(RT2)\,(D1)} + [WS2]_{(S1)\,(D1)} + [WS2]_{(S4)\,(D1)} + [WS2]_{(S5)\,(D1)} + [WS2]_{(T5)\,(D1)}$$

$$[WS3]_{(TOTAL)\,(D1)} = [WS3]_{(C1)\,(D1)} + [WS3]_{(C7)\,(D1)} + [WS3]_{(C11)\,(D1)} + [WS3]_{(C12)\,(D1)} + [WS3]_{(TR1)\,(D1)} + [WS3]_{(TR3)\,(D1)} + [WS3]_{(TR4)\,(D1)} + [WS3]_{(RT2)\,(D1)} + [WS3]_{(S1)\,(D1)} + [WS3]_{(S3)\,(D1)} + [WS3]_{(S4)\,(D1)} + [WS3]_{(S5)\,(D1)} + [WS3]_{(T5)\,(D1)}$$

$$[WS4]_{(TOTAL)\,(D1)} = [WS4]_{(C1)\,(D1)} + [WS4]_{(C7)\,(D1)} + [WS4]_{(C11)\,(D1)} + [WS4]_{(C12)\,(D1)} \quad [WS4]_{(TR1)\,(D1)} + [WS4]_{(TR3)\,(D1)} + [WS4]_{(TR4)\,(D1)} + [WS4]_{(RT2)\,(D1)} + [WS4]_{(S1)\,(D1)} + [WS4]_{(S3)\,(D1)} + [WS4]_{(S4)\,(D1)} + [WS4]_{(S5)\,(D1)} + [WS4]_{(T5)\,(D1)} + [WS4]_{(T7)\,(D1)} + [WS4]_{(T8)\,(D1)}$$

$$[WS5]_{(TOTAL)\,(D1)} = [WS5]_{(C1)\,(D1)} + [WS5]_{(C7)\,(D1)} + [WS5]_{(C11)\,(D1)} + [WS5]_{(C12)\,(D1)} + [WS5]_{(TR1)\,(D1)} + [WS5]_{(TR3)\,(D1)} + [WS5]_{(TR4)\,(D1)} + [WS5]_{(RT2)\,(D1)} + [WS5]_{(S1)\,(D1)} + [WS5]_{(S4)\,(D1)} + [WS5]_{(S5)\,(D1)} + [WS5]_{(T5)\,(D1)}$$

$$[WS6]_{(TOTAL)\,(D1)} = [WS6]_{(C1)\,(D1)} + [WS6]_{(C7)\,(D1)} + [WS6]_{(C11)\,(D1)} + [WS6]_{(C12)\,(D1)} + [WS6]_{(TR1)\,(D1)} + [WS6]_{(TR3)\,(D1)} + [WS6]_{(TR4)\,(D1)} + [WS6]_{(RT2)\,(D1)} + [WS6]_{(S1)\,(D1)} + [WS6]_{(S4)\,(D1)} + [WS6]_{(S5)\,(D1)} + [WS6]_{(T5)\,(D1)} + [WS6]_{(T7)\,(D1)} + [WS6]_{(T8)\,(D1)}$$

Table 3.41 (continued)

Waste stream sets (WS)	WS7 = {MYTL, MYTO}	WS8 = {MCCR}	WS9 = {MCNR, MNNR}	WS10 = {MCCN}	WS11 = {MCNN, MNNN}	WS12 = {CCCR, CCCN}	WS13 = {CCNR, CNNR, CCNN, CNNN}
Potential origin nodes	C13, C16, C17, C18, TR1, RT2, S1, T5	C13, C16, C17, C18, TR1, RT2, S1, S3, T5	C13, C16, C17, C18, TR1, RT2, S1, S3, T5, T7, T8	C13, C16, C17, C18, TR1, RT2, S1, T5	C13, C16, C17, C18, TR1, RT2, S1, T5, T7, T8	C20, TR1, RT2, S1, T5	C20, TR1, RT2, S1, T5, T7, T8

Mass flow equations:

$$[WS7]_{(TOTAL)\,(D1)} = [WS7]_{(C13)\,(D1)} + [WS7]_{(C16)\,(D1)} + [WS7]_{(C17)\,(D1)} + [WS7]_{(C18)\,(D1)} + [WS7]_{(TR1)\,(D1)} + [WS7]_{(RT2)\,(D1)} + [WS7]_{(S1)\,(D1)} + [WS7]_{(T5)\,(D1)}$$

$$[WS8]_{(TOTAL)\,(D1)} = [WS8]_{(C13)\,(D1)} + [WS8]_{(C16)\,(D1)} + [WS8]_{(C17)\,(D1)} + [WS8]_{(C18)\,(D1)} + [WS8]_{(TR1)\,(D1)} + [WS8]_{(RT2)\,(D1)} + [WS8]_{(S1)\,(D1)} + [WS8]_{(S3)\,(D1)} + [WS8]_{(T5)\,(D1)}$$

$$[WS9]_{(TOTAL)\,(D1)} = [WS9]_{(C13)\,(D1)} + [WS9]_{(C16)\,(D1)} + [WS9]_{(C17)\,(D1)} + [WS9]_{(C18)\,(D1)} + [WS9]_{(TR1)\,(D1)} + [WS9]_{(RT2)\,(D1)} + [WS9]_{(S1)\,(D1)} + [WS9]_{(S3)\,(D1)} + [WS9]_{(T5)\,(D1)} + [WS9]_{(T7)\,(D1)} + [WS9]_{(T8)\,(D1)}$$

$$[WS10]_{(TOTAL)\,(D1)} = [WS10]_{(C13)\,(D1)} + [WS10]_{(C16)\,(D1)} + [WS10]_{(C17)\,(D1)} + [WS10]_{(C18)\,(D1)} + [WS10]_{(TR1)\,(D1)} + [WS10]_{(RT2)\,(D1)} + [WS10]_{(S1)\,(D1)} + [WS10]_{(T5)\,(D1)}$$

$$[WS11]_{(TOTAL)\,(D1)} = [WS11]_{(C13)\,(D1)} + [WS11]_{(C16)\,(D1)} + [WS11]_{(C17)\,(D1)} + [WS11]_{(C18)\,(D1)} + [WS11]_{(TR1)\,(D1)} + [WS11]_{(RT2)\,(D1)} + [WS11]_{(S1)\,(D1)} + [WS11]_{(T5)\,(D1)} + [WS11]_{(T7)\,(D1)} + [WS11]_{(T8)\,(D1)}$$

$$[WS12]_{(TOTAL)\,(D1)} = [WS12]_{(C20)\,(D1)} + [WS12]_{(TR1)\,(D1)} + [WS12]_{(RT2)\,(D1)} + [WS12]_{(S1)\,(D1)} + [WS12]_{(T5)\,(D1)}$$

$$[WS13]_{(TOTAL)\,(D1)} = [WS13]_{(C20)\,(D1)} + [WS13]_{(TR1)\,(D1)} + [WS13]_{(RT2)\,(D1)} + [WS13]_{(S1)\,(D1)} + [WS13]_{(T5)\,(D1)} + [WS13]_{(T7)\,(D1)} + [WS13]_{(T8)\,(D1)}$$

3.9.2. Ash landfill (D2)

Table 3. 42: Mass flow through disposal option D2

Waste stream sets (WS)	WS = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN, RNNN, MYTL, MYTO, MCCR, MCNR, MNNR, MCCN, MCNN, MNNN, CCCR, CCNR, CNNR, CCCN, CCNN, CNNN}
Potential origin nodes	Ashes from combustion facility T3

Mass flow equations:

$$[WS(ASH)]_{(TOTAL)\,(D2)} = [WS(ASH)]_{(T3)\,(D2)}$$

3.9.3. Enhanced Bioreactor (D3)

Table 3. 43: Mass flow through disposal option D3

Waste stream sets (WS)	WS1 = {RYTL}	WS2 = {RYTO}	WS3 = {RCCR}	WS4 = {RCNR, RNNR}	WS5 = {RCCN}	WS6 = {RCNN, RNNN}
Potential origin nodes	C0, C1, C7, C9, C10, C11, C12, TR1, TR3, TR4, RT3, S1, S4, S5, T5	C0, C1, C7, C10, C11, C12, TR1, TR3, TR4, RT3 S1, S4, S5 T5	C1, C7, C11, C12, TR1, TR3, TR4, RT3, S1, S3, S4, S5, T5	C1, C7, C11, C12, TR1, TR3, TR4, RT3, S1, S3, S4, S5, T5, T7, T8	C1, C7, C11, C12, TR1, TR3, TR4, RT3, S1, S4, S5, T5	C1, C7, C11, C12, TR1, TR3, TR4, RT3, S1, S4, S5, T5, T7, T8

Mass flow equations:

$$[WS1]_{(TOTAL)\,(D3)} = [WS1]_{(C0)\,(D3)} + [WS1]_{(C1)\,(D3)} + [WS1]_{(C7)\,(D3)} + [WS1]_{(C9)\,(D3)} + [WS1]_{(C10)\,(D3)} + [WS1]_{(C11)\,(D3)} + [WS1]_{(C12)\,(D3)} + [WS1]_{(TR1)\,(D3)} + [WS1]_{(TR3)\,(D3)} + [WS1]_{(TR4)\,(D3)} + [WS1]_{(RT3)\,(D3)} + [WS1]_{(S1)\,(D3)} + [WS1]_{(S4)\,(D3)} + [WS1]_{(S5)\,(D3)} + [WS1]_{(T5)\,(D3)}$$

$$[WS2]_{(TOTAL)\,(D3)} = [WS2]_{(C0)\,(D3)} + [WS2]_{(C1)\,(D3)} + [WS2]_{(C7)\,(D3)} + [WS2]_{(C10)\,(D3)} + [WS2]_{(C11)\,(D3)} + [WS2]_{(C12)\,(D3)} + [WS2]_{(TR1)\,(D3)} + [WS2]_{(TR3)\,(D3)} + [WS2]_{(TR4)\,(D3)} + [WS2]_{(RT3)\,(D3)} + [WS2]_{(S1)\,(D3)} + [WS2]_{(S4)\,(D3)} + [WS2]_{(S5)\,(D3)} + [WS2]_{(T5)\,(D3)}$$

$$[WS3]_{(TOTAL)\,(D3)} = [WS3]_{(C1)\,(D3)} + [WS3]_{(C7)\,(D3)} + [WS3]_{(C11)\,(D3)} + [WS3]_{(C12)\,(D3)} + [WS3]_{(TR1)\,(D3)} + [WS3]_{(TR3)\,(D3)} + [WS3]_{(TR4)\,(D3)} + [WS3]_{(RT3)\,(D3)} + [WS3]_{(S1)\,(D3)} + [WS3]_{(S3)\,(D3)} + [WS3]_{(S4)\,(D3)} + [WS3]_{(S5)\,(D3)} + [WS3]_{(T5)\,(D3)}$$

$$[WS4]_{(TOTAL)(D3)} = [WS4]_{(C1)(D3)} + [WS4]_{(C7)(D3)} + [WS4]_{(C11)(D3)} + [WS4]_{(C12)(D3)} \; [WS4]_{(TR1)(D3)} + [WS4]_{(TR3)(D3)} + [WS4]_{(TR4)(D3)} + [WS4]_{(RT3)(D3)} + [WS4]_{(S1)(D3)} + [WS4]_{(S3)(D3)} + [WS4]_{(S4)(D3)} + [WS4]_{(S5)(D3)} + [WS4]_{(T5)(D3)} + [WS4]_{(T7)(D3)} + [WS4]_{(T8)(D3)}$$

$$[WS5]_{(TOTAL)(D3)} = [WS5]_{(C1)(D3)} + [WS5]_{(C7)(D3)} + [WS5]_{(C11)(D3)} + [WS5]_{(C12)(D3)} + [WS5]_{(TR1)(D3)} + [WS5]_{(TR3)(D3)} + [WS5]_{(TR4)(D3)} + [WS5]_{(RT3)(D3)} + [WS5]_{(S1)(D3)} + [WS5]_{(S4)(D3)} + [WS5]_{(S5)(D3)} + [WS5]_{(T5)(D3)}$$

$$[WS6]_{(TOTAL)(D3)} = [WS6]_{(C1)(D3)} + [WS6]_{(C7)(D3)} + [WS6]_{(C11)(D3)} + [WS6]_{(C12)(D3)} + [WS6]_{(TR1)(D3)} + [WS6]_{(TR3)(D3)} + [WS6]_{(TR4)(D3)} + [WS6]_{(RT3)(D3)} + [WS6]_{(S1)(D3)} + [WS6]_{(S4)(D3)} + [WS6]_{(S5)(D3)} + [WS6]_{(T5)(D3)} + [WS6]_{(T7)(D3)} + [WS6]_{(T8)(D3)}$$

Table 3.43 (continued)

Waste stream sets (WS)	WS7 = {MYTL, MYTO}	WS8 = {MCCR}	WS9 = {MCNR, MNNR}	WS10 = {MCCN}	WS11 = {MCNN, MNNN}	WS12 = {CCCR, CCCN}	WS13 = {CCNR, CNNR, CCNN, CNNN}
Potential origin nodes	C13, C16, C17, C18, TR1, RT3, S1, T5	C13, C16, C17, C18, TR1, RT3, S1, S3, T5	C13, C16, C17, C18, TR1, RT3 S1, S3, T5, T7, T8	C13, C16, C17, C18, TR1, RT3, S1, T5	C13, C16, C17, C18, TR1 RT3, S1, T5, T7, T8	C20, TR1, RT3, S1, T5	C20, TR1, RT3 S1, T5, T7, T8

Mass flow equations:

$$[WS7]_{(TOTAL)(D3)} = [WS7]_{(C13)(D3)} + [WS7]_{(C16)(D3)} + [WS7]_{(C17)(D3)} + [WS7]_{(C18)(D3)} + [WS7]_{(TR1)(D3)} + [WS7]_{(RT3)(D3)} + [WS7]_{(S1)(D3)} + [WS7]_{(T5)(D3)}$$

$$[WS8]_{(TOTAL)(D3)} = [WS8]_{(C13)(D3)} + [WS8]_{(C16)(D3)} + [WS8]_{(C17)(D3)} + [WS8]_{(C18)(D3)} + [WS8]_{(TR1)(D3)} + [WS8]_{(RT3)(D3)} + [WS8]_{(S1)(D3)} + [WS8]_{(S3)(D3)} + [WS8]_{(T5)(D3)}$$

$$[WS9]_{(TOTAL)(D3)} = [WS9]_{(C13)(D3)} + [WS9]_{(C16)(D3)} + [WS9]_{(C17)(D3)} + [WS9]_{(C18)(D3)} + [WS9]_{(TR1)(D3)} + [WS9]_{(RT3)(D3)} + [WS9]_{(S1)(D3)} + [WS9]_{(S3)(D3)} + [WS9]_{(T5)(D3)} + [WS9]_{(T7)(D3)} + [WS9]_{(T8)(D3)}$$

$$[WS10]_{(TOTAL)(D3)} = [WS10]_{(C13)(D3)} + [WS10]_{(C16)(D3)} + [WS10]_{(C17)(D3)} + [WS10]_{(C18)(D3)} + [WS10]_{(TR1)(D3)} + [WS10]_{(RT3)(D3)} + [WS10]_{(S1)(D3)} + [WS10]_{(T5)(D3)}$$

$$[WS11]_{(TOTAL)(D3)} = [WS11]_{(C13)(D3)} + [WS11]_{(C16)(D3)} + [WS11]_{(C17)(D3)} + [WS11]_{(C18)(D3)} + [WS11]_{(TR1)(D3)} + [WS11]_{(RT3)(D3)} + [WS11]_{(S1)(D3)} + [WS11]_{(T5)(D3)} + [WS11]_{(T7)(D3)} + [WS11]_{(T8)(D3)}$$

$$[WS12]_{(TOTAL)(D3)} = [WS12]_{(C20)\ (D3)} + [WS12]_{(TR1)\ (D3)} + [WS12]_{(S1)\ (D3)} + [WS12]_{(T5)\ (D3)}$$

$$[WS13]_{(TOTAL)(D3)} = [WS13]_{(C20)\ (D3)} + [WS13]_{(TR1)\ (D3)} + [WS13]_{(RT3)\ (D3)} + [WS13]_{(S1)\ (D3)} + [WS13]_{(T5)\ (D3)} + [WS13]_{(T7)\ (D3)} + [WS13]_{(T8)\ (D3)}$$

Chapter 4: Model Definition

The mathematical optimization model developed for this study uses an LP formulation. The mass flow equations described in Chapter 3 represent the primary set of constraints in this optimization model. Additional constraints to represent specific requirements and restrictions such as minimum diversion rates, exclusion of a SWM option, or requiring an SWM option to be included in the final SWM strategy, can be also added to the set of constraints. The objective function used in this study defines the net annual cost of a SWM strategy. The solution to this model represents a solid waste management strategy defined by the best combination of collection, separation, treatment and disposal options, and the waste items, if any, to be recovered.

4.1. Notations

4.1.1. Decision variables

The decision variables are defined according to the following general structure:

$$\textbf{Variable}_{\textbf{subscript 1, subscript 2, subscript 3, subscript 4}}$$

Where:

subscript 1: subscript to indicate the generation sector
subscript 2: subscript to indicate the potential origin of waste
subscript 3: subscript to indicate the potential destination of waste
subscript 4: subscript to indicate the waste stream item
Note: Some of the variables have only the first three subscripts.

The generation sectors are the residential, multi-family and commercial sectors. The origin nodes are generation (G), collection (C), transfer stations (TF), separation (S) and treatment (TR). The potential destination nodes are collection, transfer stations, separation, treatment and disposal (D). The waste stream items were described in Chapter 2.

Each decision variable represents a fraction that can take values from 0 to 1. The product of a decision variable and the total mass of solid waste generated in a generation sector represents the total mass of waste generated in that sector flowing from the potential origin node to the potential destination node.

4.1.2. Definition of sets

To simplify the presentation of the equations in this chapter, a group of set variables are introduced. Their definitions are as follows.

Set of generation nodes:

S = {residential, multi-family, commercial}

Set of origin nodes:

A = {generation, collection, transfer, separation, treatment}

Set of destination nodes:

Z = {collection, transfer, separation, treatment, disposal}

Set of all waste stream items:

W = {RYTL, RYTO, RCCR, RCNR, RNNR, RCCN, RCNN,
RNNN, MYTL, MTYO, MCCR, MCNR, MNNR, MCCN,
MCNN, MNNN, CCCR, CCNR, CNNR, CCCN, CCNN,
CNNN}

Set of all recyclable items:

RW = {RCCR, RCNR, RNNR, MCCR, MCNR, MNNR, CCCR, CCNR,
CNNR}

Set of all products:

P = {recyclables, yardwaste compost, mixed waste compost, refuse to derive
fuel}

Set of all residential collection options:

RC = {yardwaste collection, mixed waste collection, recyclables collection,
co-collection, wet-dry system collection, residuals collection} =
{C0, C1, C2, C3, C4, C5, C6, C7, C8, C9, C10, C11, C12}

Set of all multi-family collection options:

MC = {mixed waste collection, recyclables collection, residual collection,
wet-dry system collection} =
{C8, C13, C14, C15, C16, C17, C18}

Set of all commercial collection options:

CC = {mixed waste collection, recyclables collection} =
{C19, C20}

Set of all collection options:

$C = RC \cup MC \cup CC$

Set of all transfer options:

TF = {mixed waste transfer, pre-sorted recyclables transfer, commingled recyclables transfer, co-collected waste transfer} =
{TR1, TR2, TR3, TR4, TR5}

Set of all rail transfer stations:

R = {RT1, RT2, RT3}

Set of all separation options:

SE = {mixed waste MRF, pre-sorted recyclables MRF, commingled recyclables MRF, co-collected waste MRFs} =
{S1, S2, S3, S4, S5}

Set of all treatment options:

TR = {yardwaste compost, combustion, RDF, mixed waste composting, anaerobic digestion} =
{T1, T3, T5, T7, T8}

Set of all disposal options:

D = {dry landfill, ash mono-landfill, wet landfill} =
{D1, D2, D3}

4.2. Objective function

The objective function is the total net cost of the solid waste management strategy. The total net cost is equal to the difference between the total cost and the total revenues. The total cost is the sum of collection, transfer, separation, transportation, treatment and disposal costs. The revenues are the sum of the revenues from sale of recyclable material, waste as fuel, compost product, landfill gas and electricity generated at the combustion plant. The objective function is defined in Equation (1).

$$\textbf{Total\_NetCost} = \textbf{Total\_Cost} - \textbf{Revenues} \quad (1)$$

The quantity **Total_Cost** is defined in Equation (2) and the quantity **Revenues** is defined in Equation (3).

$$\textbf{Total\_Cost} = \sum_{i \in S} \sum_{j \in A} \sum_{k \in Z} \sum_{w \in W} \text{costcoeff}_{k,w} * \text{SWAG}_i * \mathbf{XT}_{i,j,k,w} \quad (2)$$

where:
$\mathbf{XT}_{i,j,k,w}$: is the decision variable that represents the mass fraction of a waste item w from a generation sector i, flowing from a potential origin node j to a potential destination node k,
SWAG i : is the actual generation of solid waste in generation sector i (ton/year),
$\text{costcoeff}_{k,w}$: is the cost coefficient associated with processing a waste item w in a management node k (\$/ton/year),

$$\textbf{Revenues} = \sum_{i \in S} \sum_{j \in A} \sum_{p \in P} \sum_{w \in W} \text{revcoeff}_{j,p,w} * \text{SWAG}_i * \mathbf{XT}_{i,j,p,w}$$

$$+ \sum_{i \in S} \sum_{j \in A} \text{electvalue} * \text{combusteff} * \text{averfuelcont} * \text{SWAG}_i * \mathbf{XT}_{i,j,k=T3} \quad (3)$$

where:
$\mathbf{XT}_{i,j,p,w}$: is the decision variable that represents the mass fraction of a waste stream item w from a generation sector i, processed at a management option j and leaving as a recoverable product p (recyclables, waste as fuel or compost),
$\mathbf{XT}_{i,j,k=T3}$: is the decision variable that represents the mass fraction of MSW from a generation sector i, flowing from a potential generation node j to the combustion facility T3,
$\text{revcoeff}_{j,p,w}$: is the revenue coefficient associated with a waste item w recovered as a product p at a management option j (\$/ton-year),
electvalue: is the value of generated electricity (\$/BTU),
combusteff: is the efficiency of the combustion facility, ($0 \le \text{combusteff} \le 1$),
averfuelcont: is the average value for the energy content of MSW (BTU/ton),
SWAG_i : is the actual generation of solid waste in generation sector i (ton/year).

4.3. Mass flow constraints

The mass flow constraints ensure mass conservation at the management nodes. A constraint represents a relationship between mass fractions flowing from all potential origins into a node and mass fractions flowing out to all potential destinations. They prevent waste stream items from entering nodes into which they can not enter. In this section, the mass flow constraints are organized by management nodes.

4.3.1. Constraints for the generation node

The generation node has two important groups of constraints. The first group of constraints, represented by Equation (4), ensures that all MSW generated in a sector is collected by one collection option or a combination of collection options available for that sector. The second group of constraints, represented by Equations (5) and (6), ensures that the total amount of each waste stream item collected is equal to the actual generation of that item.

I) Mass flows from generation to collection

$$\sum_{k \in C} \sum_{w \in W} \mathbf{XT}_{\mathbf{i,\, j\, =\, generation,\, k,\, w}} = 1.0 \qquad \forall\, i \in S \qquad (4)$$

where:
$\mathbf{XT}_{\mathbf{i,\, j\, =\, generation,\, k,\, w}}$: is the mass fraction of a waste item w from a sector i, collected by a collection option k.

II) Constraints to relate fractions with actual generation

$$\sum_{k \in C} \mathbf{XT}_{\mathbf{i,\, j\, =\, generation,\, k,\, w}} = AGT_{i,\, w} \qquad \forall\, i \in S,\ \forall\, w \in W \qquad (5)$$

$$\sum_{w \in W} AGT_{i,\, w} = 1.0 \qquad \forall\, i \in S \qquad (6)$$

where:
$AGT_{i,\, w}$: is the fraction that represents the actual generation of a waste item w in a sector i: ($0 \le AGT_{i,\, w} \le 1$).

4.3.2. Constraints for the collection nodes

The constraints for the collection nodes are of two types: the general constraints for all collection options and the collection-option-specific constraints. The general constraints are the mass balances. The collection-option-specific constraints are necessary to include other modeling issues not captured by the general constraints.

4.3.2.1. General constraints

The general constraints consist of mass balances for each collection option. The mass fraction collected in a collection option has to be equal to the sum of mass fractions flowing out to the potential destination options. These conditions are represented by Equation (7).

$$\mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection}} = \sum_{m \in Z} \mathbf{XT}_{\mathbf{i,\ k\ =\ collection,\ m}} \qquad \forall\ i \in S,\ \forall\ k \in C \qquad (7)$$

where:

$\mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection}}$: is the mass fraction generated in a sector i and collected by a collection option k,

$\mathbf{XT}_{\mathbf{i,\ k\ =\ collection,\ m}}$: is the mass fraction generated in a sector i, collected by a collection option k and flowing out to a management option m.

4.3.2.2. Constraints to define the in-truck waste composition in collection options

The constraints in this section model the in-truck solid waste composition for the collection options that collect all wastes in the same truck. The constraints apply to the following collection options: the mixed waste collection options (C1, C13 and C20); the co-collection options (C5 and C6); and the wet-dry-recyclables collection options (C11 and C17). Equation (8) defines the composition of waste collected by each collection option and Equation (9) defines the in-truck composition for the mass flowing from the collection options to any other management node.

$$\mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}} = \mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection}} * AGT_{i,\ w}$$
$$\forall\ i \in S,\ \forall\ k \in \{C1, C5, C6, C11, C13, C17, C20\},\ \forall\ w \in W \qquad (8)$$

$$\mathbf{XT}_{\mathbf{i,\ k\ =\ collection,\ m,\ w}} = \mathbf{XT}_{\mathbf{i,\ k\ =\ collection,\ m}} * AGT_{i,\ w}$$

$\forall$ i $\in$ S, $\forall$ k $\in$ {C1, C5, C6, C11, C13, C17, C20}, $\forall$ m $\in$ Z, $\forall$ w $\in$ W (9)

where:

$\mathbf{XT}_{i,\, j = generation,\, k = collection,\, w}$: is the mass fraction of a waste item w generated in a sector i, collected by a collection option k,

$\mathbf{XT}_{i,\, j = generation,\, k = collection}$: is the total mass fraction generated in a sector i, collected by a collection option k,

$\mathbf{XT}_{i,\, k = collection,\, m,\, w}$: is the mass fraction of a waste item w generated in a sector i, collected by a collection option k and flowing out to a potential destination m,

$\mathbf{XT}_{i,\, k = collection,\, m}$: is the total mass fraction generated in a sector i, collected by a collection option k and flowing out to a potential destination node m,

$AGT_{i,\, w}$: is the fraction that represents the actual generation of a waste item w in a sector i: $(0 \le AGT_{i,\, w} \le 1)$.

4.3.2.3. Collection- option- specific constraints

I) Constraints to define the bagging system in the co-collection options C5 and C6

Collection options C5 and C6 collect waste bagged in different colored bags. The collection efficiency (CEFF) describes the fraction of recyclable material actually placed in the blue bags. For a non-recyclable waste item, the value of the collection efficiency is zero, meaning that no non-recyclable material will be in the black bags. Equation (10) defines the total fraction of a waste item collected by collection options C5 or C6. Equations (11) and (12) define the fractions of a waste item in the blue and black bags, respectively, in terms of the collection participation rate (CPR) and the collection efficiency (CEFF).

$$\mathbf{XT}_{i,\, j = generation,\, k,\, w} = \mathbf{XIB}_{i,\, j = generation,\, k,\, w} + \mathbf{XIK}_{i,\, j = generation,\, k,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C5, C6\},\ \forall\, w \in W \qquad (10)$$

$$\mathbf{XAB}_{i,\, j = generation,\, k,\, w} = CPR_{k} * CEFF_{k,\, w} * \mathbf{XIB}_{i,\, j = generation,\, k,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C5, C6\},\ \forall\, w \in W \qquad (11)$$

$$\mathbf{XAK}_{i,\, j = generation,\, k,\, w} = (1 - CPR_{k}) * \mathbf{XIB}_{i,\, j = generation,\, k,\, w} + CPR_{k} * (1 - CEFF_{k,\, w}) * \mathbf{XIB}_{i,\, j = generation,\, k,\, w} + \mathbf{XIK}_{i,\, j = generation,\, k,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C5, C6\},\ \forall\, w \in W \qquad (12)$$

where:

$\mathbf{XT}_{i,\, j = generation,\, k,\, w}$: is the mass fraction of a waste item w from a generation sector i, collected by a co-collection option k (C5 or C6),

$\mathbf{XIB}_{i,\, j\, =\, generation,\, k\, ,\, w}$: is the initially allocated mass fraction of a waste stream item w from a generation sector i, collected by a co-collection option k (C5 or C6) in a blue bag,

$\mathbf{XIK}_{i,\, j\, =\, generation,\, k\, ,\, w}$: is the initially allocated mass fraction of a waste stream item w from a generation sector i, collected by a co-collection option k (C5 or C6) in a black bag,

$\mathbf{XAB}_{i,\, j\, =\, generation,\, k\, ,\, w}$: is the actually collected mass fraction of a waste stream item w from a generation sector i, collected by a co-collection option k (C5 or C6) in a blue bag,

$\mathbf{XAK}_{i,\, j\, =\, generation,\, k\, ,\, w}$: is the actually collected mass fraction of a waste stream item w from a generation sector i, collected by a co-collection option k (C5 or C6) in a black bag,

CPR_{k} : is the collection participation rate of a co-collection option k (C5 or C6),

$CEFF_{k,\, w}$: is the collection efficiency of a co-collection option k (C5 or C6) collecting a waste stream item w, from the residential sector.

II) Constraints to define the wet/dry system collection options C11 and C17

The wet-dry collection options C11 and C17 have three compartments: the wet, dry and recyclable compartments. Equation (13) defines the total mass fraction collected by the wet-dry collection options C12 and C18. Equations (14) through (17) define the mass fractions collected in each compartment. As explained in Chapter 3, the user can specify the fraction of each item that is allowed to go in each of the three different compartments. These fractions are calculated from the total mass by applying the user defined multipliers $F_{wet,k,w}$, $F_{dry,k,w}$ and $F_{rec,k,w}$.

$$\mathbf{XT}_{i,\, j\, =\, generation,\, k\, ,\, w} = \mathbf{XTW}_{i,\, j\, =\, generation,\, k\, ,\, w} + \mathbf{XTD}_{i,\, j\, =\, generation,\, k\, ,\, w} + \mathbf{XTR}_{i,\, j\, =\, generation,\, k\, ,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C11, C17\},\ \forall\, w \in W \qquad (13)$$

$$\mathbf{XTW}_{i,\, j\, =\, generation,\, k\, ,\, w} = F_{wet,k,w} * \mathbf{XT}_{i,\, j\, =\, generation,\, k\, ,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C11, C17\},\ \forall\, w \in W \qquad (14)$$

$$\mathbf{XTD}_{i,\, j\, =\, generation,\, k\, ,\, w} = F_{dry,k,w} * \mathbf{XT}_{i,\, j\, =\, generation,\, k\, ,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C11, C17\},\ \forall\, w \in W \qquad (15)$$

$$\mathbf{XTR}_{i,\, j\, =\, generation,\, k\, ,\, w} = F_{rec,k,w} * \mathbf{XT}_{i,\, j\, =\, generation,\, k\, ,\, w}$$
$$\forall\, i \in S,\ \forall\, k \in \{C11, C17\},\ \forall\, w \in W \qquad (16)$$

$$F_{wet,k,w} + F_{dry,k,w} + F_{rec,k,w} = 1 \qquad (17)$$

where:

$\mathbf{XT}_{i,\, j\, =\, generation,\, k\, ,\, w}$: is the mass fraction of a waste stream item w from a sector i, collected by a wet/dry system k (C11 or C17),

$\mathbf{XTW}_{i,\, j = generation,\, k,\, w}$: is the fraction of a waste item w in the wet compartment,
$\mathbf{XTD}_{i,\, j = generation,\, k,\, w}$: is the fraction of a waste item w in the dry compartment,
$\mathbf{XTR}_{i,\, j = generation,\, k,\, w}$: is the fraction of a waste item w in the recyclable compartment,
$F_{wet,k,w}$: is the multiplier used to obtain the fraction of mass of a waste item w that is collected in the wet compartment of the collection option k (C11 or C17),
$F_{dry,k,w}$: is the multiplier used to obtain the fraction of mass of a waste item w that is collected in the dry compartment of the collection option k (C11 or C17),
$F_{rec,k,w}$: is the multiplier used to obtain the fraction of mass of a waste item w that is collected in the recyclables compartment of the collection option k (C11 or C17).

III) Constraints to define the wet/dry system collection options C12 and C18

The wet-dry collection options C12 and C18 have two compartments: the wet and dry compartments. Equation (18) defines the total mass fraction collected by the wet-dry collection options C11 and C17. Equations (19) through (21) define the mass fractions collected in each compartment. As explained in Chapter 3, the user can specify the fraction of each item that is allowed to go in each of the two different compartments. These fractions are calculated from the total mass by applying the user defined multipliers $F_{wet,k,w}$ and $F_{dry,k,w}$.

$$\mathbf{XT}_{i,\, j = generation,\, k,\, w} = \mathbf{XTW}_{i,\, j = generation,\, k,\, w} + \mathbf{XTD}_{i,\, j = generation,\, k,\, w} \quad \forall\, i \in S,\ \forall\, k \in \{C12, C18\},\ \forall\, w \in W \qquad (18)$$

$$\mathbf{XTW}_{i,\, j = generation,\, k,\, w} = F_{wet,k,w} * \mathbf{XT}_{i,\, j = generation,\, k,\, w} \quad \forall\, i \in S,\ \forall\, k \in \{C12, C18\},\ \forall\, w \in W \qquad (19)$$

$$\mathbf{XTD}_{i,\, j = generation,\, k,\, w} = F_{dry,k,w} * \mathbf{XT}_{i,\, j = generation,\, k,\, w} \quad \forall\, i \in S,\ \forall\, k \in \{C12, C18\},\ \forall\, w \in W \qquad (20)$$

$$F_{wet,k,w} + F_{dry,k,w} = 1 \qquad (21)$$

where:
$\mathbf{XT}_{i,\, j = generation,\, k,\, w}$: is the mass fraction of a waste stream item w from a sector i, collected by a wet/dry system k (C12 or C18),
$\mathbf{XTW}_{i,\, j = generation,\, k,\, w}$: is the fraction of a waste item w in the wet compartment,
$\mathbf{XTD}_{i,\, j = generation,\, k,\, w}$: is the fraction of a waste item w in the dry compartment.
$F_{wet,k,w}$: is the multiplier used to obtain the fraction of mass of a waste item w that is collected in the wet compartment of the collection option k (C12 or C18),
$F_{dry,k,w}$: is the multiplier used to obtain the fraction of mass of a waste item w that is collected in the dry compartment of the collection option k (C12 or C18).

4.3.2.4. Collection of residuals constraints

Residual waste, resulting after collection of recyclables and yardwaste, is collected by a set of residuals collection options (C7, C13 and C20). Chapter 3 explains how the residuals not collected by other collection options flow into the system. Some of the recyclables collection options will not collect 100% of the mass fraction initially allocated to them. One of the reasons for that is a less than 100% participation rate factor. The participation factor for a collection option is the percentage of the area actually participating in that collection option. The other reason is collection efficiency that reduces the mass fraction actually collected by a recyclables collection option. This section presents equations that include the concepts of initially allocated mass and actually collected mass to the collection options.

I) Constraints to relate initially allocated and actually collected mass fractions

The following constraints apply to the yardwaste collection options (C0, C9 and C10), and to the recyclables collection options (C2, C3, C4, C8, C14, C15 and C19). Equation (22) defines the relationship between the mass fraction of a waste item initially allocated to a collection option and the mass fractions of that waste item actually collected by that collection option. Equation (23) defines the residual amount of a waste item remaining after collection of recyclables and yardwaste.

$$\mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}} = CEFF_{k,\,w} * CPR_{k} * \mathbf{XA}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}}$$
$$\forall i \in S,\ \forall\ k \in \{C0, C9, C10, C2, C3, C4, C8, C14, C15, C19\},\ \forall w \in W \qquad (22)$$

$$\mathbf{XR}_{\mathbf{i,\ k\ =\ collection,\ w}} = (1 - CPR_{k}) * \mathbf{XA}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}} + (1 - CEFF_{k,\,w}) * CPR_{k} * \mathbf{XA}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}}$$
$$\forall i \in S,\ \forall\ k \in \{C0, C9, C10, C2, C3, C4, C8, C14, C15, C19\},\ \forall w \in W \qquad (23)$$

where:

$\mathbf{XT}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}}$: is the actually collected mass fraction of a waste item w by a yardwaste or recyclables collection option k,

$\mathbf{XA}_{\mathbf{i,\ j\ =\ generation,\ k\ =\ collection,\ w}}$: is the initially allocated mass fraction of a waste item w to a yardwaste or recyclables collection option k,

$\mathbf{XR}_{\mathbf{i,\ k\ =\ collection,\ w}}$: is the residual of a waste item w not collected by a yardwaste or recyclables collection option k, due to collection efficiencies and participation factors,

$CEFF_{k,\,w}$: is the collection efficiency of a waste item w in a yardwaste or recyclables collection option k ($1 \geq CEFF_{k,\,w} \geq 0$),

CPR_k : is the participation rate for a yardwaste or recyclables collection option k
($1 \geq CPR_k \geq 0$).

II) Mass flows constraints for residuals collection options

Equation (24) defines the mass flows for the residuals collection options. The residuals collection options are C7 for the residential sectors, C16 for the multi-family sectors and C20 for the commercial sectors.

$$\sum_{k \in C} \sum_{w \in W} \mathbf{XR}_{\mathbf{i,\, k = collection,\, w}} = \sum_{m \in Z} \mathbf{XT}_{\mathbf{i,\, l = C7,\, C16\ or\ C20,\, m}} \qquad \forall i \in S \qquad (24)$$

where:

$\mathbf{XR}_{\mathbf{i,\, k = collection,\, w}}$: is the residual of a waste item w not collected by a yardwaste or recyclables collection option k, k ∈ {C0, C9, C10, C2, C3, C4, C8, C14, C15, C19},

$\mathbf{XT}_{\mathbf{i,\, l = C7,\, C16\ or\ C20,\, m}}$: is the total mass fraction collected by a residuals collection option l (C7, C16 or C20) and flowing out to a potential destination option m.

III) Initially allocated mass constraints from generation to collection

The sum of the initially allocated mass to a collection option for a waste item generated in a generation sector has to be equal to 1. Equation (25) ensures that all generated mass of a waste item is initially allocated to at least one collection option.

$$\sum_{k \in C} \sum_{w \in W} \mathbf{XA}_{\mathbf{i,\, j = generation,\, k,\, w}} = 1.0 \qquad \forall i \in S \qquad (25)$$

where:

$\mathbf{XA}_{\mathbf{i,\, j = generation,\, k,\, w}}$: is the initially allocated mass fraction of a waste item w from a sector i, collected by a collection option k.

IV) Constraints to relate initially allocated mass fractions with actual generation

Equation (26) ensures that the initially allocated mass of a waste item to all possible collection options is equal to the actual generation of that waste item.

$$\sum_{k \in C} \mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k,\, w}} = \text{AGT}_{\text{i, w}} \qquad \forall i \in S, \forall w \in W \qquad (26)$$

where:
$\mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k,\, w}}$: is the initially allocated mass fraction of a waste item w from a sector i, collected by a collection option k,
$\text{AGT}_{\text{i, w}}$: is the fraction that represents the actual generation of a waste item w in a sector i: $(0 \le \text{AGT}_{\text{i, w}} \le 1)$,

V) Constraints to define the in-truck composition for yardwaste collection options and recyclables collection options

The next set of constraints apply for the yardwaste collection options (C0, C9 and C10) and the recyclables collection options (C2, C3, C4, C8, C14, C15 and C19). For these collection options, the in-truck composition is defined using the initially allocated mass instead of the actually collected mass. Equation (27) defines the in-truck composition of solid waste collected by the above mentioned collection options. Equation (28) defines the mass fraction for each waste item flowing out the collection options, in terms of the initially allocated mass.

$$\mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k\, =\, collection,\, w}} = \mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k\, =\, collection}} * \text{AGT}_{\text{i, w}}$$
$$\forall i \in S, \forall k \in \{C0, C9, C10, C2, C3, C4, C8, C14, C15, C19\}, \forall w \in W \qquad (27)$$

$$\mathbf{XT}_{\mathbf{i,\, k\, =\, collection,\, m,\, w}} = \text{CEFF}_{\text{k, w}} * \text{CPR}_{\text{k}} * \mathbf{XA}_{\mathbf{i,\, k\, =\, collection,\, m,\, w}}$$
$$\forall i \in S, \forall k \in \{C0, C9, C10, C2, C3, C4, C8, C14, C15, C19\}, \forall w \in W \qquad (28)$$

where:
$\mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k\, =\, collection,\, w}}$: is the initially allocated mass fraction of a waste item w generated in a sector i, collected by a collection option k,
$\mathbf{XA}_{\mathbf{i,\, j\, =\, generation,\, k\, =\, collection}}$: is the initially allocated total mass fraction generated in a sector i, collected by a collection option k,
$\mathbf{XA}_{\mathbf{i,\, k\, =\, collection,\, m,\, w}}$: is the mass fraction of a waste item w generated in a sector i, initially allocated to a collection option k and flowing out to a potential destination option m,
$\mathbf{XT}_{\mathbf{i,\, k\, =\, collection,\, m,\, w}}$: is the mass fraction of a waste item w generated in a sector i, actually collected by a collection option k and flowing out to a potential destination option m,
$\text{AGT}_{\text{i, w}}$: is the fraction that represents the actual generation of a waste item w in a sector i: $(0 \le \text{AGT}_{\text{i, w}} \le 1)$,

$CEFF_{k,w}$: is the collection efficiency of a waste item w in a yardwaste or recyclables collection option k ($1 \geq CEFF_{k,w} \geq 0$),

CPR_k : is the participation rate for a yardwaste or recyclables collection option k ($1 \geq CPR_k \geq 0$).

4.3.3. Constraints for the transfer station nodes

The constraints for the transfer stations ensures conservation of mass at these facilities. Equation (29) ensures that the mass entering a transfer station is equal to the mass exiting that facility.

$$\sum_{i \in S} \sum_{j \in C} \mathbf{XT}_{\mathbf{i,\,j\,=\,collection,\,k\,=\,transfer}} = \sum_{i \in S} \sum_{m \in Z} \mathbf{XT}_{\mathbf{i,\,k\,=\,transfer,\,m}} \qquad \forall k \in TF \qquad (29)$$

where:

$\mathbf{XT}_{\mathbf{i,\,j\,=\,collection,\,k\,=\,transfer}}$: is the mass fraction collected by a collection option j and flowing to a transfer option k,

$\mathbf{XT}_{\mathbf{i,\,k\,=\,transfer,\,m}}$: is the mass fraction flowing from a transfer option k to a management option m.

4.3.4. Constraints for the rail transfer station nodes

The rail transfer station nodes RT2 and RT3 receive waste only from the transfer station RT1. Railroad transportation connects transfer station RT1 with rail transfer stations RT2 and RT3. Waste from transfer station RT2 can flow only to landfill D1. Waste from transfer station RT3 can flow only to landfill D3. This is represented by Equation (30).

$$\sum_{i \in S} \mathbf{XT}_{\mathbf{i,\,j\,=\,RT1,\,k\,=\,rail\,transfer}} = \sum_{i \in S} \sum_{d \in D} \mathbf{XT}_{\mathbf{i,\,k\,=\,rail\,transfer,\,d}} \qquad \forall i \in S, \forall k \in \{RT2, RT3\} \qquad (30)$$

where:

$\mathbf{XT}_{\mathbf{i,\,j\,=\,RT1,\,k\,=\,rail\,transfer}}$: is the mass fraction generated in sector i , flowing from the transfer station RT1 to a rail transfer station (RT2 or RT3),

$\mathbf{XT}_{\mathbf{i,\,k\,=\,rail\,transfer,\,d}}$: is the mass fraction generated in sector i, flowing from a rail transfer station (RT2 or RT3) to a disposal option d.

4.3.5. Constraints for the separation nodes

The separation nodes have two types of constraints. The first group of constraints consist of mass balance constraints. The second group of constraints are constraints to define recoverable products.

The mass balance constraints ensure that the mass coming into each separation facility is equal to what is leaving that separation facility. The mass flowing into a separation facility can potentially come from the collection nodes or the transfer nodes. The mass leaving a separation facility can potentially go to a remanufacturing process, a facility to recover waste as fuel, a treatment facility or a landfill. The recyclable materials go to the remanufacturing processes and the residuals go either to the treatment nodes or to the disposal nodes.

4.3.5.1 Mass flows constraints for the separation nodes

Equation (31) ensures that the mass entering a separation option is equal to the mass leaving that separation option. Equation (32) ensures that the mass entering a separation option is equal to the mass of recovered material (including recyclables and waste as fuel) plus the mass of residuals generated in the separation process.

$$\sum_{i\in S}\sum_{j\in A} \mathbf{XT}_{\mathbf{i,\, j,\, k\, =\, separation}} = \sum_{i\in S}\sum_{m\in Z} \mathbf{XT}_{\mathbf{i,\, k\, =\, separation,\, m}} \qquad \forall k \in SE \qquad (31)$$

$$\sum_{i\in S}\sum_{j\in A} \mathbf{XT}_{\mathbf{i,\, j,\, k\, =\, separation}} = \sum_{i\in S}\sum_{p\in P} \mathbf{XA}_{\mathbf{i,\, k\, =\, separation,\, p}} + \sum_{i\in S}\sum_{m\in Z} \mathbf{XR}_{\mathbf{i,\, k\, =\, separation,\, m}} \qquad \forall k \in SE \qquad (32)$$

where:

$\mathbf{XT}_{\mathbf{i,\, j,\, k\, =\, separation}}$: is the mass fraction generated in a sector i, entering separation option k from a potential origin node j,

$\mathbf{XT}_{\mathbf{i,\, k\, =\, separation,\, m}}$: is the mass fraction generated in a sector i, leaving separation option k to a potential destination option m,

$\mathbf{XA}_{\mathbf{i,\, k\, =\, separation,\, p}}$: is the mass fraction generated in a sector i, leaving separation option k as a recoverable product p,

$\mathbf{XR}_{\mathbf{i,\, k\, =\, separation,\, m}}$: is the residual mass fraction generated in the separation process of a separation option k, and flowing out to a final destination m.

4.3.5.2. Constraints to define the recoverable materials and residuals

Equation (33) defines the mass for each individual waste item leaving a separation option to a potential destination option. Equation (34) defines the mass fractions for the residuals generated at a separation facility. Equation (35) defines the mass fractions for the recyclables recovered at a separation facility.

$$\mathbf{XT}_{i,\,k\,=\,\text{separation},\,m} = \sum_{w \in W} \mathbf{XT}_{i,\,k\,=\,\text{separation},\,m,\,w} \qquad \forall i \in S,\ \forall\ k \in SE,\ \forall\ m \in Z \qquad (33)$$

$$\sum_{i \in S} \sum_{m \in Z} \mathbf{XR}_{i,\,k\,=\,\text{separation},\,m} = \sum_{i \in S} \sum_{m \in Z} \sum_{w \in W} (1 - SEF_{k,\,w}) * \mathbf{XT}_{i,\,k\,=\,\text{separation},\,m,\,w} \qquad \forall\ k \in SE \qquad (34)$$

$$\sum_{i \in S} \sum_{p \in P} \mathbf{XA}_{i,\,k\,=\,\text{separation},\,p,\,w} = \sum_{i \in S} \sum_{m \in Z} SEF_{k,\,w} * \mathbf{XT}_{i,\,k\,=\,\text{separation},\,m,\,w} \qquad \forall\ k \in SE,\ \forall\ w \in W \qquad (35)$$

where:

$\mathbf{XT}_{i,\,k\,=\,\text{separation},\,m}$: is the mass fraction generated in a sector i, leaving a separation option k to a potential destination option m,

$\mathbf{XT}_{i,\,k\,=\,\text{separation},\,m,\,w}$: is the mass fraction of a waste item w generated in a sector i, leaving a separation option k to a potential destination option m,

$\mathbf{XR}_{i,\,k\,=\,\text{separation},\,m}$: is the residual fraction generated at a separation facility k due to separation efficiencies, and leaving that separation option k to a final destination m,

$\mathbf{XA}_{i,\,k\,=\,\text{separation},\,p,\,w}$: is the mass fraction of a waste item w generated in a sector i, leaving a separation option k as a recoverable product p,

$SEF_{k,\,w}$: is the separation efficiency of a recoverable item w in a separation option k.

4.3.6. Constraints for the treatment nodes

There are general mass balance constraints and treatment-option-specific constraints associated with the treatment options.

4.3.6.1. General constraints

General constraints are defined to ensure mass conservation at each treatment option. The total mass fractions entering a treatment facility is set equal to the sum of mass fractions of wastes treated plus the mass fractions of separated materials and residuals generated in the pre-screening process. At Refuse Derived Fuel, Mixed Waste Compost and Anaerobic Digestion treatment options, waste is processed to remove any non desirable waste item. During this pre-processing, recyclables in the waste stream are removed.

I) Mass flows constraints for the treatment nodes

Equation (36) ensures that the total mass entering a treatment option through potential origin nodes is equal to the total mass to be treated to generate a useful product plus the recovered recyclable materials plus the mass leaving as residuals.

$$\sum_{i \in S} \sum_{j \in A} \mathbf{XT}_{\mathbf{i,\,j,\,k\,=\,treatment}} = \sum_{i \in S} \sum_{p \in P} \mathbf{XA}_{\mathbf{i,\,k\,=\,treatment,\,p}} + \sum_{i \in S} \sum_{d \in D} \mathbf{XR}_{\mathbf{i,\,k\,=\,treatment,\,d}} \qquad \forall k \in TR \qquad (36)$$

where:

$\mathbf{XT}_{\mathbf{i,\,j,\,k\,=\,treatment}}$: is the mass fraction generated in a sector i, entering a treatment option k from a potential origin node j,

$\mathbf{XA}_{\mathbf{i,\,k\,=\,treatment,\,p}}$: is the mass fraction generated in a sector i, leaving a treatment option k as a product or recoverable material p,

$\mathbf{XR}_{\mathbf{i,\,k\,=\,treatment,\,d}}$: is the residual fraction generated on the pre-process or process of the treatment option k, and leaving treatment option k to a disposal option d.

II) Constraints to define treatment products and residuals

Equation (37) specifies the mass for each individual waste item w leaving a treatment option to a potential destination option. Equation (38) represents the residual mass generated at the pre-process stage at a treatment option. Equation (39) defines the mass of the products or recoverable materials generated at a treatment option.

$$\mathbf{XT}_{\mathbf{i,\,k\,=\,treatment,\,m}} = \sum_{w \in W} \mathbf{XT}_{\mathbf{i,\,k\,=\,treatment,\,m,\,w}} \qquad \forall i \in S, \forall k \in TR, \forall m \in Z \qquad (37)$$

$$\sum_{i \in S} \sum_{d \in D} \mathbf{XR}_{\mathbf{i,\,k\,=\,treatment,\,d}} = \sum_{i \in S} \sum_{m \in Z} \sum_{w \in W} (1 - SE_{k,w}) * \mathbf{XT}_{\mathbf{i,\,k\,=\,treatment,\,m,\,w}}$$

$$\forall k \in TR \qquad (38)$$

$$\sum_{i \in S} \sum_{p \in P} \mathbf{XA}_{\mathbf{i, k = treatment, p}} = \sum_{i \in S} \sum_{m \in Z} \sum_{w \in W} SE_{k,w} * TF_{k,w} * \mathbf{XT}_{\mathbf{i, k = treatment, m, w}}$$

$$\forall k \in TR \qquad (39)$$

where:

$\mathbf{XT}_{\mathbf{i, k = treatment, m}}$: is the mass fraction generated in a sector i, leaving a treatment option k to a potential destination option m,

$\mathbf{XT}_{\mathbf{i, k = treatment, m, w}}$: is the mass fraction of a waste item w generated in a sector i, leaving a treatment option k to a potential destination option m,

$\mathbf{XR}_{\mathbf{i, k = treatment, d}}$: is the residual fraction of waste generated during the pre-process and treatment stages, leaving a treatment option k to a disposal option d,

$\mathbf{XA}_{\mathbf{i, k = treatment, p}}$: is the mass fraction from a sector i, leaving a treatment option k as a product or recoverable material p,

$SE_{k,w}$: is the pre-processing separation efficiency of a recoverable item w in a treatment option k,

$TF_{k,w}$: is the treatment transformation factor used to represent the transformation of a waste item w treated at a treatment facility k and transformed to some final product (e.g. compost) ($1 \geq TF_{k,w} \geq 0$).

4.3.6.2. Treatment-option-specific constraints

I) Constraints for the total mass in combustion facility T3

The combustion treatment option recovers energy as electricity from the waste stream. The residuals from this process are bottom and fly ash that are disposed of in an ash mono-landfill. Equation (40) represents the total mass fraction entering the combustion facility. The left hand side term represents all mass fractions coming from all potential origin nodes. The right hand side term represents the sum of the mass of all the individual waste items.

$$\sum_{i \in S} \sum_{j \in A} \mathbf{XT}_{\mathbf{i, j, k = T3}} = \sum_{i \in S} \sum_{j \in A} \sum_{w \in W} \mathbf{XT}_{\mathbf{i, j, k = T3, w}} \qquad (40)$$

where:

$\mathbf{XT}_{\mathbf{i, j, k = T3}}$: is the mass fraction from a sector i, entering the combustion facility from a potential origin node j,

$\mathbf{XT}_{\mathbf{i, j, k = T3, w}}$: is the mass fraction of a waste item w from a sector i, entering the combustion facility from a potential origin node j.

II) Constraints to define ash production at the combustion facility T3

The total mass fraction of ash generated in the combustion facility has to be disposed of in an ash mono-landfill. The ash fraction, which is the percentage of mass that does not combust and reduces to ash, determines the total mass of ash. Equation (41) represents the total mass of ash generated at the combustion facility and disposed of at landfill D2.

$$\sum_{i \in S} \mathbf{XT}_{\mathbf{i,\,T3,\,D2}} = \sum_{i \in S} \sum_{j \in A} \sum_{w \in W} \mathrm{ASHF}_{i,\,w} * \mathbf{XT}_{\mathbf{i,\,j,\,k\,=\,T3,\,w}} \qquad (41)$$

where:

$\mathbf{XT}_{\mathbf{i,\,T3,\,D2}}$: is the mass fraction of ash produced at combustion facility T3 and disposed of at landfill D2,

$\mathbf{XT}_{\mathbf{i,\,j,\,k\,=\,T3,\,w}}$: is the mass fraction of a waste item w from a sector i, entering the combustion facility T3 from a potential origin node j,

$\mathrm{ASHF}_{i,\,w}$: is the ash fraction of a waste item w from a sector i,

$\mathrm{ASHF}_{i,\,w}$ = (% volatile solids of w)*(1 - combustion efficiency) + (1 - % volatile solids of w).

4.3.7. Constraints for the disposal options

The type of waste that can enter each of the disposal options, wet landfill, ash mono-landfill and dry landfill is restricted as follows: the ash mono-landfill can receive ash from the combustion facility; and the wet and dry landfills can receive wastes from collection options, transfer stations, separation options and treatment options.

The total mass entering landfills D1 and D3 is the sum of all mass entering the landfills from all potential origin nodes. Equation (42) represents total mass entering landfill D1 or D3. The left hand side term represents the total mass coming from all potential origin nodes, and the right hand side term represents the total mass of all the individual waste items.

$$\sum_{i \in Z} \sum_{j \in A} \mathbf{XT}_{\mathbf{i,\,j,\,k}} = \sum_{i \in Z} \sum_{j \in A} \sum_{w \in W} \mathbf{XT}_{\mathbf{i,\,j,\,k,\,w}} \qquad \forall k \in \{D1, D3\} \qquad (42)$$

where:

$\mathbf{XT}_{i,\,j,\,k}$: is the mass fraction of waste from a sector i, entering landfill D1 or D3 from a potential origin node j,
$\mathbf{XT}_{i,\,j,\,k,\,w}$: is the mass fraction of a waste item w from a sector i, entering landfill D1 or D3 from a potential origin node j.

4.4. Mass balance at the final destination of all items

Every individual waste item generated will have only two final destinations. It can flow out of the system as a recoverable material or a product; or it can end up at a combustion facility or a landfill. A recoverable product can be either a recyclable material going to a manufacturing process or waste as fuel. Products can be yardwaste compost or mixed waste compost. Non-recoverable materials and residuals from all facilities may flow into combustion facilities or landfills.

Equation (43) represents mass conservation for each individual item generated. The generated mass of a waste item must be equal to the sum of the mass of that item flowing out of the system as a recoverable material plus the mass of that item flowing into the combustion facility and the landfills.

$$\sum_{j \in A} \sum_{p \in P} \mathbf{XT}_{i,\,j,\,p,\,w} + \sum_{j \in A} \mathbf{XT}_{i,\,j,\,k\,=\,T3,\,w} + \sum_{j \in A} \mathbf{XT}_{i,\,j,\,m\,=\,D1\text{ or }D3,\,w} = AGT_{i,\,w} \qquad \forall i \in S,\ \forall w \in W \qquad (43)$$

where:
$\mathbf{XT}_{i,\,j,\,p,\,w}$: is the mass fraction of a waste item w from a sector i, leaving a potential origin node j as a recoverable material or product p,
$\mathbf{XT}_{i,\,j,\,k\,=\,T3,\,w}$: is the mass fraction of a waste item w from a sector i, leaving a potential origin node j and entering the combustion facility T3,
$\mathbf{XT}_{i,\,j,\,k\,=\,D1\text{ or }D3,\,w}$: is the mass fraction of a waste item w from a sector i, leaving a potential origin node j and entering landfills D1 or D3,
$AGT_{i,\,w}$: is the actual generation of a waste item w in sector i ($0 \le AGT_{i,\,w} \le 1$).

4.5. User defined constraints

The only user defined constraint that is included in the current study represents a mandated overall recovery rate. The overall diversion rate is defined as the percentage of all generated solid waste recovered as recyclable or diverted to be converted to compost. The recyclable materials can be recovered at the separation or treatment nodes. For example, the Environmental Protection Agency (EPA) established a recovery rate of 25% as a goal for the decade of the 90's (EPA, 1989). Equation (44) represents the mandated overall recovery rate.

$$\sum_{i \in S} \sum_{j \in SE \cup TR} \sum_{p \in P} \sum_{w \in W} \mathbf{XT}_{\mathbf{i,\,j,\,p,\,w}} * \text{SWAG}_{i} \geq \text{OverRecovRate} * \sum_{i \in S} \text{SWAG}_{i} \tag{44}$$

where:

$\mathbf{XT}_{\mathbf{i,\,j,\,p,\,w}}$: is the mass fraction of a waste stream item w from a sector i, recovered at a facility j and sent to a remanufacturing process as a recyclable material p, or treated at a facility j to produce compost,

OverRecovRate : is the user defined overall recovery rate ($0 \leq \text{OverRecovRate} \leq 1$)

SWAG_{i} : is the total actual generation in sector i (ton/year).

Chapter 5: Model test and evaluation

5.1. Descriptions of scenarios

The model was implemented and tested for a hypothetical basic scenario. Then, some variations on the basic scenario were created and tested. The effects of mandated overall diversion rates on SWM are analyzed in scenarios A1 through A4. The effects of increasing the disposal and combustion tipping fees are analyzed in scenarios B1 through B4. The effects of increasing the disposal tipping fees only are analyzed in scenarios C1 through C4.

5.2. Basic scenario

The mathematical model described in Chapter 4 is tested using a basic scenario that represents a hypothetical municipality. The basic scenario includes the following management options: all collection options except the co-collection options for the residential sector (C5 and C6), all separation options, yardwaste compost, combustion and all disposal options. Residential co-collection options (C5 and C6), transfer stations, refuse derived fuel, mixed waste composting and anaerobic digestion are not included due to lack of information. This model includes one residential sector, one multi-family sector and one commercial sector. Input data include three types of information: cost coefficients, coefficients related to the management options and coefficients related to the waste stream items.

5.2.1. Cost coefficients

Cost coefficients are expressed in dollars per ton of waste processed in each facility. For the collection options, cost coefficients are expressed in units of dollars per ton of waste collected. For the separation options, cost coefficients are expressed in terms of dollars per ton of each recyclable item processed at the facility. The yardwaste compost plant has a cost coefficient in terms of dollars per ton of yardwaste processed. The combustion facility and the disposal facility costs are expressed in terms of dollars per ton of waste processed. Market prices of recyclable materials, waste as fuel, electricity generated at a waste-to-energy facility and compost products are also included. These cost coefficients are computed in spreadsheet-based preprocessors for each unit operation. In each preprocessor, functional level data and information is used to estimate the cost and life cycle parameters. These preprocessors are being developed by the NCSU research team.

Appendix A presents the cost information for the management options from the available pre-processors. This includes the cost coefficients for the collection options (Table A.1), the cost coefficients for the separation options specified by waste stream item (Table A.2), the cost coefficients for the transportation options (Table A.3), the tipping fees for the treatment and disposal options (Tables A.4, A.5 and A.6), the prices of recyclable materials (Table A.7), and the market prices for compost, waste as fuel and electricity from waste combustion (Tables A.8 and A.9).

5.2.2. Coefficients related to the management options

Process specific coefficients associated with the different management options are also included in Appendix A. This includes: the collection efficiencies for each waste stream item collected by the residential recyclables collection options C2, C3, C4 and C8 (Table A.10); the collection efficiencies for the multi-family recyclables collection options C8, C14 and C15 (Table A.11); the collection efficiencies for commercial recyclables collection option C19 (Table A.12); the bagging efficiencies for the collection options C4 and C5 (Table A.13); the participation rates for all the collection options (Table A.14); the separation efficiencies or picking efficiencies per waste stream item for the five types of Material Recovery Facilities (Table A.15); the combustion efficiency at the combustion plant (Table A.16); the fractions of each waste stream item allowed to enter the wet, dry or recyclables compartments in the collection options C11 and C17 (Table A.17); and the fractions of each waste stream item present either in the dry or wet compartment in the collection options C12 and C18 (Table A.18).

5.2.3. Coefficients related to the waste stream items

The waste stream compositions for the three sectors considered in this analysis are listed in Tables A.19 and A.20 in Appendix A. Waste composition is given based on wet weight basis. Basic data on composition were taken from the Franklin report (Franklin Associates, 1994) where data are expressed on a dry weight basis except for yard trimmings and food waste. Moisture contents are then applied to obtain the wet weight basis. Ash fractions and energy content per item are also shown in Table A.19 in Appendix A. The ash fraction of a material is the percentage by weight of that material potentially convertible to ash in a combustion facility. To obtain values in wet weight basis, these data are corrected by moisture content too.

5.2.4. Waste generation

The basic scenario is tested for a population of 200,000 inhabitants in the residential sector and 20,000 inhabitants in the multi family sector. Waste generation rates are 3 pounds per person per day in both sectors. For the commercial sector, a generation rate of 1.4 pounds per person per day was used. The total waste generation amounts were calculated as follows:

Residential sector:

(3 lb/day/per-capita) * (365 days/year) * (200,000 people) = 109,500 ton/year

Multi-family sector:

(3 lb/day/per-capita) * (365 days/year) * (20,000 people) = 10, 950 ton/year

Commercial sector:

(1.4 lb/day/per-capita) * (365 days/year) * (220,000 people) = 56, 210 Ton/year

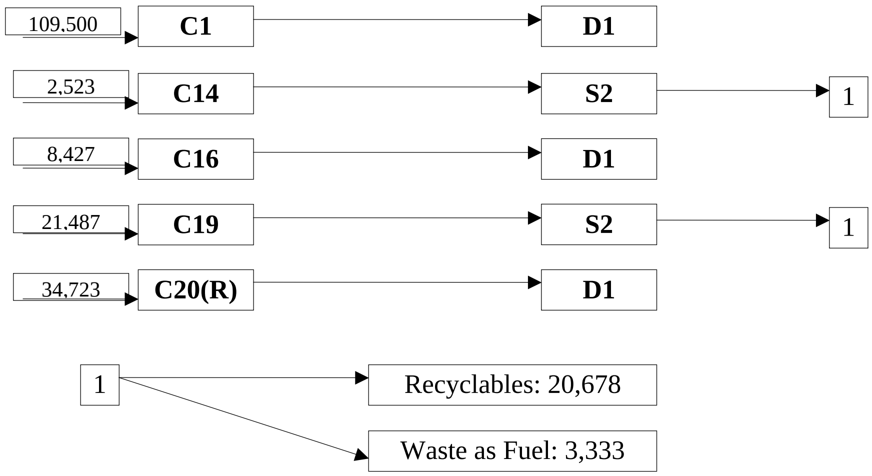
5.2.5. Least cost management strategy for the basic scenario

The model for the basic scenario defined by the above mentioned parameters was implemented and solved using the CPLEX® linear programming solver. This model incorporated only the mass balance equations in the constraint set, and the objective function was to minimize the net cost of the solid waste management strategy. The least cost management strategy for this basic scenario is shown in Table 5.1.

Table 5. 1 : Least cost solution for the Basic Scenario

1. Costs	**Million dollars per year**
Collection	8.57
Separation	0.26
Treatment	0.00
Disposal	3.82
Transportation	0.11
Total Cost	12.65
2. Revenues	
Recyclables	1.66
Waste as fuel	0.003
Electricity	0
Total Revenues	1.66
Total Net Cost	**10,98**

The solution specifies that 100% of the residential waste will be collected by the mixed waste collection option (C1) and disposed of in a dry landfill (D1). In the multi-family sector, recyclable materials will be collected by the pre-sorted recyclables collection option (C14) and residual waste will be collected by the residuals collection option (C16). In the commercial sector, recyclable materials will be collected by the recyclables collection option (C19) and the residual waste will be collected by the residuals collection option (C20). Recyclable materials will be sent to the pre-sorted recyclable Material Recovery Facility S2. In this strategy, 11.7 % of waste generated in all sectors is recovered as recyclables and about 1.9 % of waste as fuel at the MRF S2. The mass flows in the optimal strategy are shown in Figure 5.1.



Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B1

Figure 5.1: Mass flows in the least cost SWM strategy for the Basic Scenario

5.3. Effect of mandated overall diversion rates on SWM

The model for the basic scenario is modified by incorporating a constraint that represents a minimum overall diversion rate. The overall diversion rate is the percentage of the total mass of MSW generated in all three generation sectors that is recycled and composted. For example, a 25% overall diversion rate means that 25% of the total waste generated will be diverted from disposal or combustion. The model will seek for SWM strategies that recover a certain amount of recyclable and compostable material by diverting recyclables at the separation facilities or compost product at the yardwaste compost facility. The model was solved repeatedly for different diversion rates. The maximum overall diversion rate is defined by the percentage of all recyclables and compostables in the MSW generated in all sectors. The maximum overall diversion rate corresponding to the waste generation rates assumed in these scenarios is about 33%.

5.3.1. Range of diversion rates

A set of four scenarios with diversion rates of 15%, 20%, 25% and 30% is defined for this analysis. All other parameters are set equal to the values used in the basic scenario.

Scenario A1: Recycling rate of 15 %

Scenario A2: Recycling rate of 20 %

Scenario A3: Recycling rate of 25 %

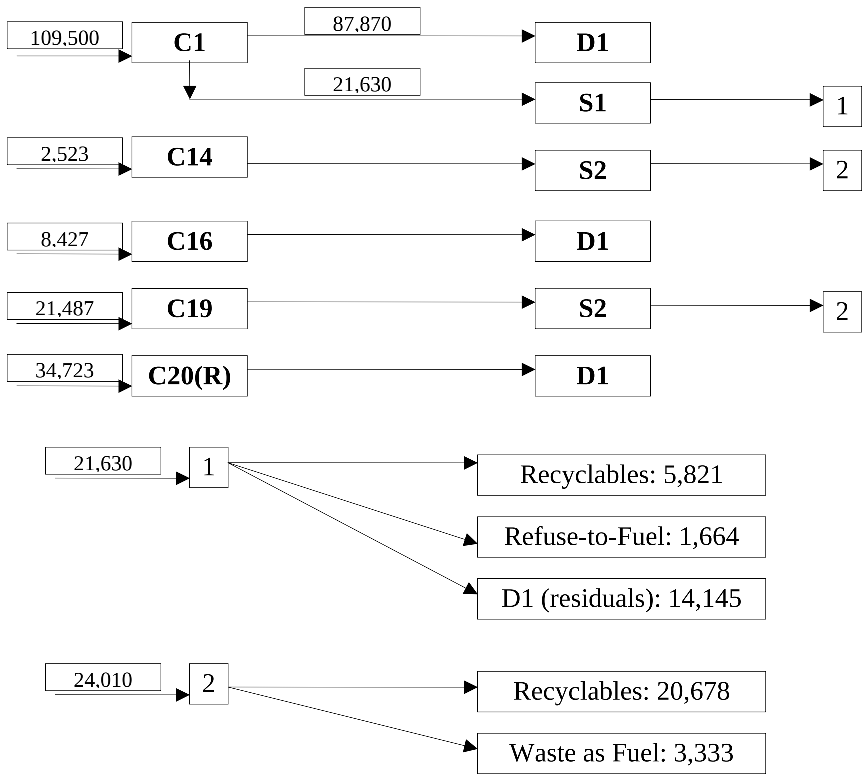
Scenario A4: Recycling rate of 30 %

5.3.2. Least cost management strategies for the minimum overall diversion rate scenarios

The least cost management strategy for the 15% recovery rate scenario (Scenario A1) is shown in Table 5.2. The mass flows associated with the least cost management strategy for this scenario are shown in Figure 5.2. Mixed waste collection option C1 will collect all residential wastes. About 20% of this waste will be sent to the mixed waste MRF S1 and the rest to a landfill (D1). In the multi-family and commercial sectors, mass flows will remain the same as in the basic scenario.

Table 5. 2 : Least cost solution for Scenario A1 (15% recovery rate)

1. Costs	**Million dollars per year**
Collection	8.57
Separation	1.98
Treatment	0.00
Disposal	3.63
Transportation	0.02
Total Cost	14.20
2. Revenues	
Recyclables	2.11
Waste as fuel	0.003
Electricity	0
Total Revenues	2.11
Total Net Cost	**12.09**



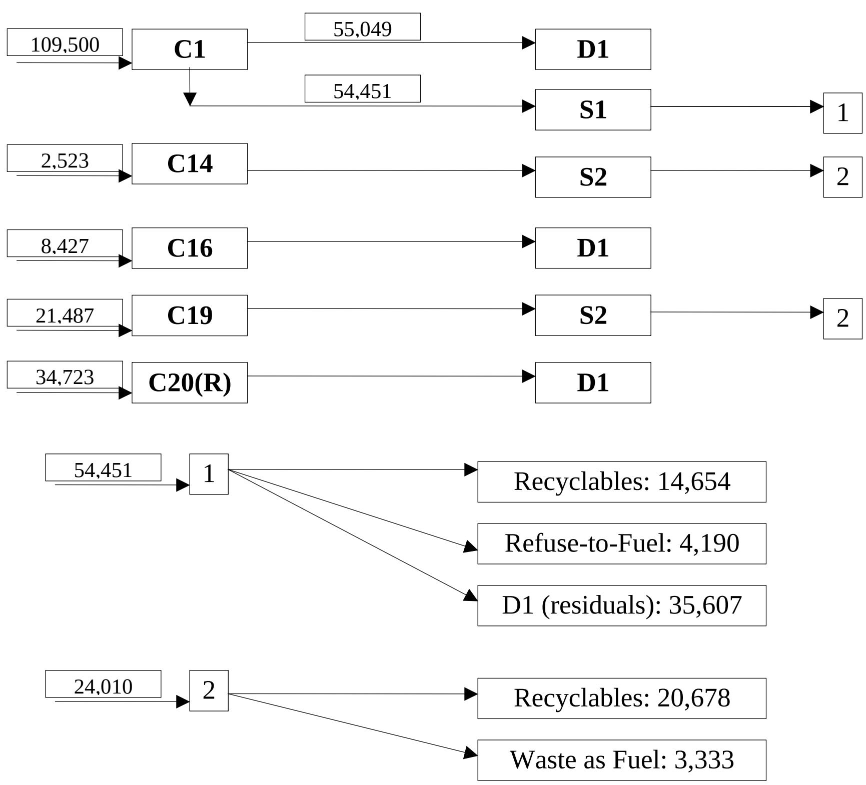
Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B2

Figure 5. 1: Mass flows in the least cost SWM strategy for Scenario A1

The least cost management strategy for the 20% recovery rate scenario (Scenario A2) is shown in Table 5.3. The mass flows associated with the least cost management strategy for this scenario are shown in Figure 5.3. Mixed waste collection option C1 will collect all residential wastes. About 49.7% of this waste will be sent to the mixed waste MRF S1, and the rest to a landfill (D1). More mass is sent to S1 than in Scenario A1. In the multi-family and commercial sectors, mass flows will remain the same as in the basic scenario.

Table 5. 3 : Least cost solution for Scenario A2 (20% recovery rate)

1. Costs	**Million dollars per year**
Collection	8.57
Separation	4.59
Treatment	0.00
Disposal	3.35
Transportation	0.05
Total Cost	16.55
2. Revenues	
Recyclables	2.78
Waste as fuel	0.003
Electricity	0
Total Revenues	2.78
Total Net Cost	**13.77**



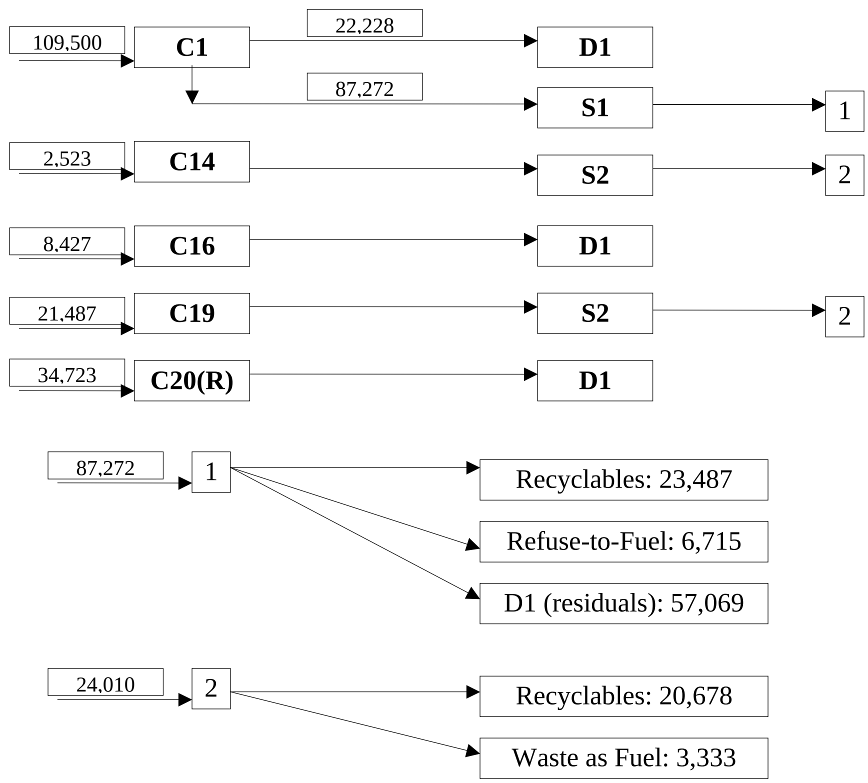
Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B3

Figure 5. 2: Mass flows in the least cost SWM strategy for Scenario A2

The least cost management strategy for the 25% recovery rate scenario (Scenario A3) is shown in Table 5.4. The mass flows associated with the least cost management strategy for this scenario are shown in Figure 5.4. Mixed waste collection option C1 will collect all residential wastes. About 79.7% of this waste will be sent to the mixed waste MRF S1, and the rest to a landfill (D1). More mass is sent to S1 than in Scenario A2. In the multi-family and commercial sectors, mass flows will remain the same as in the basic scenario.

Table 5. 4 : Least cost solution for Scenario A3 (25% recovery rate)

1. Costs	**Million dollars per year**
Collection	8.57
Separation	7.19
Treatment	0.00
Disposal	3.06
Transportation	0.08
Total Cost	18.90
2. Revenues	
Recyclables	3.45
Waste as fuel	0.003
Electricity	0
Total Revenues	3.46
Total Net Cost	**15.44**



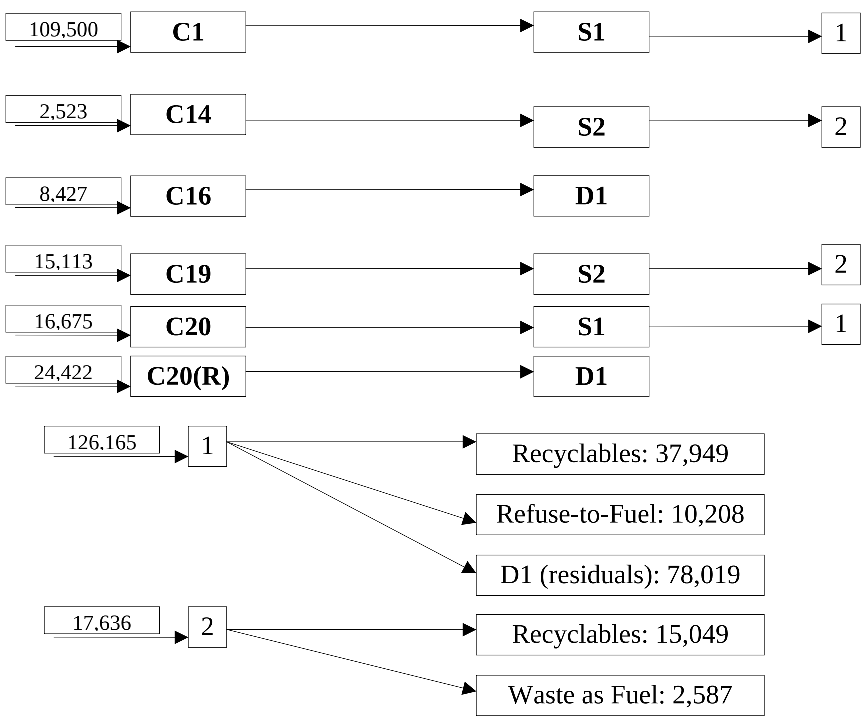
Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B4

Figure 5. 3: Mass flows in the least cost SWM strategy for Scenario A3

The least cost management strategy for the 30% recovery rate scenario (Scenario A4) is shown in Table 5.5. The mass flows associated with the least cost management strategy for this scenario are shown in Figure 5.5. Mixed waste collection option C1 will collect all residential wastes and send them to the mixed waste MRF S1. In the multi-family sector mass flows will remain the same as in the basic scenario. In the commercial sector, recyclable material will be collected by the recyclable collection option (C19) and the residual waste will be collected by the residuals collection option (C20). More recyclables than in Scenarios A1 through A3 will be collected by C19 (26.9 % of total commercial generation) and routed to an S2 MRF. The residuals after recyclables collection C19 will be collected by collection option C20 and sent to a landfill (D1). Additionally, the mixed waste collection option C20 will collect 29.7 % of the commercial generation and route it to an S1 MRF.

Table 5. 5 : Least cost solution for Scenario A4 (30% recovery rate)

1. Costs	Million dollars per year
Collection	8.44
Separation	10.20
Treatment	0.00
Disposal	2.77
Transportation	0.11
Total Cost	21.51
2. Revenues	
Recyclables	4.08
Waste as fuel	0.002
Electricity	0
Total Revenues	4.09
Total Net Cost	**17.42**



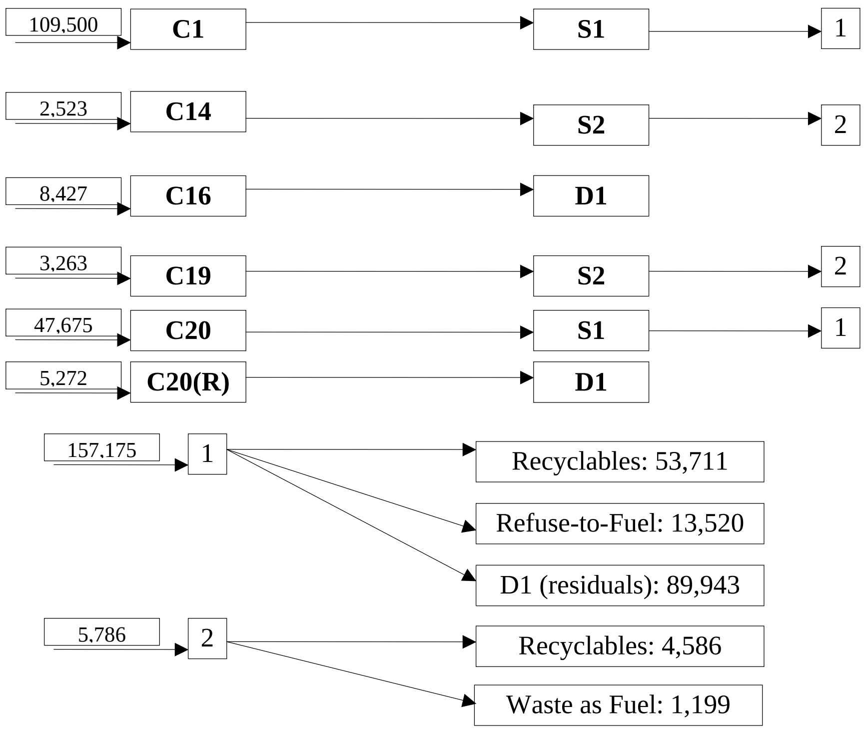
Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B5

Figure 5. 4: Mass flows in the least cost SWM strategy for Scenario A4

To achieve the maximum overall recycling rate of 33%, the total cost of the corresponding SWM strategy will be $18.99 million/year. The least cost management strategy for the 33% recovery rate scenario is shown in Table 5.6. Mass flows are shown in figure 5.6. Presorted recyclables (3,263 Ton/year) will be collected by C19 and processed at a S2 MRF and the residual waste (5,272 Ton/year) will be collected by C20. Mixed waste will be collected by the mixed waste collection option C20 (47,675 Ton/year).

Table 5. 6 : Least cost solution for the maximum recovery rate scenario (33% recovery rate)

1. Costs	**Million dollars per year**
Collection	8.21
Separation	12.48
Treatment	0.00
Disposal	2.59
Transportation	0.11
Total Cost	23.40
2. Revenues	
Recyclables	4.40
Waste as fuel	0.00
Electricity	0
Total Revenues	4.40
Total Net Cost	**18.99**



Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B6

Figure 5. 6: Mass flows in the least cost SWM strategy for the maximum recovery rate scenario

5.3.3. Integrated analysis of scenarios A1, A2, A3 and A4

The effects of mandated overall diversion rate on the total net cost and the individual management costs are shown in Figure 5.7. As expected, total net cost increases with increasing overall diversion rate. Total revenue increases and disposal cost decreases as more recyclables are diverted from a landfill and sold as recyclable material. Collection costs remain the same for scenarios A1 through A3, and decrease in Scenario A4. Collection costs decrease in Scenario A4 because the model selects the mixed waste collection option C20 to send waste to a S1 MRF. Although the C19 collection - S2 MRF combination is more cost effective, the limitation on the number of recyclables items that can be collected by C19 prevents achieving the highly mandated diversion rates. Therefore, at higher mandated diversion rates, the more expensive C20 collection - S1 MRF combination is selected to achieve higher recovery rates. This results in a reduction in collection cost since C20 is less expensive than C19, and an increase in the separation cost since S1 is more expensive than S2. As the total mass processed at the separation facilities increase with the recovery rate, the residuals generated during the sorting process increase. Consequently, the transportation costs of routing these residuals to the landfill increase.

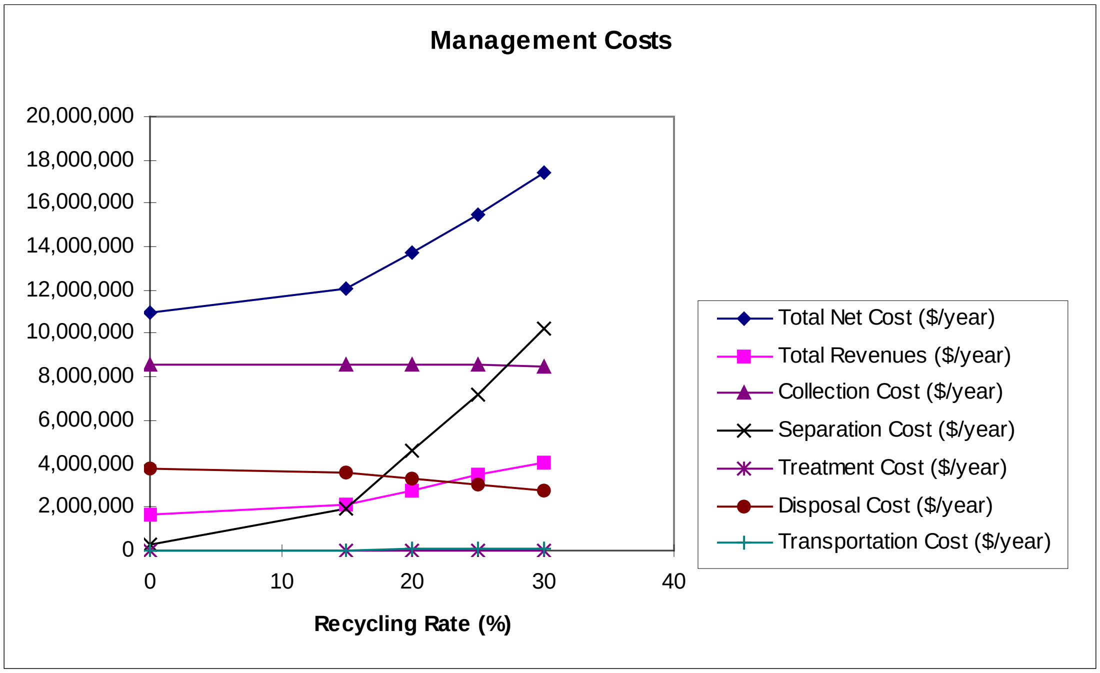


Figure 5. 7: Variations in management costs with different mandated overall diversion rates

The effects of the recycling rates on the total recycled amounts are shown in Figure 5.8. It shows the recycled amounts of the broader categories of recyclables, namely, paper and cardboard, plastic, metals, glass and wood. Paper and cardboard represents 31.8 % of the total generation (56,139 Ton/year), the category with highest recycling rate. As the recycling rate increases, more mass of all categories of recyclables is recovered.

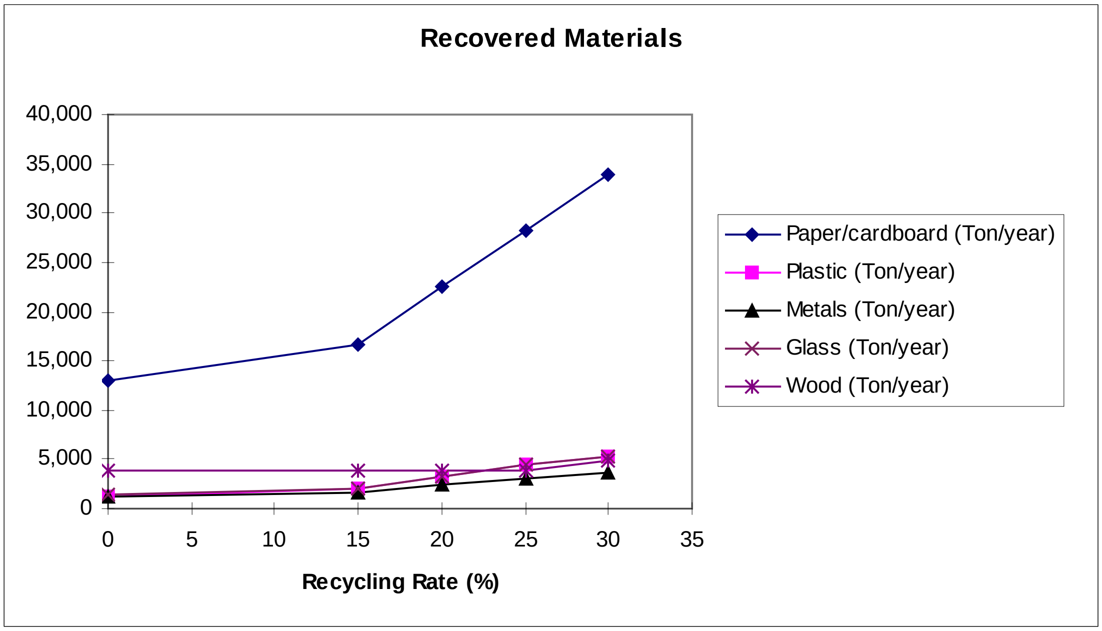


Figure 5.8: Variations in recovered amounts of different material categories with different mandated overall diversion rates

5.3.4. Total recovered recyclable materials per sector

Figure 5.9 shows the distribution of recyclable material recovered by sector for different diversion rates. Three different bars are used to represent the three sectors. Each bar shows the percentage of waste recovered in each sector. For the base scenario, only materials from the multi-family and commercial sectors are recovered. Recyclables recovery in these two sectors is cheaper than that in the residential sector. The fractions recycled in the multi-family sector (38%) is the maximum value that can be obtained, i.e., all recyclables in this sector are recovered. In the base scenario, 49% of the waste from the commercial sector is also recovered. At increasing diversion rates up to 25%, additional recyclables recovery is obtained by increasing recyclables recovery from the residential sector. At diversion rates above 25%, more recovery is obtained through recovery of recyclables from both residential and commercial sectors. These trends suggest that it is most cost effective to recover waste from the multi-family and commercial sectors first and then from the residential sector.

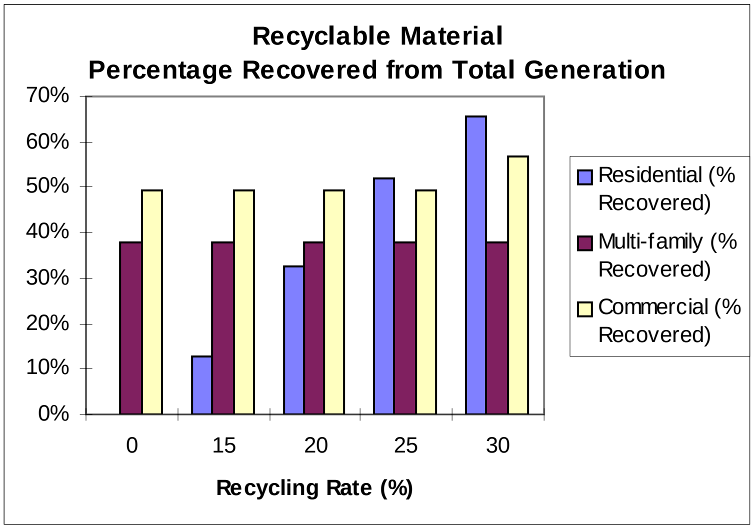


Figure 5.9: Variations of recyclable material recovered by sector with different mandated overall diversion rates

5.4. Effects of changes in disposal and combustion tipping fees on SWM

The sensitivity of the optimal SWM strategy to changes in disposal and combustion tipping fees is examined in this analysis. For this analysis, no mandated overall diversion requirement is imposed. By increasing the tipping fees at both landfills and combustion facilities, the model is expected to find SWM strategies that will recover more recyclable materials, even without a mandated overall diversion requirement.

5.4.1. Definition of scenarios

The scenarios to be examined will consider changes in the tipping fees at the three landfills and the combustion facility. Increments of 200%, 400%, 600% and 800% of the values used in the basic scenario are selected. All other parameters values will remain the same as in the basic scenario.

Scenario B1: Increment of 200% in the combustion and disposal tipping fees
Scenario B2: Increment of 400% in the combustion and disposal tipping fees
Scenario B3: Increment of 600% in the combustion and disposal tipping fees

Scenario B4: Increment of 800% in the combustion and disposal tipping fees

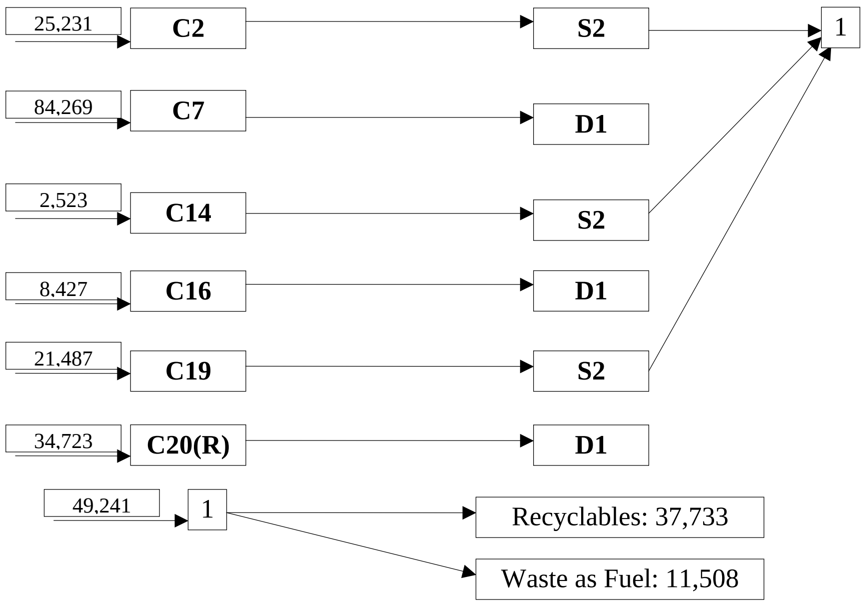
5.4.2. Least cost management strategies for the scenarios B1 through B4

Mass flows for the least cost SWM strategies corresponding to Scenario B1 and Scenario B2 are similar to the mass flows for the basic scenario. The total amount recycled in Scenarios B1 and B2 is 11.7 % of the total generation, the same as in the basic scenario. Therefore, up to 400% increase in the tipping fees, it is more cost effective to landfill the residual waste than to implement another option to divert waste from the landfill. The total cost will increase proportionally to the increments on the tipping fees. The least cost management strategy for the scenarios in this section (Scenarios B1 through B4) are shown in Table 5.7.

Table 5. 7 : Least cost solution for Scenarios B1 through B4

	Basic Scenario	**Scenario B1**	**Scenario B2**	**Scenario B3**	**Scenario B4**
1. Costs	**Million dollars per year**				
Collection	8.57	8.57	8.57	14.00	8.57
Separation	0.26	0.26	0.26	0.53	8.96
Treatment	0.00	0.00	0.00	0.00	0.00
Disposal	3.82	11.45	19.08	22.30	25.82
Transportation	0.11	0.00	0.00	0.00	0.1
Total Cost	12.65	20.28	27.91	36.83	43.45
2. Revenues	**Million dollars per year**				
Recyclables	1.66	1.66	1.66	3.23	3.91
Waste as fuel	0.003	0.003	0.003	0.01	0.003
Electricity	0.00	0.00	0.00	0.00	0.00
Total Revenues	1.66	1.66	1.66	3.24	3.91
Total Net Cost	**10,98**	**18. 62**	**26.25**	**33.59**	**39.53**

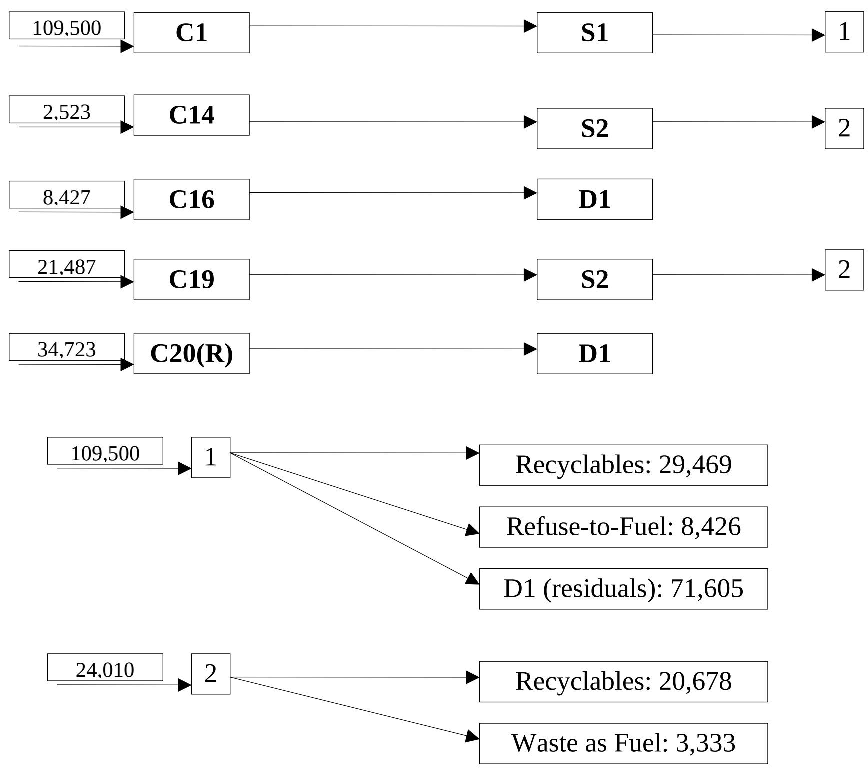
Figure 5.10 shows the mass flows in the least cost SWM strategy corresponding to Scenario B3. In this case, recyclables in the residential sector will be collected by the recyclable collection option C2 and sent to MRF S2. The residuals will be collected by C7. Mass flows for multi-family and commercial sectors are the same as in the basic scenario. The fraction of solid waste diverted is 21.4 % of the total generation of MSW.



Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B7

Figure 5.10: Mass flows in the least cost SWM strategy for Scenario B3

Mass flows for the least cost SWM strategy corresponding to Scenario B4 are shown in Figure 5.11. In this solution, mixed waste collection option C1 will collect all waste generated in the residential sector and send it to MRF S1. Again, the mass flows for multi-family and commercial sectors are the same as in the basis scenario. The diverted fraction is 28.4 % of the total generation of MSW. Mixed waste MRF S1 and pre-sorted recyclables MRF S2 will recover waste items as recyclables and waste as fuel.



Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, Section B8

Figure 5.11: Mass flows in the least cost MSW strategy for Scenario B4

5.4.3. Integrated analysis of scenarios B1, B2, B3 and B4

Figure 5.12 shows the variations in the costs with increments on the disposal and combustion tipping fees. The mass flows will be the same as in the basic scenario up to 400% increment in the disposal and combustion tipping fees (Scenarios B1 and B2). Changes in the total cost will be proportional to the increments in the tipping fees. Disposal costs and total costs have the same slope up to the 400% increment. Separation and collection costs and revenues remain constant in this range, and therefore, the increments in the total costs are due to the increments in the tipping fees. At 600% increment in the tipping fees, collection costs increase due to the selection of the recyclables collection option C2 for the residential sector. In this scenario, additional recycling effort with a higher diversion fraction of 21.4% is achieved to reduce the amounts disposed in a landfill with a higher tipping fee. Therefore, revenues from sale of recyclable materials increase. Disposal costs increase but with a smaller slope, since less material is sent to the landfill. At 800% increase in the tipping fees, more recyclables need to be recovered to further reduce the waste disposed in a landfill. Although the C2-S2 combination is less expensive to recover recyclables, the amount that can be recovered by this combination is limited by the number of items in C2. Therefore, the combination C1-S1 which can recover more material, is chosen in the least cost SWM strategy. As a result, the collection cost decreases since the less expensive collection C1 replaces the more expensive collection option C2. At the same time, the separation cost increases since the more expensive MRF S1 replaces the less expensive MRF S2.

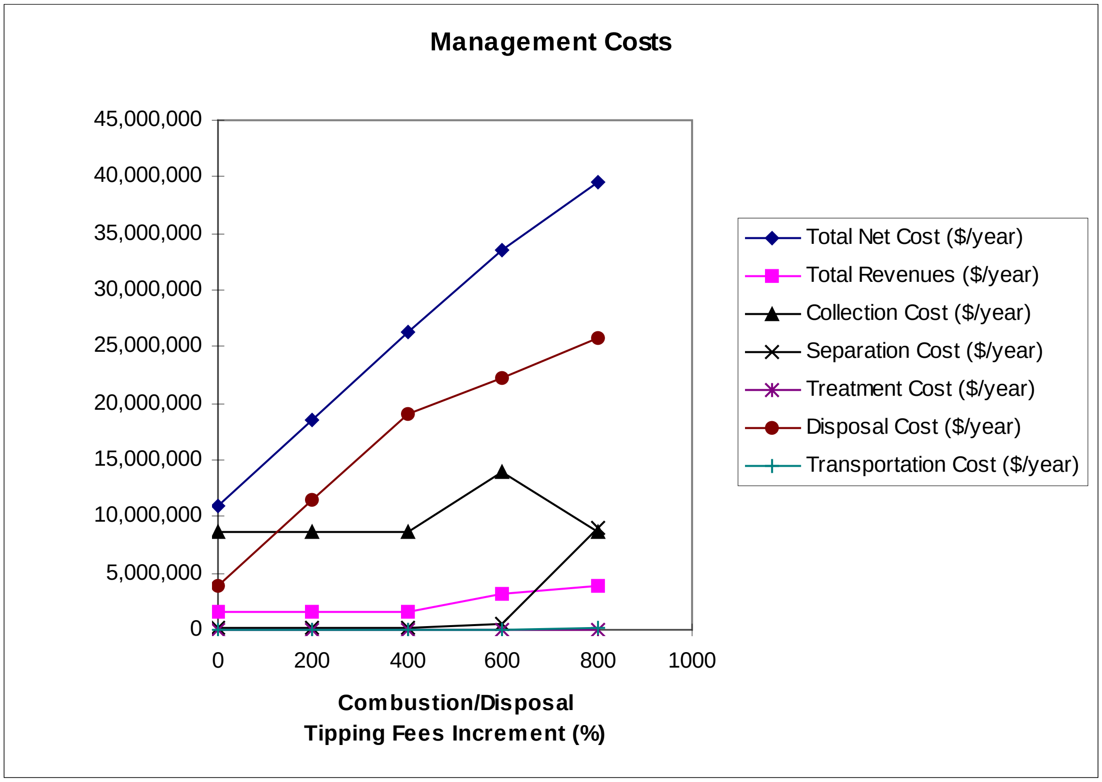


Figure 5.12: Variations in management costs with increments on the disposal and combustion tipping fees

Figure 5.13 shows the variations in amounts recycled in paper and cardboard, metals, glass, plastic and wood waste categories. Up to 400% increment, the recycled amounts remain constant. After this point, high tipping fees force the model to select SWM strategies that divert more waste from the landfill and combustion facilities. Paper and cardboard is the waste category with highest recovery rate.

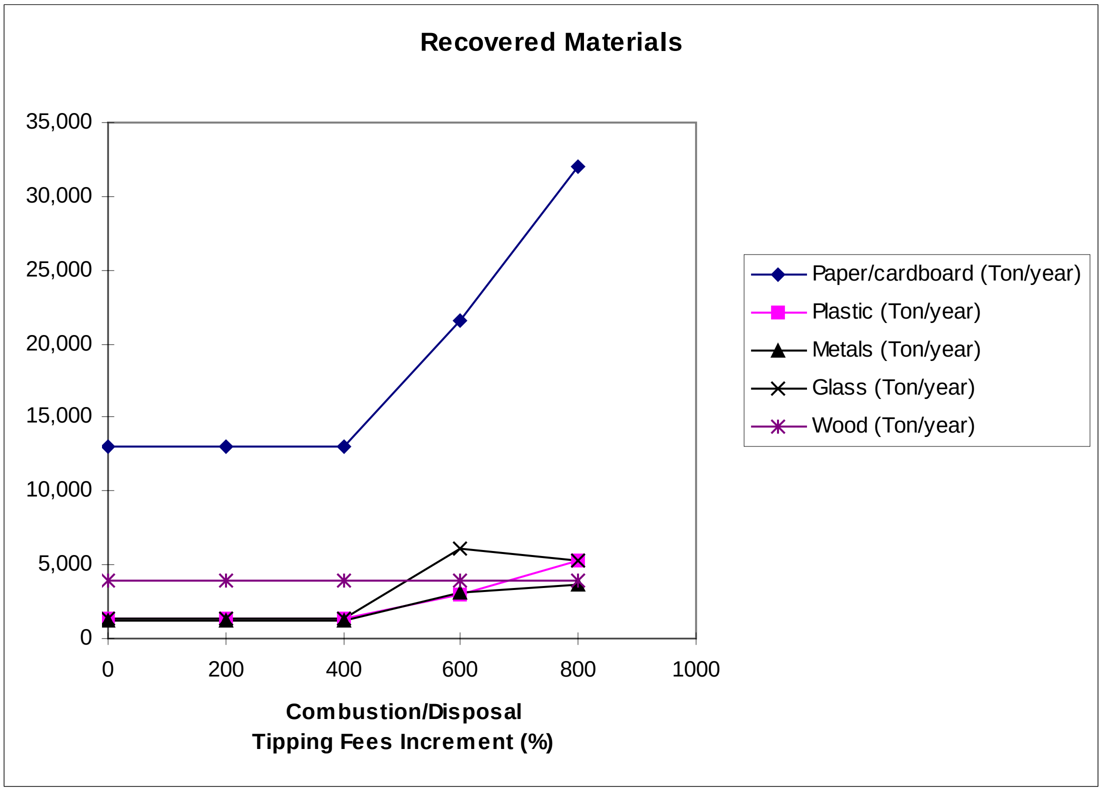


Figure 5. 13: Variations in recovered amounts of different material categories with varying the disposal and combustion tipping fees

Figure 5.14 shows the variations in the landfilled and recycled amounts with the increments in the tipping fees.

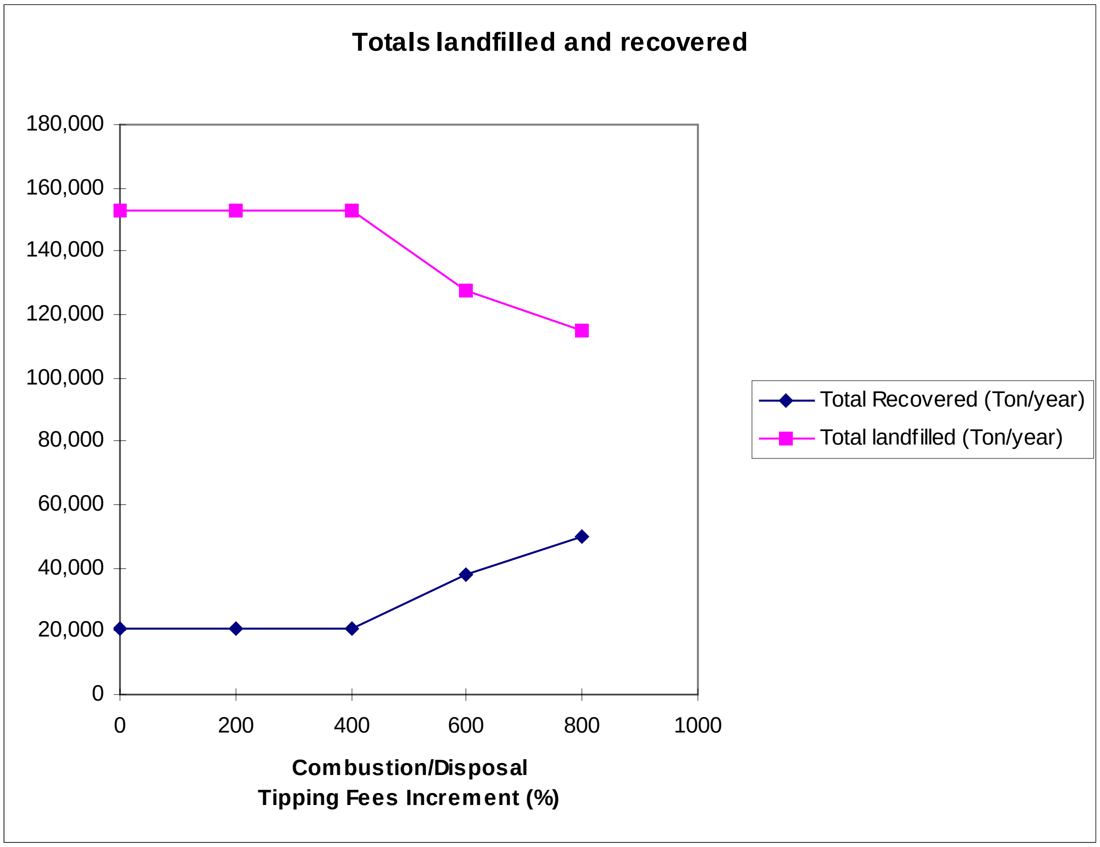


Figure 5.14: Variations in landfilled and recycled total amounts with varying disposal and combustion tipping fees

5.5. Effects of changes in landfill tipping fees on SMW

The response of the optimal SWM strategy to changes in disposal tipping fees is examined in this section. For this analysis, no mandated overall diversion requirement is imposed. The tipping fees for the three landfills will be increased without modifying the combustion tipping fee. By increasing the disposal tipping fee, the model is expected to find SWM strategies that will send more waste to the combustion facility, increase recyclables recovery or any combination of the above.

5.5.1. Definition of scenarios

The scenarios to be examined consider changes in the tipping fees at the three landfills. Increments of 200%, 400%, 600% and 800% of the values used in the basic scenario are selected. The combustion tipping fee and other parameters will remain the same as in the basic scenario.

Scenario C1: 200% increment in landfill tipping fees
Scenario C2: 400% increment in landfill tipping fees
Scenario C3: 600% increment in landfill tipping fees
Scenario C4: 800% increment in landfill tipping fees

5.5.2. Least cost management strategies for scenarios C1 through C4

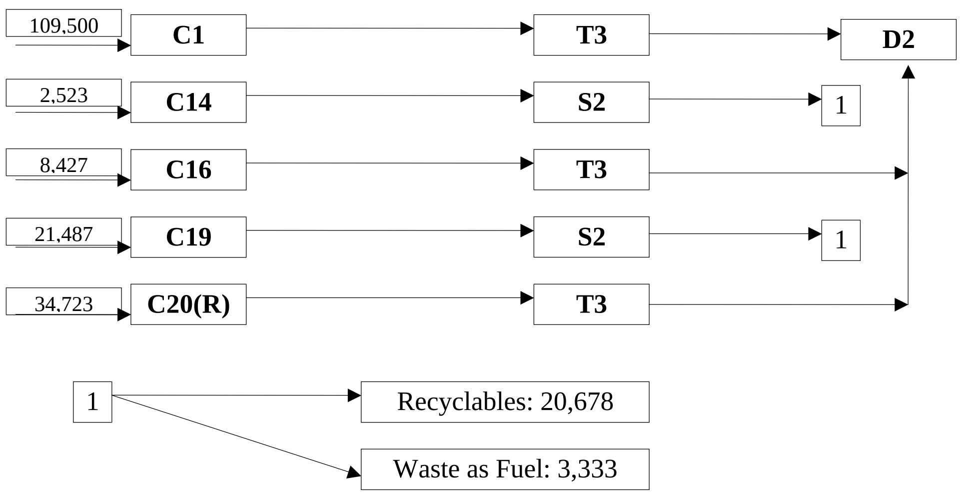
The least cost management strategy for the scenarios in this section (Scenarios C1 through C4) are summarized in Table 5.8.

Table 5. 8 : Least cost solution for Scenarios C1 through C4

	Basic Scenario	Scenario C1	Scenario C2	Scenario C3	Scenario C4
1. Costs	**Million dollars per year**				
Collection	8.57	8.57	8.57	8.57	8.57
Separation	0.26	0.26	0.26	0.26	0.26
Treatment	0.00	8.40	8.40	8.40	8.40
Disposal	3.82	2.75	4.59	6.43	8.26
Transportation	0.11	0.04	0.04	0.04	0.04
Total Cost	12.65	20.02	21.86	23.70	25.53
2. Revenues	**Million dollars per year**				
Recyclables	1.66	1.66	1.66	1.66	1.66
Waste as fuel	0.003	0.003	0.003	0.003	0.003
Electricity	0.00	3.75	3.75	3.75	3.75
Total Revenues	1.66	5.41	5.41	5.41	5.41
Total Net Cost	**10,98**	**14.61**	**16.45**	**18.28**	**20.12**

Figure 5.15 shows the mass flows in the least cost SWM strategy corresponding to all scenarios in this section. As in the basic scenario, collection option C1 will collect all residential wastes, recyclables collection option C16 will collect recyclables from the multi family sector and collection option C16 will collect the residuals, C19 will collect recyclables in the commercial sector and collection option

C20(R) will collect the residuals. The difference between the basic scenario and this is that mixed waste and residuals will go to the combustion facility (T3) instead of the landfill D1. Ash generated at the combustion facility will be disposed of at an ash mono-landfill D2. The overall recovery rate is the same in all scenarios, and is equal to that in the basic scenario: 11.7% of all generated MSW. Mass processed at the combustion facility represents 86.4 % of the total generation of MSW.



Notes: all mass flows are expressed in Ton/year; detailed information about this solution is presented in Appendix B, section B9

Figure 5.15: Mass flows in the least cost SWM strategy for Scenarios C1, C2, C3 and C4

5.5.3. Integrated analysis of scenarios C1, C2, C3 and C4

Figure 5.16 shows the variation in the management costs with varying disposal tipping fees. Since mass flows do not change for the scenarios, the total cost will increase with a constant slope. The model specifies that waste will flow to a combustion facility (T3) instead of a landfill (D1). Ash is disposed of at landfill D2 and disposal costs decrease with respect to the basic scenario. The total cost increases because disposal costs at landfill D2 increase from Scenario C1 to Scenario C4. Total revenues increase with the sale of generated electricity at the combustion facility. The scenarios C1 through C4 recover 11.7% of the total generated MSW. It is more cost effective to send mass flows to the combustion facility than to recover more than 11.7% of the total generated MSW. The combustion cost is only treatment cost and it is the same for all scenarios.

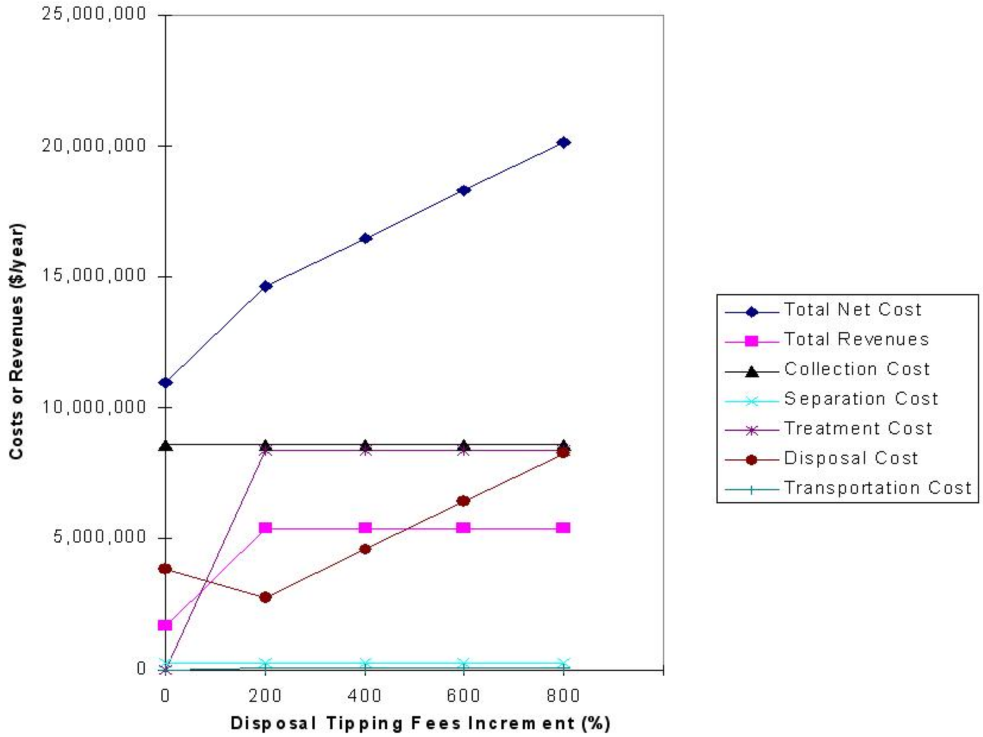


Figure 5. 16: Variations in management costs with increments on the disposal tipping fees

Figure 5.17 shows the variations in total recovered and landfilled amounts with varying the disposal tipping fees. Although the total amount recovered remains constant, the waste going to the landfill is reduced by diverting it to the waste-to-energy option.

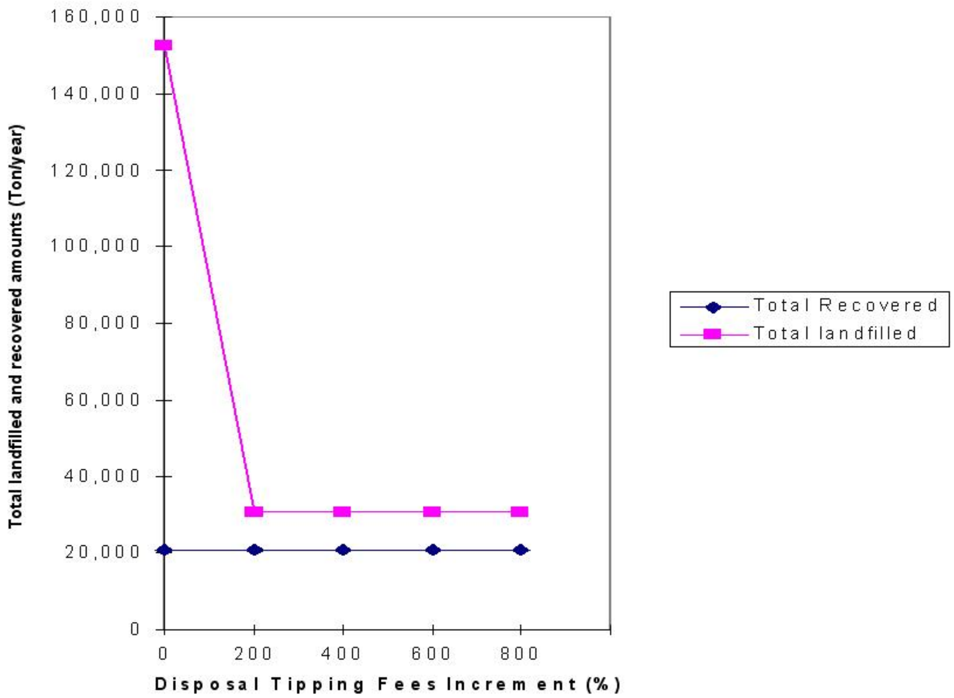


Figure 5.17: Variations in landfilled and recovered amounts with varying disposal tipping fees

5.6. Computational requirements

The LP model has 7868 constraints and 7956 variables. A Pentium™ 90 MHz was used to solve the model using CPLEX® Linear Optimizer 3.0. The CPLEX Presolve function eliminated 2823 rows and 2880 columns from the original model for the Basic Scenario. The CPLEX Aggregator function did 3173 substitutions. The reduced problem had 1872 rows, 1903 columns and 9337 nonzero elements. The solution time was 8.07 seconds and the solver made 738 iterations to get the optimal solution for the Basic Scenario.

Chapter 6: Conclusions

A mathematical model was developed and implemented for an integrated SWM system consisting of: 21 collection options, 8 transfer stations, 5 Material Recovery Facilities (MRF), 6 treatment facilities and 3 final disposal facilities. The system included 38 different waste stream items in the residential and multi-family sectors and 21 different waste stream items in the commercial sectors. The model was implemented as an LP optimization model consisting of nearly 7900 constraints and 8000 variables. The constraints consisted of mass balance equations and minimum mandated diversion requirements. The net cost of the SWM strategy was defined as the objective function. This model was tested for several hypothetical scenarios to evaluate its applicability and accuracy. The first group of scenarios was run for different mandated overall diversion rates. The second group of scenarios was run for different increments on both the disposal and combustion tipping fees. The third group of scenarios was run for different increments on the disposal fees.

The linear programming approach was found to be effective in modeling and analyzing the SWM system. Although the SWM system studied in this thesis was complex due to a large number of components and interrelationships, the linear programming approach was able to capture most of the system characteristics with reasonable simplifying assumptions. The model was tested for the scenarios described above, and the resulting least cost SWM strategies were examined and compared. The least cost SWM strategies obtained for those scenarios consisted of rational choices of process options and waste flow configurations. Changes in the process options and waste flow configurations in the least cost SWM strategies for varying model parameters in the different scenarios were as expected and consistent. The least cost SWM strategy for the Basic Scenario consisted of a combination of a recyclable collection option and a pre-sorted recyclables MRF for both the multi-family and commercial sectors, and a combination of a mixed waste collection option and a landfill for the residential sectors. As anticipated, recyclables were recovered only from the multi-family and commercial sectors, since the recycling process, including the collection and MRF processes, was cheaper for those sectors. A recovery rate of 11.7% was achieved in the least cost SWM strategy for the Basic Scenario. To recover more recyclables when a mandated overall diversion rate greater than 11.7% was imposed, more efficient but expensive recycling options consisting of either a combination of pre-sorted recyclables collection - pre-sorted recyclables MRF or a combination of mixed waste collection- mixed waste MRF were chosen for each generation sector.

When both the disposal and combustion tipping fees were increased, waste flowing into those options was diverted to other options. The least cost SWM strategy for each scenario, consisted of process options and waste flow configurations that collect and recover more recyclable material to offset increasing combustion and disposal costs. When only the disposal tipping fee was increased, the resulting least cost SWM strategies included recycling and waste-to-energy to divert waste from the landfill.

The model was found to be efficient in terms of required computational time. A typical execution time to generate a least cost SWM strategy was about 8 seconds on a Pentium 90 MHz processor with 32 MB of RAM. The reduced problem consisted of about 1900 constraints and 1900 variables. The CPLEX® solver needed about 740 iterations to generate a least cost SWM strategy. The model was tested and found to be flexible to modify to represent inclusion or exclusion of specific process options. This capability of the model was used to exclude from consideration several process options for which data are lacking.

The current model is set up to include LCI factors for consideration in the analysis. However, this feature of the model was not tested due to lack of LCI information on the process options. Future research on life cycle assessment of municipal solid waste management alternatives could include LCI parameters such as energy consumption, emission releases and raw material usage. Depending on the process option and the corresponding allocation schemes, these LCI parameters may be defined for each component of SWM. This item-specific information requires the model to have item-specific variables. One important effect of adding item-specific variables when developing this model was that prohibited mass flows were obtained. This problem was solved by introducing a set of aggregate variables. The inclusion of other LCI parameters may require item-specific variables. It may be necessary to modify this model or write a new one to capture these additional requirements and to avoid infeasible mass flows.

Chapter 7: References

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Appendices

Appendices

Appendix A

Input information

Table A.1 shows the cost coefficients for the collection options. Table A.2 shows the cost coefficients for the separation options specified by waste stream item. Table A.3 shows the cost coefficients for the transportation options. Tables A.4, A.5 and A.6 show the tipping fees for the treatment and disposal options. Table A.7 lists the prices of recyclable materials. Tables A.8 and A.9 show the market prices for compost, refuse to derive fuel and electricity from waste combustion.

Table A.10 shows the collection efficiencies for each waste stream item collected by the residential recyclables collection options (C2, C3, C4 and C8). Table A.11 shows the collection efficiencies for the multi-family recyclables collection options C8, C14 and C15. Table A.12 shows the collection efficiencies for commercial recyclables collection option C19. Table A.13 shows the bagging efficiencies for the collection options C4 and C5. Table A.14 lists the participation rates for all the collection options. Table A.15 shows the separation efficiencies or picking efficiencies per waste stream item for the five types of Material Recovery Facilities. Table A.16 shows the combustion efficiency at the combustion plant. Table A.17 lists the fractions of each waste stream item allowed to enter the wet, dry or recyclables compartments in the collection options C11 and C17. Table A.18 lists the fractions of each waste stream item present either in the dry or wet compartment in the collection options C12 and C18.

Tables A.19 and A.20 show the waste stream compositions for the three sectors considered in this thesis. They show ash fractions and energy content per item too.

Table A.1. Collection cost coefficients	
Collection option	Cost
1. Residential sector	($/ton)
C0	165.00
C1	45.00
C2	160.00
C3	190.00
C4	160.00
C5	45.00
C6	60.00
C7	75.00
C8	40.00
C9	225.00
C10	40.00
C11	65.00
C12	50.00
2. Multi-family sector	
C8	40.00
C13	30.00
C14	60.00
C15	80.00
C16	30.00
C17	50.00
C18	40.00
3. Commercial sector	
C19	70.00
C20	50.00
C20R	50.00

Source: Ed Curtis (1996), Collection pre-processor

Table A.2. Separation cost coefficients					
Residential and multi-family sectors					
Separation option	**S1**	**S2**	**S3**	**S4**	**S5**
Items					
	Cost($/ton)				
Yard trimmings, leaves	20			25	25
Yard trimmings, grass	20			25	25
Yard trimmings, branches	20			25	25
Old newsprint	66	11	12	14	20
Old corrugated cardboard	66	11	14	17	22
Office paper	66	11	14	17	22
Phone books	66	11	14	17	22
Books	66	11	14	17	22
Old magazines	66	11	14	17	22
Third class mail	66	11	14	17	22
Other recyclable paper 1	66	11	14	17	22
Other recyclable paper 2	66	11	14	17	22
Other recyclable paper 3	66	11	14	17	22
Other recyclable paper 4	66	11	14	17	22
Other recyclable paper 5	66	11	14	17	22
Mixed paper	66	11	14	17	22
Transparent HDPE	508	11	216	219	224
Pigmented HDPE	324	11	135	137	142
PET beverage bottles	508	11	216	219	224
Other recyclable plastics 1	1553	11	623	626	631
Other recyclable plastics 2	1553	11	623	626	631
Other recyclable plastics 3	1553	11	623	626	631
Other recyclable plastics 4	1553	11	623	626	631
Other recyclable plastics 5	1553	11	623	626	631
Mixed plastics	500	11	623	350	350
Ferrous metal cans	16	10	13	15	20
Other ferrous metal	16	10	13	15	20
Aluminum cans	16	10	13	15	20
Aluminum other 1	16	10	13	15	20
Aluminum other 2	16	10	13	15	20
Clear glass	101	9	62	64	70
Brown glass	142	9	94	97	102
Green glass	511	9	257	259	265
Mixed glass	25	9	100	100	100
Non-recyclable paper	20	0	0	25	25
Food waste	20	0		25	25
Non-recyclable plastics	20	0	0	25	25
Miscellaneous	20	0	0	25	25
Non-recyclable ferrous metal	20	0	0	25	25
Non-recyclable aluminum	20	0	0	25	25
Non-recyclable glass	20	0	0	25	25
Miscellaneous	20	0	0	25	25
Black bags process				15	0
Residuals	15	0	15		

Table A.2. (continued)		
Commercial sector	**S1**	**S2**
Old newsprint	66	11
Old corrugated cardboard	66	11
Office paper	66	11
Phone books	66	11
Third class mail	66	11
Pallets	66	11
Other recyclable paper 1 (1)	66	11
Other recyclable paper 2 (2)	66	11
Other recyclable paper 3 (3)	66	11
Combust compost recyc other (4)	66	11
Mixed paper	66	11
PET beverage bottles	508	11
Mixed plastics	500	11
Combust non-compost other (5)	1553	11
Aluminum cans (6)	16	10
Clear glass (7)	101	9
Brown glass (8)	142	9
Green glass (9)	511	9
Mixed glass	500	9
Ferrous cans (10)	16	10
Non-comb non-comp rec other (11)	50	11
Combust compost non-recyc other (12)	25	11
Combust non-compost non-recyc other (13)	25	11
Non-comb non-comp non-recyc other (14)	25	11

Table A.3. Transportation costs

Origin node	Destination node	Capacity (Ton)	Distance (mile)	Cost ($/mile)	Cost ($/ton)	Average ($/ton)
TR1	S1	17	50	2.3	6.76	NOT USED
	T3	17	50	2.3	6.76	
	T5	17	50	2.3	6.76	
	D1	17	50	2.3	6.76	
	D3	17	50	2.3	6.76	
TR2	S3	17	50	2.3	6.76	NOT USED
TR3	S3	17	50	2.3	6.76	NOT USED
	S4	17	50	2.3	6.76	
	T3	17	50	2.3	6.76	
	T5	17	50	2.3	6.76	
	T7	17	50	2.3	6.76	
	T8	17	50	2.3	6.76	
	D1	17	50	2.3	6.76	
	D3	17	50	2.3	6.76	
TR4	S3	17	50	2.3	6.76	NOT USED
	T3	17	50	2.3	6.76	
	T5	17	50	2.3	6.76	
	T7	17	50	2.3	6.76	
	T8	17	50	2.3	6.76	
	D1	17	50	2.3	6.76	
	D3	17	50	2.3	6.76	
TR5	S2	17	50	2.3	6.76	NOT USED
RT1	RT2	17	50	2.3	6.76	NOT USED
	RT3	17	50	2.3	6.76	
S1	Product buyer	17	0	2.3	0.00	1.35
	T3	17	10	2.3	1.35	
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
S2	Product buyer	17	0	2.3	0.00	0.00
S3	Product buyer	17	0	2.3	0.00	1.35
	T3	17	10	2.3	1.35	
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
S4	Product buyer	17	0	2.3	0.00	1.35
	T3	17	10	2.3	1.35	
	T5	17	10	2.3	1.35	
	T7	17	10	2.3	1.35	
	T8	17	10	2.3	1.35	
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
S5	Product buyer	17	0	2.3	0.00	1.35
	T3	17	10	2.3	1.35	
	T5	17	10	2.3	1.35	
	T7	17	10	2.3	1.35	
	T8	17	10	2.3	1.35	
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
T1	Product buyer	17	0	2.3	0.00	0.00
T3	D2	17	10	2.3	1.35	1.35
T5	Product buyer	17	0	2.3	0.00	NOT USED
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
T7	Product buyer	17	0	2.3	0.00	NOT USED
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	
T8	Product buyer	17	0	2.3	0.00	NOT USED
	D1	17	10	2.3	1.35	
	D3	17	10	2.3	1.35	

Table A.4. Incineration Cost	
	Cost ($/Ton)
Incineration	55

Table A.5. Yardwaste compost	
	Cost ($/Ton)
Process	18

Source: Yardwaste pre-processor

Table A.6. Landfill tipping fees	
Landfill	Tipping fee ($/Ton)
D1	25
D2	30
D3	30

Source: hypothetical case

Table A.7. Revenues from sale of recyclable material ($/ton)					
	Separation options				
Residential/multi-family sectors	S1	S2	S3	S4	S5
Items					
	Price ($/ton)				
Yard trimmings, leaves					
Yard trimmings, grass					
Yard trimmings, branches					
Old newsprint	70	70	70	70	70
Old corrugated cardboard	100	100	100	100	100
Office paper	70	70	70	70	70
Phone books	30	30	30	30	30
Books	30	30	30	30	30
Old magazines	30	0	30	30	30
Third class mail	30	0	30	30	30
Other recyclable paper 1	30	0	30	30	30
Other recyclable paper 2	30	0	30	30	30
Other recyclable paper 3	30	0	30	30	30
Other recyclable paper 4	30	0	30	30	30
Other recyclable paper 5	30	0	30	30	30
Mixed paper	0	0	0	0	0
Transparent HDPE	140	140	140	140	140
Pigmented HDPE	140	140	140	140	140
PET beverage bottles	140	140	140	140	140
Other recyclable plastics 1	70	70	70	70	70
Other recyclable plastics 2	70	70	70	70	70
Other recyclable plastics 3	70	0	70	70	70
Other recyclable plastics 4	70	0	70	70	70
Other recyclable plastics 5	70	0	70	70	70
Mixed plastics	0	0	0	0	0
Ferrous metal cans	45	45	45	45	45
Other ferrous metal	45	45	45	45	45
Aluminum cans	800	800	800	800	800
Aluminum other 1	100	100	100	100	100
Aluminum other 2	100	100	100	100	100
Clear glass	50	50	50	50	50
Brown glass	50	50	50	50	50
Green glass	15	15	15	15	15
Mixed glass	10	0	0	0	0
Non-recyclable paper					
Food waste					
Non-recyclable plastics					
Miscellaneous					
Non-recyclable ferrous metal					
Non-recyclable aluminum					
Non-recyclable glass					
Miscellaneous					

Table A.7 (continued).		
Commercial #1		
	S1	S2
Old newsprint	70	70
Old corrugated cardboard	100	100
Office paper	70	70
Phone books	30	30
Third class mail	30	30
Pallets	60	60
Other recyclable paper 1	30	0
Other recyclable paper 2	30	0
Other recyclable paper 3	30	0
Combust compost recyc other	30	0
Mixed paper	0	0
PET beverage bottles	140	140
Mixed plastics	70	70
Combust non-compost other	10	10
Aluminum cans	800	800
Clear glass	50	50
Brown glass	50	50
Green glass	15	15
Mixed glass	0	10
Ferrous cans	45	45
Non-comb non-comp rec other	30	30
Combust compost non-recyc other		
Combust non-compost non-recyc other		
Non-comb non-comp non-recyc other		

Table A.8. Revenues from selling compost product		
		($/ton)
1. Mixed waste compost		5
2. Yardwaste compost		5
Table A.9. Revenues from selling electricity		
		Value
Electric energy value ($/MWH)		20
Electric energy value ($/BTU)		5.86E-06
Note: This is the same as $25/MWH and 1KWH = 3413 BTU		
	Source: Hypothetical case	

Table A.10. Collection efficiencies for the collection options C2/C3/C4/C8

Residential sector Items	C2	C3	C4	C8
	Capture rates: Percentage actually collected by the collection options in the participating houses			
Yard trimmings, leaves	0	0	0	0
Yard trimmings, grass	0	0	0	0
Yard trimmings, branches	0	0	0	0
Old newsprint	0.80	0.85	0.85	0.60
Old corrugated cardboard	0.80	0.85	0.85	0.60
Office paper	0.80	0.85	0.85	0.60
Phone books	0.80	0.85	0.85	0.60
Books	0.80	0.85	0.85	0.60
Old magazines	0.80	0.85	0.85	0.60
Third class mail	0.80	0.85	0.85	0.60
Other recyclable paper 1	0.80	0.85	0.85	0.60
Other recyclable paper 2	0.80	0.85	0.85	0.60
Other recyclable paper 3	0.80	0.85	0.85	0.60
Other recyclable paper 4	0.80	0.85	0.85	0.60
Other recyclable paper 5	0.80	0.85	0.85	0.60
Mixed paper	0.80	0.85	0.85	0.60
Transparent HDPE	0.80	0.85	0.85	0.60
Pigmented HDPE	0.80	0.85	0.85	0.60
PET beverage bottles	0.80	0.85	0.85	0.60
Other recyclable plastics 1	0.80	0.85	0.85	0.60
Other recyclable plastics 2	0.80	0.85	0.85	0.60
Other recyclable plastics 3	0.80	0.85	0.85	0.60
Other recyclable plastics 4	0.80	0.85	0.85	0.60
Other recyclable plastics 5	0.80	0.85	0.85	0.60
Mixed plastics	0.80	0.85	0.85	0.60
Ferrous metal cans	0.80	0.85	0.85	0.60
Other ferrous metal	0.80	0.85	0.85	0.60
Aluminum cans	0.80	0.85	0.85	0.60
Aluminum other 1	0.80	0.85	0.85	0.60
Aluminum other 2	0.80	0.85	0.85	0.60
Clear glass	0.80	0.85	0.85	0.60
Brown glass	0.80	0.85	0.85	0.60
Green glass	0.80	0.85	0.85	0.60
Mixed glass	0.80	0.85	0.85	0.60
Non-recyclable paper	0	0	0	0
Food waste	0	0	0	0
Non-recyclable plastics	0	0	0	0
Miscellaneous	0	0	0	0
Non-recyclable ferrous metal	0	0	0	0
Non-recyclable aluminum	0	0	0	0
Non-recyclable glass	0	0	0	0
Miscellaneous	0	0	0	0

Source: Subba Nishtala (1994), MRF pre-processor

Table A.11. Collection efficiencies for the collection options C8/C14/C15

			C8	C14	C15
Multi-family sector					
Items					
Yard trimmings, leaves			0	0	0
Yard trimmings, grass			0	0	0
Yard trimmings, branches			0	0	0
Old newsprint			0.6	0.8	0.85
Old corrugated cardboard			0.6	0.8	0.85
Office paper			0.6	0.8	0.85
Phone books			0.6	0.8	0.85
Books			0.6	0.8	0.85
Old magazines			0.6	0.8	0.85
Third class mail			0.6	0.8	0.85
Other recyclable paper 1			0.6	0.8	0.85
Other recyclable paper 2			0.6	0.8	0.85
Other recyclable paper 3			0.6	0.8	0.85
Other recyclable paper 4			0.6	0.8	0.85
Other recyclable paper 5			0.6	0.8	0.85
Mixed paper			0.6	0.8	0.85
Transparent HDPE			0.6	0.8	0.85
Pigmented HDPE			0.6	0.8	0.85
PET beverage bottles			0.6	0.8	0.85
Other recyclable plastics 1			0.6	0.8	0.85
Other recyclable plastics 2			0.6	0.8	0.85
Other recyclable plastics 3			0.6	0.8	0.85
Other recyclable plastics 4			0.6	0.8	0.85
Other recyclable plastics 5			0.6	0.8	0.85
Mixed plastics			0.6	0.8	0.85
Ferrous metal cans			0.6	0.8	0.85
Other ferrous metal			0.6	0.8	0.85
Aluminum cans			0.6	0.8	0.85
Aluminum other 1			0.6	0.8	0.85
Aluminum other 2			0.6	0.8	0.85
Clear glass			0.6	0.8	0.85
Brown glass			0.6	0.8	0.85
Green glass			0.6	0.8	0.85
Mixed glass			0.6	0.8	0.85
Non-recyclable paper			0	0	0
Food waste			0	0	0
Non-recyclable plastics			0	0	0
Miscellaneous			0	0	0
Non-recyclable ferrous metal			0	0	0
Non-recyclable aluminum			0	0	0
Non-recyclable glass			0	0	0
Miscellaneous			0	0	0

Source: Derivation from table for residential recyclable collection

Table A.12. Collection efficiencies in C19		
Commercial sector		
Old newsprint		0.80
Old corrugated cardboard		0.80
Office paper		0.80
Phone books		0.80
Third class mail		0.80
Pallets		0.80
Other recyclable paper 1		0.80
Other recyclable paper 2		0.80
Other recyclable paper 3		0.80
Combust compost recyc other		0.80
Mixed paper		0.80
PET beverage bottles		0.80
Mixed plastics		0.80
Combust non-compost other		0.80
Aluminum cans		0.80
Clear glass		0.80
Brown glass		0.80
Green glass		0.80
Mixed glass		0.80
Ferrous cans		0.80
Non-comb non-comp rec other		0.80
Combust compost non-recyc other		0
Combust non-compost non-recyc other		0
Non-comb non-comp non-recyc other		0

Source: Derivation from table for residential recyclable collection

Table A.13. Bagging efficiency for co-collection options C5/C6

Residential sector				
Items			**C5**	**C6**
Yard trimmings, leaves			0.00	0.00
Yard trimmings, grass			0.00	0.00
Yard trimmings, branches			0.00	0.00
Old newsprint			0.70	0.70
Old corrugated cardboard			0.60	0.60
Office paper			0.50	0.50
Phone books			0.60	0.60
Books			0.60	0.60
Old magazines			0.60	0.60
Third class mail			0.60	0.60
Other recyclable paper 1			0.60	0.60
Other recyclable paper 2			0.60	0.60
Other recyclable paper 3			0.60	0.60
Other recyclable paper 4			0.60	0.60
Other recyclable paper 5			0.60	0.60
Mixed paper			0.60	0.60
Transparent HDPE			0.60	0.60
Pigmented HDPE			0.60	0.60
PET beverage bottles			0.60	0.60
Other recyclable plastics 1			0.60	0.60
Other recyclable plastics 2			0.60	0.60
Other recyclable plastics 3			0.60	0.60
Other recyclable plastics 4			0.60	0.60
Other recyclable plastics 5			0.60	0.60
Mixed plastics			0.60	0.60
Ferrous metal cans			0.60	0.60
Other ferrous metal			0.60	0.60
Aluminum cans			0.60	0.60
Aluminum other 1			0.60	0.60
Aluminum other 2			0.60	0.60
Clear glass			0.60	0.60
Brown glass			0.60	0.60
Green glass			0.60	0.60
Mixed glass			0.60	0.60
Non-recyclable paper			0.00	0.00
Food waste			0.00	0.00
Non-recyclable plastics			0.00	0.00
Miscellaneous			0.00	0.00
Non-recyclable ferrous metal			0.00	0.00
Non-recyclable aluminum			0.00	0.00
Non-recyclable glass			0.00	0.00
Miscellaneous			0.00	0.00

Note: These numbers represent the people's participation effectiveness in placing items in the right bag. For example: 0.6 for OCC means that 60% of the item is placed in the blue bag. All non-recyclable items are placed in the black bags. No non-recyclable items are placed in the blue bags.

Source: Subba Nishtala (1994), MRF pre-processor

Table A.14. Participation rates in collection options

Collection option	Participation rate
1. Residential sectors	
C0	0.80
C1	1.00
C2	0.70
C3	0.70
C4	0.70
C5	1.00
C6	1.00
C7	1.00
C8	0.05
C9	0.80
C10	0.05
C11	1.00
C12	1.00
2. Multi-family sectors	
C8	0.05
C13	1.00
C14	0.70
C15	0.70
C16	1.00
C17	1.00
C18	1.00
3. Commercial sectors	
C19	0.70
C20	1.00

Source: Hypothetical case

Table A.15. Separation efficiencies at MRF's					
	S1	S2	S3	S4	S5
Residential and multi-family sectors					
Items					
Yard trimmings, leaves	0.00			0.00	0.00
Yard trimmings, grass	0.00			0.00	0.00
Yard trimmings, branches	0.00			0.00	0.00
Old newsprint	0.70	1.00	0.99	0.90	0.99
Old corrugated cardboard	0.70	1.00	0.99	0.90	0.99
Office paper	0.70	1.00	0.99	0.90	0.99
Phone books	0.70	1.00	0.99	0.90	0.99
Books	0.70	1.00	0.99	0.90	0.99
Old magazines	0.70	1.00	0.99	0.90	0.99
Third class mail	0.70	1.00	0.99	0.90	0.99
Other recyclable paper 1	0.70	1.00	0.99	0.90	0.99
Other recyclable paper 2	0.70	1.00	0.99	0.90	0.99
Other recyclable paper 3	0.70	1.00	0.99	0.90	0.99
Other recyclable paper 4	0.70	1.00	0.99	0.90	0.99
Other recyclable paper 5	0.70	1.00	0.99	0.90	0.99
Mixed paper	0.70	1.00	0.99	0.90	0.99
Transparent HDPE	0.70	1.00	0.99	0.90	0.99
Pigmented HDPE	0.70	1.00	0.99	0.90	0.99
PET beverage bottles	0.70	1.00	0.99	0.90	0.99
Other recyclable plastics 1	0.70	1.00	0.99	0.90	0.99
Other recyclable plastics 2	0.70	1.00	0.99	0.90	0.99
Other recyclable plastics 3	0.70	1.00	0.99	0.90	0.99
Other recyclable plastics 4	0.70	1.00	0.99	0.90	0.99
Other recyclable plastics 5	0.70	1.00	0.99	0.90	0.99
Mixed plastics	0.70	1.00	0.99	0.90	0.99
Ferrous metal cans	0.70	1.00	0.99	0.90	0.99
Other ferrous metal	0.70	1.00	0.99	0.90	0.99
Aluminum cans	0.70	1.00	0.99	0.90	0.99
Aluminum other 1	0.70	1.00	0.99	0.90	0.99
Aluminum other 2	0.70	1.00	0.99	0.90	0.99
Clear glass	0.50	1.00	0.94	0.85	0.94
Brown glass	0.50	1.00	0.94	0.85	0.94
Green glass	0.50	1.00	0.94	0.85	0.94
Mixed glass	0.50	1.00	0.94	0.85	0.94
Non-recyclable paper	0.40			0.40	0.40
Food waste	0.40			0.40	0.40
Non-recyclable plastics	0.40			0.40	0.40
Miscellaneous	0.40			0.40	0.40
Non-recyclable ferrous metal	0.00			0.00	0.00
Non-recyclable aluminum	0.00			0.00	0.00
Non-recyclable glass	0.00			0.00	0.00
Miscellaneous	0.00			0.00	0.00
	Source: Subba Nishtala (1994): MRF pre-processor				

Table A.15 (continued).		
Commercial sector	**S1**	**S2**
Old newsprint	0.70	1.00
Old corrugated cardboard	0.70	1.00
Office paper	0.70	1.00
Phone books	0.70	1.00
Third class mail	0.70	1.00
Pallets	1.00	1.00
Other recyclable paper 1	0.70	1.00
Other recyclable paper 2	0.70	1.00
Other recyclable paper 3	0.70	1.00
Combust compost recyc other	0.70	1.00
Mixed paper	0.70	1.00
PET beverage bottles	0.70	1.00
Mixed plastics	0.70	1.00
Combust non-compost other	0.70	1.00
Aluminum cans	0.70	1.00
Clear glass	0.50	1.00
Brown glass	0.50	1.00
Green glass	0.50	1.00
Mixed glass	0.50	1.00
Ferrous cans	0.70	1.00
Non-comb non-comp rec other	0.70	1.00
Combust compost non-recyc other	0.40	0.00
Combust non-compost non-recyc other	0.40	0.00
Non-comb non-comp non-recyc other	0.00	0.00

Source: Subba Nishtala (1994): MRF pre-processor

Table A.16. Combustion efficiency	
Efficiency	0.33

Sources: hypothetical case

Table A.17. Factors for the wet/dry/recyclables collection			C11/C17	
		Fractions		
Sets	Items	Wet (rw)	Dry (rd)	Rec (rr)
RYTL/MYTL	Yard trimmings, leaves	1.000	0.000	0.000
RYTO/MYTO	Yard trimmings, grass	1.000	0.000	0.000
	Yard trimmings, branches	1.000	0.000	0.000
RCCR/MCCR	Old newsprint	0.000	0.250	0.750
	Old corrugated cardboard	0.000	0.250	0.750
	Office paper	0.000	0.250	0.750
	Phone books	0.000	0.250	0.750
	Books	0.000	0.250	0.750
	Old magazines	0.000	0.250	0.750
	Third class mail	0.000	0.250	0.750
	Other recyclable paper 1	0.000	0.250	0.750
	Other recyclable paper 2	0.000	0.250	0.750
	Other recyclable paper 3	0.000	0.250	0.750
	Other recyclable paper 4	0.000	0.250	0.750
	Other recyclable paper 5	0.000	0.250	0.750
	Mixed paper	0.000	0.250	0.750
RCNR/MCNR	Transparent HDPE	0.000	0.250	0.750
	Pigmented HDPE	0.000	0.250	0.750
	PET beverage bottles	0.000	0.250	0.750
	Other recyclable plastics 1	0.000	0.250	0.750
	Other recyclable plastics 2	0.000	0.250	0.750
	Other recyclable plastics 3	0.000	0.250	0.750
	Other recyclable plastics 4	0.000	0.250	0.750
	Other recyclable plastics 5	0.000	0.250	0.750
	Mixed plastics	0.000	0.250	0.750
RNNR/MNNR	Ferrous metal cans	0.000	0.250	0.750
	Other ferrous metal	0.000	0.250	0.750
	Aluminum cans	0.000	0.250	0.750
	Aluminum other 1	0.000	0.250	0.750
	Aluminum other 2	0.000	0.250	0.750
	Clear glass	0.000	0.250	0.750
	Brown glass	0.000	0.250	0.750
	Green glass	0.000	0.250	0.750
	Mixed glass	0.000	0.250	0.750
RCCN/MCCN	Non-recyclable paper	0.000	1.000	0.000
	Food waste	1.000	0.000	0.000
RCNN/MCNN	Non-recyclable plastics	0.000	1.000	0.000
	Miscellaneous	0.000	1.000	0.000
RNNN/MNNN	Non-recyclable ferrous metal	0.000	1.000	0.000
	Non-recyclable aluminum	0.000	1.000	0.000
	Non-recyclable glass	0.000	1.000	0.000
	Miscellaneous	0.000	1.000	0.000
	Source: Hypothetical case			

Table A.18. Factors for the wet/dry collection

		Fractions	(C12/C18)
Sets	**Items**	**Wet (rw)**	**Dry (rd)**
RYTL/MYTL	Yard trimmings, leaves	1.000	0.000
RYTO/MYTO	Yard trimmings, grass	1.000	0.000
	Yard trimmings, branches	1.000	0.000
RCCR/MCCR	Old newsprint	0.200	0.800
	Old corrugated cardboard	0.200	0.800
	Office paper	0.200	0.800
	Phone books	0.200	0.800
	Books	0.200	0.800
	Old magazines	0.200	0.800
	Third class mail	0.200	0.800
	Other recyclable paper 1	0.200	0.800
	Other recyclable paper 2	0.200	0.800
	Other recyclable paper 3	0.200	0.800
	Other recyclable paper 4	0.200	0.800
	Other recyclable paper 5	0.200	0.800
	Mixed paper	0.200	0.800
RCNR/MCNR	Transparent HDPE	0.100	0.900
	Pigmented HDPE	0.100	0.900
	PET beverage bottles	0.100	0.900
	Other recyclable plastics 1	0.100	0.900
	Other recyclable plastics 2	0.100	0.900
	Other recyclable plastics 3	0.100	0.900
	Other recyclable plastics 4	0.100	0.900
	Other recyclable plastics 5	0.100	0.900
	Mixed plastics	0.100	0.900
RNNR/MNNR	Ferrous metal cans	0.100	0.900
	Other ferrous metal	0.100	0.900
	Aluminum cans	0.100	0.900
	Aluminum other 1	0.100	0.900
	Aluminum other 2	0.100	0.900
	Clear glass	0.100	0.900
	Brown glass	0.100	0.900
	Green glass	0.100	0.900
	Mixed glass	0.100	0.900
RCCN/MCCN	Non-recyclable paper	0.250	0.750
	Food waste	1.000	0.000
RCNN/MCNN	Non-recyclable plastics	0.100	0.900
	Miscellaneous	0.100	0.900
RNNN/MNNN	Non-recyclable ferrous metal	0.100	0.900
	Non-recyclable aluminum	0.100	0.900
	Non-recyclable glass	0.100	0.900
	Miscellaneous	0.100	0.900

Source: Hypothetical case

Table A.19. Total generation

Residential/multifamily sectors

Sets	Items	Generation (10^6 ton/year)	Moisture (%)	Wet weight (10^6 ton/year)	Wet compo.
RYTL	Yard trimmings, leaves	7.875	0%	7.875	6.20%
RYTO	Yard trimmings, grass	15.750	0%	15.750	12.40%
	Yard trimmings, branches	7.875	0%	7.875	6.20%
RCCR	Old newsprint	11.600	6%	12.340	9.71%
	Old corrugated cardboard	2.400	5%	2.526	1.99%
	Office paper	1.600	6%	1.702	1.34%
	Phone books	0.300	6%	0.319	0.25%
	Books	0.800	6%	0.851	0.67%
	Old magazines	1.800	6%	1.915	1.51%
	Third class mail	2.500	6%	2.660	2.09%
	Other recyclable paper 1 (1)	3.600	6%	3.830	3.01%
	Other recyclable paper 2 (2)	3.000	6%	3.191	2.51%
	Other recyclable paper 3 (3)	2.200	6%	2.340	1.84%
	Other recyclable paper 4	0.000	6%	0.000	0.00%
	Other recyclable paper 5	0.000	6%	0.000	0.00%
	Mixed paper	0.000	6%	0.000	0.00%
RCNR	Transparent HDPE (4)	0.380	2%	0.388	0.31%
	Pigmented HDPE (5)	0.040	2%	0.041	0.03%
	PET beverage bottles	0.300	2%	0.306	0.24%
	Other recyclable plastics 1 (6)	0.800	2%	0.816	0.64%
	Other recyclable plastics 2 (7)	2.000	2%	2.041	1.61%
	Other recyclable plastics 3 (8)	2.940	2%	3.000	2.36%
	Other recyclable plastics 4	0.000	2%	0.000	0.00%
	Other recyclable plastics 5	0.000	2%	0.000	0.00%
	Mixed plastics	0.000	2%	0.000	0.00%
RNNR	Ferrous metal cans (9)	2.300	3%	2.371	1.87%
	Other ferrous metal	0.000	3%	0.000	0.00%
	Aluminum cans (10)	1.300	2%	1.327	1.04%
	Aluminum other 1 (11)	0.300	2%	0.306	0.24%
	Aluminum other 2	0.000	2%	0.000	0.00%
	Clear glass (12)	6.566	2%	6.700	5.27%
	Brown glass (12)	2.450	2%	2.500	1.97%
	Green glass (12)	0.784	2%	0.800	0.63%
	Mixed glass	0.000	2%	0.000	0.00%
RCCN	Non-recyclable paper (13)	7.000	6%	7.447	5.86%
	Food waste	6.600	0%	6.600	5.20%
RCNN	Non-recyclable plastics (14)	3.720	2%	3.796	2.99%
	Miscellaneous (15)	6.200	6%	6.596	5.19%
RNNN	Non-recyclable ferrous metal (16)	7.440	3%	7.670	6.04%
	Non-recyclable aluminum	0.000	2%	0.000	0.00%
	Non-recyclable glass (17)	0.940	2%	0.959	0.76%
	Miscellaneous (18)	8.160	20%	10.200	8.03%
Total		121.520		127.039	100.00%

Source: Franklin Report, appendix C (1994)
Moisture content from table 4.1, George Tchobanoglous et al (1993)
Note: Durable goods generation was 22.7 million tons (including major appliances, furniture and other miscellaneous durables. We will assume that from the total, 40 % corresponded to metals, 20 % to plastics, 18% to rubber and leather, 18% to wood and 4 % to glass based on recent generation studies (Franklin, 1994) (see table A.20).

(1) Other commercial printings
(2) Milk cartons; folding cartons; other paperboard packaging
(3) Paper bags and sacks
(4) Milk bottles
(5) Estimated 10 % of translucid HDPE
(6) Trash bags
(7) Bags and sacks; wraps (LDPE)
(8) Other containers; other plastic packaging
(9) Beer and soft drink cans; food and other cans
(10) Beer and soft drink cans
(11) Foil and closures
(12) Total glass generation was 9.8 millions tons. Glass discards include:food and other bottles and jars; beer and soft drink bottles; wine and liquor bottles.
67 % of this amount is clear glass, 25 % is brown glass and 8% green glass
(13) Tissue paper and towels; paper plates; disposable diapers; other non-pacckaging paper; wrapping paper; other paper packaging
(14) Plastic from durable goods
(15) Clothing and footwear; towels, sheets and pillowcases; other non-durables; carpets and rugs; rubber tires
(16) Metals from durable goods
(17) Glass fron durable goods
(18) Other miscellaneous packaging; miscellaneous inorganic; batteries; plastics from durable goods; wood from durable goods

Table A.19. (continued)					
Commercial sector					
Sets	**Items**	**Generation**	**Moisture**	**Wet weight**	**Wet compo.**
		(10^6 ton/year)	**(%)**	**(10^6 ton/year)**	
CCCR	Old newsprint	1.300	6%	1.383	1.73%
	Old corrugated cardboard	21.500	5%	22.632	28.33%
	Office paper	4.800	6%	5.106	6.39%
	Phone books	0.200	6%	0.213	0.27%
	Third class mail	1.300	6%	1.383	1.73%
	Pallets	7.900	20%	9.875	12.36%
	Other recyclable paper 1 (1)	0.200	6%	0.213	0.27%
	Other recyclable paper 2 (2)	1.000	6%	1.064	1.33%
	Other recyclable paper 3 (3)	1.900	6%	2.021	2.53%
	Combust compost recyc other (4)	2.900	6%	3.085	3.86%
	Mixed paper	0.000	6%	0.000	0.00%
CCNR	PET beverage bottles	0.100	2%	0.102	0.13%
	Mixed plastics	0.000	2%	0.000	0.00%
	Combust non-compost other (5)	2.680	2%	2.735	3.42%
CNNR	Aluminum cans (6)	0.300	2%	0.306	0.38%
	Clear glass (7)	1.407	2%	1.436	1.80%
	Brown glass (7)	0.525	2%	0.536	0.67%
	Green glass (7)	0.168	2%	0.171	0.21%
	Mixed glass	0.000	2%	0.000	0.00%
	Ferrous cans (8)	0.400	3%	0.412	0.52%
	Non-comb non-comp rec other (9)	1.800	3%	1.856	2.32%
CCCN	Combust compost non-recyc other (10)	12.300	6%	13.085	16.38%
CCNN	Comb non-comp non-recyc other (11)	7.760	6%	8.255	10.33%
CNNN	Non-comb non-comp non-recyc other (12)	3.410	15%	4.012	5.02%
Total		73.850		79.881	100.00%

(1) Books
(2) Magazines
(3) Other commercial printing
(4) Paper plates and cups; milk cartons; folding cartons; other paperboard packaging;bags and sacks
(5) Plastic plates and cups; milk bottles; other plastic containers; other LDPE materials:bags, sacks, wraps; other plastic packaging; tissue paper
(6) Beer and soft drink cans
(7) Total glass generation was 9.8 millions tons. Glass discards include:food and other bottles and jars; beer and soft drink bottles; wine and liquor bottles.
67 % of this amount is clear glass, 25 % is brown glass and 8% green glass
(8) Food and other cans
(9) Other steel packaging; batteries (lead acid)
(10) Other non-packaging paper; other paper packaging; food wastes; yard trimmings
(11) Disposable diapers; clothing and footwear; towels, sheets and pillowcases; other non-durables; carpets and rugs; rubber tires; durable (plastics, rubber, wood)
(12) Other miscellaneous packaging; miscellaneous inorganic; durables (metal, glass)

Table A.20. Generation of durable goods (10^6 tons/year)						
	Metals	**Plastics**	**Rubber/leather**	**Wood**	**Glass**	**Total**
Overall percentage	**40.00%**	**20.00%**	**17.00%**	**18.00%**	**5.00%**	**100.00%**
1. Residential						
Major appliances	1.08	0.54	0.46	0.49	0.14	2.70
Furniture	2.36	1.18	1.00	1.06	0.30	5.90
Miscellaneous	4.00	2.00	1.70	1.80	0.50	10.00
Totals	**7.44**	**3.72**	**3.16**	**3.35**	**0.93**	**18.60**
2. Commercial						
Major appliances	0.04	0.02	0.02	0.02	0.01	0.10
Furniture	0.60	0.30	0.26	0.27	0.08	1.50
Miscellaneous	1.00	0.50	0.43	0.45	0.13	2.50
Totals	**1.64**	**0.82**	**0.70**	**0.74**	**0.21**	**4.10**
				Grand Total		22.70

Appendix B

Least Cost Solutions for the Analyzed Scenarios

Section B.1. Least Cost Solution for the Basic Scenario
Section B.2. Least Cost Solution for Scenario A1
Section B.3. Least Cost Solution for Scenario A2
Section B.4. Least Cost Solution for Scenario A3
Section B.5. Least Cost Solution for Scenario A4
Section B.6. Least Cost Solution for the Maximum Recovery Rate Scenario
Section B.7. Least Cost Solution Scenario B3
Section B.8. Least Cost Solution Scenario B4
Section B.9. Least Cost Solution Scenarios C1 through C4

Section B.1. Least cost solution for the Basic Scenario

Table B.1. Materials diverted at separation options: Basic Scenario

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.1. (continued)

Materials diverted at separation facilities					
Commercial area		S2		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**

Section B.2. Least Cost Solution for Scenario A1 (15 % recovery rate)

Table B.2. Materials diverted at separation options: Scenario A1

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	1,470.81	0.00	**1,470.81**	**0.00**
	Old corrugated cardboard	301.10	0.00	**301.10**	**0.00**
	Office paper	202.87	0.00	**202.87**	**0.00**
	Phone books	38.04	0.00	**38.04**	**0.00**
	Books	101.44	0.00	**101.44**	**0.00**
	Old magazines	228.23	0.00	**228.23**	**0.00**
	Third class mail	316.99	0.00	**316.99**	**0.00**
	Other recyclable paper 1	456.46	0.00	**456.46**	**0.00**
	Other recyclable paper 2	380.38	0.00	**380.38**	**0.00**
	Other recyclable paper 3	278.95	0.00	**278.95**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	46.22	0.00	**46.22**	**0.00**
	Pigmented HDPE	4.86	0.00	**4.86**	**0.00**
	PET beverage bottles	36.49	0.00	**36.49**	**0.00**
	Other recyclable plastics 1	97.29	0.00	**97.29**	**0.00**
	Other recyclable plastics 2	243.24	0.00	**243.24**	**0.00**
	Other recyclable plastics 3	357.56	0.00	**357.56**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	282.61	n/a	**282.61**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	158.10	n/a	**158.10**	n/a
	Aluminum other 1	36.49	n/a	**36.49**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	570.39	n/a	**570.39**	n/a
	Brown glass	212.83	n/a	**212.83**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	507.18	n/a	**507.18**
	Food waste	n/a	449.50	n/a	**449.50**
RCNN	Non-recyclable plastics	n/a	258.53	n/a	**258.53**
	Miscellaneous	n/a	449.21	n/a	**449.21**
Totals		**5,821.34**	**1,664.42**	**5,821.34**	**1,664.42**
Paper/cardboard		**3,775.26**	**0.00**	**3,775.26**	**0.00**
Plastic		**785.66**	**0.00**	**785.66**	**0.00**
Metals		**477.20**	n/a	**477.20**	n/a
Glass		**783.22**	n/a	**783.22**	n/a
Other		n/a	**1,664.42**	n/a	**1,664.42**

Table B.2. (continued)

Materials diverted at separation facilities					
				Totals	Totals
Multi-family area		S2			
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
MCCR	Old newsprint	595.66	0.00	595.66	0.00
	Old corrugated cardboard	121.94	0.00	121.94	0.00
	Office paper	82.16	0.00	82.16	0.00
	Phone books	15.40	0.00	15.40	0.00
	Books	41.08	0.00	41.08	0.00
	Old magazines	0.00	92.43	0.00	92.43
	Third class mail	0.00	128.37	0.00	128.37
	Other recyclable paper 1	0.00	184.86	0.00	184.86
	Other recyclable paper 2	0.00	154.05	0.00	154.05
	Other recyclable paper 3	0.00	112.97	0.00	112.97
	Other recyclable paper 4	0.00	0.00	0.00	0.00
	Other recyclable paper 5	0.00	0.00	0.00	0.00
	Mixed paper	0.00	0.00	0.00	0.00
MCNR	Transparent HDPE	18.72	0.00	18.72	0.00
	Pigmented HDPE	1.97	0.00	1.97	0.00
	PET beverage bottles	14.78	0.00	14.78	0.00
	Other recyclable plastics 1	39.40	0.00	39.40	0.00
	Other recyclable plastics 2	98.51	0.00	98.51	0.00
	Other recyclable plastics 3	0.00	144.81	0.00	144.81
	Other recyclable plastics 4	0.00	0.00	0.00	0.00
	Other recyclable plastics 5	0.00	0.00	0.00	0.00
	Mixed plastics	0.00	0.00	0.00	0.00
MNNR	Ferrous metal cans	114.45	n/a	114.45	n/a
	Other ferrous metal	0.00	n/a	0.00	n/a
	Aluminum cans	64.03	n/a	64.03	n/a
	Aluminum other 1	14.78	n/a	14.78	n/a
	Aluminum other 2	0.00	n/a	0.00	n/a
	Clear glass	323.40	n/a	323.40	n/a
	Brown glass	120.67	n/a	120.67	n/a
	Green glass	38.62	n/a	38.62	n/a
	Mixed glass	0.00	n/a	0.00	n/a
Totals		1,705.56	817.49	1,705.56	817.49
Paper/cardboard		856.24	672.68	856.24	672.68
Plastic		173.37	144.81	173.37	144.81
Metals		193.26	n/a	193.26	n/a
Glass		482.69	n/a	482.69	n/a

Table B.2. (continued)

Materials diverted at separation facilities					
Commercial area		**S2**		**Totals**	**Totals**
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**

Section B.3. Least Cost Solution for Scenario A2 (20% recovery rate)

Table B.3. Materials diverted at separation options: Scenario A2

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	3,702.54	0.00	**3,702.54**	**0.00**
	Old corrugated cardboard	757.98	0.00	**757.98**	**0.00**
	Office paper	510.70	0.00	**510.70**	**0.00**
	Phone books	95.76	0.00	**95.76**	**0.00**
	Books	255.35	0.00	**255.35**	**0.00**
	Old magazines	574.53	0.00	**574.53**	**0.00**
	Third class mail	797.96	0.00	**797.96**	**0.00**
	Other recyclable paper 1	1,149.07	0.00	**1,149.07**	**0.00**
	Other recyclable paper 2	957.55	0.00	**957.55**	**0.00**
	Other recyclable paper 3	702.21	0.00	**702.21**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	116.34	0.00	**116.34**	**0.00**
	Pigmented HDPE	12.25	0.00	**12.25**	**0.00**
	PET beverage bottles	91.85	0.00	**91.85**	**0.00**
	Other recyclable plastics 1	244.93	0.00	**244.93**	**0.00**
	Other recyclable plastics 2	612.31	0.00	**612.31**	**0.00**
	Other recyclable plastics 3	900.10	0.00	**900.10**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	711.42	n/a	**711.42**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	398.00	n/a	**398.00**	n/a
	Aluminum other 1	91.85	n/a	**91.85**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	1,435.88	n/a	**1,435.88**	n/a
	Brown glass	535.77	n/a	**535.77**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	1,276.74	n/a	**1,276.74**
	Food waste	n/a	1,131.56	n/a	**1,131.56**
RCNN	Non-recyclable plastics	n/a	650.80	n/a	**650.80**
	Miscellaneous	n/a	1,130.83	n/a	**1,130.83**
Totals		**14,654.34**	**4,189.92**	**14,654.34**	**4,189.92**
Paper/cardboard		**9,503.64**	**0.00**	**9,503.64**	**0.00**
Plastic		**1,977.77**	**0.00**	**1,977.77**	**0.00**
Metals		**1,201.27**	n/a	**1,201.27**	n/a
Glass		**1,971.65**	n/a	**1,971.65**	n/a
Other		n/a	**4,189.92**	n/a	**4,189.92**

Table B.3. (continued)

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.3. (continued)

Materials diverted at separation facilities					
Commercial area		**S2**		**Totals**	**Totals**
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**

Section B.4. Least Cost solution for Scenario A3 (25% recovery rate)

Table B.4. Materials diverted at separation options: Scenario A3

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	5,934.28	0.00	**5,934.28**	**0.00**
	Old corrugated cardboard	1,214.86	0.00	**1,214.86**	**0.00**
	Office paper	818.52	0.00	**818.52**	**0.00**
	Phone books	153.47	0.00	**153.47**	**0.00**
	Books	409.26	0.00	**409.26**	**0.00**
	Old magazines	920.84	0.00	**920.84**	**0.00**
	Third class mail	1,278.94	0.00	**1,278.94**	**0.00**
	Other recyclable paper 1	1,841.67	0.00	**1,841.67**	**0.00**
	Other recyclable paper 2	1,534.73	0.00	**1,534.73**	**0.00**
	Other recyclable paper 3	1,125.47	0.00	**1,125.47**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	186.46	0.00	**186.46**	**0.00**
	Pigmented HDPE	19.63	0.00	**19.63**	**0.00**
	PET beverage bottles	147.21	0.00	**147.21**	**0.00**
	Other recyclable plastics 1	392.56	0.00	**392.56**	**0.00**
	Other recyclable plastics 2	981.39	0.00	**981.39**	**0.00**
	Other recyclable plastics 3	1,442.64	0.00	**1,442.64**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	1,140.23	n/a	**1,140.23**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	637.90	n/a	**637.90**	n/a
	Aluminum other 1	147.21	n/a	**147.21**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	2,301.36	n/a	**2,301.36**	n/a
	Brown glass	858.72	n/a	**858.72**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	2,046.30	n/a	**2,046.30**
	Food waste	n/a	1,813.61	n/a	**1,813.61**
RCNN	Non-recyclable plastics	n/a	1,043.08	n/a	**1,043.08**
	Miscellaneous	n/a	1,812.44	n/a	**1,812.44**
Totals		**23,487.34**	**6,715.43**	**23,487.34**	**6,715.43**
Paper/cardboard		**15,232.03**	**0.00**	**15,232.03**	**0.00**
Plastic		**3,169.89**	**0.00**	**3,169.89**	**0.00**
Metals		**1,925.35**	n/a	**1,925.35**	n/a
Glass		**3,160.08**	n/a	**3,160.08**	n/a
Other		n/a	**6,715.43**	n/a	**6,715.43**

Table B.4. (continued)

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.4. (continued)

Materials diverted at separation facilities					
Commercial area		S2		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**

Section B.5. Least Cost Solution for Scenario A4 (30% recovery rate)

Table B.5. Materials diverted at separation options: Scenario A4

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	7,445.72	0.00	**7,445.72**	**0.00**
	Old corrugated cardboard	1,524.28	0.00	**1,524.28**	**0.00**
	Office paper	1,027.00	0.00	**1,027.00**	**0.00**
	Phone books	192.56	0.00	**192.56**	**0.00**
	Books	513.50	0.00	**513.50**	**0.00**
	Old magazines	1,155.37	0.00	**1,155.37**	**0.00**
	Third class mail	1,604.68	0.00	**1,604.68**	**0.00**
	Other recyclable paper 1	2,310.74	0.00	**2,310.74**	**0.00**
	Other recyclable paper 2	1,925.62	0.00	**1,925.62**	**0.00**
	Other recyclable paper 3	1,412.12	0.00	**1,412.12**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	233.96	0.00	**233.96**	**0.00**
	Pigmented HDPE	24.63	0.00	**24.63**	**0.00**
	PET beverage bottles	184.70	0.00	**184.70**	**0.00**
	Other recyclable plastics 1	492.54	0.00	**492.54**	**0.00**
	Other recyclable plastics 2	1,231.35	0.00	**1,231.35**	**0.00**
	Other recyclable plastics 3	1,810.08	0.00	**1,810.08**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	1,430.65	n/a	**1,430.65**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	800.38	n/a	**800.38**	n/a
	Aluminum other 1	184.70	n/a	**184.70**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	2,887.51	n/a	**2,887.51**	n/a
	Brown glass	1,077.43	n/a	**1,077.43**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	2,567.49	n/a	**2,567.49**
	Food waste	n/a	2,275.53	n/a	**2,275.53**
RCNN	Non-recyclable plastics	n/a	1,308.75	n/a	**1,308.75**
	Miscellaneous	n/a	2,274.06	n/a	**2,274.06**
Totals		**29,469.48**	**8,425.82**	**29,469.48**	**8,425.82**
Paper/cardboard		**19,111.57**	**0.00**	**19,111.57**	**0.00**
Plastic		**3,977.25**	**0.00**	**3,977.25**	**0.00**
Metals		**2,415.72**	n/a	**2,415.72**	n/a
Glass		**3,964.94**	n/a	**3,964.94**	n/a
Other		n/a	**8,425.82**	n/a	**8,425.82**

Table B.5. (continued)

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
MCCN	Non-recyclable paper	n/a	n/a	n/a	n/a
	Food waste	n/a	n/a	n/a	n/a
MCNN	Non-recyclable plastics	n/a	n/a	n/a	n/a
	Miscellaneous	n/a	n/a	n/a	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	**0.00**
Glass		**482.69**	n/a	**482.69**	**0.00**
Other		n/a	n/a	n/a	**0.00**

Table B.5. (continued)

Materials diverted at separation facilities							
		Separation option					
Commercial area		S1		S2		Totals	Totals
Sets	Items	Recyclables	Ref to Fuel	Recyclables	Ref to Fuel	Recyclables	Ref to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
CCCR	Old newsprint	202.09	0.00	383.30	0.00	**585.39**	**0.00**
	Old corrugated cardboard	3,307.07	0.00	6,272.50	0.00	**9,579.57**	**0.00**
	Office paper	746.18	0.00	1,415.27	0.00	**2,161.45**	**0.00**
	Phone books	31.09	0.00	58.97	0.00	**90.06**	**0.00**
	Third class mail	202.09	0.00	383.30	0.00	**585.39**	**0.00**
	Pallets	2,061.43	0.00	2,736.92	0.00	**4,798.35**	**0.00**
	Other recyclable paper 1	31.09	0.00	0.00	58.97	**31.09**	**58.97**
	Other recyclable paper 2	155.45	0.00	0.00	294.85	**155.45**	**294.85**
	Other recyclable paper 3	295.36	0.00	0.00	560.21	**295.36**	**560.21**
	Comb comp recyc other	450.82	0.00	0.00	855.06	**450.82**	**855.06**
	Mixed paper	0.00	0.00	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	14.91	0.00	28.28	0.00	**43.19**	**0.00**
	Mixed plastics	0.00	0.00	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	399.61	0.00	757.94	0.00	**1,157.55**	**0.00**
CNNR	Aluminum cans	44.73	n/a	84.84	n/a	**129.58**	n/a
	Clear glass	149.85	n/a	397.92	n/a	**547.77**	n/a
	Brown glass	55.92	n/a	148.48	n/a	**204.39**	n/a
	Green glass	0.00	n/a	47.51	n/a	**47.51**	n/a
	Mixed glass	0.00	n/a	0.00	n/a	**0.00**	n/a
	Ferrous cans	60.26	n/a	114.29	n/a	**174.55**	n/a
	Non-comb non-comp rec other	271.16	n/a	514.31	n/a	**785.47**	n/a
CCCN	Comb comp non-rec other	n/a	1,092.62	n/a	n/a	n/a	1,092.62
CCNN	Comb non-comp non-rec other	n/a	689.33	n/a	n/a	n/a	689.33
Totals		**8,479.11**	**1,781.94**	**13,343.84**	**1,769.09**	**21,822.96**	**3,551.03**
Paper/cardboard		**5,421.24**	**0.00**	**8,513.34**	**1,769.09**	**13,934.58**	**1,769.09**
Plastic		**414.52**	**0.00**	**786.22**	**0.00**	**1,200.74**	**0.00**
Metals		**376.15**	n/a	**713.45**	n/a	**1,089.60**	n/a
Glass		**205.77**	n/a	**593.91**	n/a	**799.68**	n/a
Wood		**2,061.43**	**0.00**	**2,736.92**	**0.00**	**4,798.35**	**0.00**
Other		n/a	**1,781.94**	n/a	n/a	n/a	**1,781.94**

Section B.6. Least Cost Solution for the Maximum Recovery Rate Scenario (33% recovery rate)

Table B.6. Materials diverted at separation options: Maximum Recovery Rate Scenario

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	7,445.72	0.00	**7,445.72**	**0.00**
	Old corrugated cardboard	1,524.28	0.00	**1,524.28**	**0.00**
	Office paper	1,027.00	0.00	**1,027.00**	**0.00**
	Phone books	192.56	0.00	**192.56**	**0.00**
	Books	513.50	0.00	**513.50**	**0.00**
	Old magazines	1,155.37	0.00	**1,155.37**	**0.00**
	Third class mail	1,604.68	0.00	**1,604.68**	**0.00**
	Other recyclable paper 1	2,310.74	0.00	**2,310.74**	**0.00**
	Other recyclable paper 2	1,925.62	0.00	**1,925.62**	**0.00**
	Other recyclable paper 3	1,412.12	0.00	**1,412.12**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	233.96	0.00	**233.96**	**0.00**
	Pigmented HDPE	24.63	0.00	**24.63**	**0.00**
	PET beverage bottles	184.70	0.00	**184.70**	**0.00**
	Other recyclable plastics 1	492.54	0.00	**492.54**	**0.00**
	Other recyclable plastics 2	1,231.35	0.00	**1,231.35**	**0.00**
	Other recyclable plastics 3	1,810.08	0.00	**1,810.08**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	1,430.65	n/a	**1,430.65**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	800.38	n/a	**800.38**	n/a
	Aluminum other 1	184.70	n/a	**184.70**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	2,887.51	n/a	**2,887.51**	n/a
	Brown glass	1,077.43	n/a	**1,077.43**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	2,567.49	n/a	**2,567.49**
	Food waste	n/a	2,275.53	n/a	**2,275.53**
RCNN	Non-recyclable plastics	n/a	1,308.75	n/a	**1,308.75**
	Miscellaneous	n/a	2,274.06	n/a	**2,274.06**
Totals		**29,469.48**	**8,425.82**	**29,469.48**	**8,425.82**
Paper/cardboard		**19,111.57**	**0.00**	**19,111.57**	**0.00**
Plastic		**3,977.25**	**0.00**	**3,977.25**	**0.00**
Metals		**2,415.72**	n/a	**2,415.72**	n/a
Glass		**3,964.94**	n/a	**3,964.94**	n/a
Other		n/a	**8,425.82**	n/a	**8,425.82**

Table B.6. (continued)

Materials diverted at separation facilities					
				Totals	Totals
Multi-family area		S2			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.6. (continued)

Materials diverted at separation facilities							
		Separation option					
Commercial area		S1		S2		Totals	Totals
Sets	Items	Recyclables	Ref to Fuel	Recyclables	Ref to Fuel	Recyclables	Ref to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
CCCR	Old newsprint	577.78	0.00	82.75	0.00	**660.53**	**0.00**
	Old corrugated cardboard	9,454.99	0.00	1,354.17	0.00	**10,809.15**	**0.00**
	Office paper	2,133.34	0.00	305.54	0.00	**2,438.88**	**0.00**
	Phone books	88.89	0.00	12.73	0.00	**101.62**	**0.00**
	Third class mail	577.78	0.00	82.75	0.00	**660.53**	**0.00**
	Pallets	5,893.66	0.00	590.87	0.00	**6,484.53**	**0.00**
	Other recyclable paper 1	88.89	0.00	0.00	12.73	**88.89**	**12.73**
	Other recyclable paper 2	444.45	0.00	0.00	63.65	**444.45**	**63.65**
	Other recyclable paper 3	844.45	0.00	0.00	120.94	**844.45**	**120.94**
	Comb comp recyc other	1,288.89	0.00	0.00	184.60	**1,288.89**	**184.60**
	Mixed paper	0.00	0.00	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	42.63	0.00	6.11	0.00	**48.74**	**0.00**
	Mixed plastics	0.00	0.00	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,142.50	0.00	163.63	0.00	**1,306.13**	**0.00**
CNNR	Aluminum cans	127.89	n/a	18.32	n/a	**146.21**	n/a
	Clear glass	428.44	n/a	85.91	n/a	**514.34**	n/a
	Brown glass	159.86	n/a	32.05	n/a	**191.92**	n/a
	Green glass	0.00	n/a	10.26	n/a	**10.26**	n/a
	Mixed glass	0.00	n/a	0.00	n/a	**0.00**	n/a
	Ferrous cans	172.28	n/a	24.67	n/a	**196.95**	n/a
	Non-comb non-comp rec other	775.26	n/a	111.03	n/a	**886.29**	n/a
CCCN	Comb comp non-rec other	n/a	3,123.81	n/a	n/a	n/a	3,123.81
CCNN	Comb non-comp non-rec other	n/a	1,970.80	n/a	n/a	n/a	1,970.80
Totals		24,241.96	5,094.61	2,880.80	381.93	27,122.76	5,476.54
Paper/cardboard		15,499.44	0.00	1,837.94	381.93	17,337.38	381.93
Plastic		1,185.13	0.00	169.74	0.00	1,354.86	0.00
Metals		1,075.43	n/a	154.03	n/a	1,229.46	n/a
Glass		588.30	n/a	128.22	n/a	716.52	n/a
Wood		5,893.66	0.00	590.87	0.00	6,484.53	0.00
Other		n/a	5,094.61	n/a	n/a	n/a	5,094.61

Section B.7. Least Cost Solution for Scenario B3

Table B.7. Materials diverted at separation options: Scenario B3

Materials diverted at separation facilities					
Residential area		S2		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	5,956.57	0.00	**5,956.57**	**0.00**
	Old corrugated cardboard	1,219.42	0.00	**1,219.42**	**0.00**
	Office paper	821.60	0.00	**821.60**	**0.00**
	Phone books	154.05	0.00	**154.05**	**0.00**
	Books	410.80	0.00	**410.80**	**0.00**
	Old magazines	0.00	924.30	**0.00**	**924.30**
	Third class mail	0.00	1,283.74	**0.00**	**1,283.74**
	Other recyclable paper 1	0.00	1,848.59	**0.00**	**1,848.59**
	Other recyclable paper 2	0.00	1,540.49	**0.00**	**1,540.49**
	Other recyclable paper 3	0.00	1,129.69	**0.00**	**1,129.69**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	187.16	0.00	**187.16**	**0.00**
	Pigmented HDPE	19.70	0.00	**19.70**	**0.00**
	PET beverage bottles	147.76	0.00	**147.76**	**0.00**
	Other recyclable plastics 1	394.03	0.00	**394.03**	**0.00**
	Other recyclable plastics 2	985.08	0.00	**985.08**	**0.00**
	Other recyclable plastics 3	0.00	1,448.06	**0.00**	**1,448.06**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	1,144.52	n/a	**1,144.52**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	640.30	n/a	**640.30**	n/a
	Aluminum other 1	147.76	n/a	**147.76**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	3,234.01	n/a	**3,234.01**	n/a
	Brown glass	1,206.72	n/a	**1,206.72**	n/a
	Green glass	386.15	n/a	**386.15**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**17,055.63**	**8,174.88**	**17,055.63**	**8,174.88**
Paper/cardboard		**8,562.44**	**6,726.82**	**8,562.44**	**6,726.82**
Plastic		**1,733.74**	**1,448.06**	**1,733.74**	**1,448.06**
Metals		**1,932.58**	n/a	**1,932.58**	n/a
Glass		**4,826.88**	n/a	**4,826.88**	n/a

Table B.7. (continued)

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.7. (continued)

Materials diverted at separation facilities					
Commercial area		S2		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
CCCR	Old newsprint	544.97	0.00	544.97	0.00
	Old corrugated cardboard	8,918.16	0.00	8,918.16	0.00
	Office paper	2,012.21	0.00	2,012.21	0.00
	Phone books	83.84	0.00	83.84	0.00
	Third class mail	544.97	0.00	544.97	0.00
	Pallets	3,891.32	0.00	3,891.32	0.00
	Other recyclable paper 1	0.00	83.84	0.00	83.84
	Other recyclable paper 2	0.00	419.21	0.00	419.21
	Other recyclable paper 3	0.00	796.50	0.00	796.50
	Comb comp recyc other	0.00	1,215.71	0.00	1,215.71
	Mixed paper	0.00	0.00	0.00	0.00
CCNR	PET beverage bottles	40.21	0.00	40.21	0.00
	Mixed plastics	0.00	0.00	0.00	0.00
	Combust non-compost other	1,077.63	0.00	1,077.63	0.00
CNNR	Aluminum cans	120.63	n/a	120.63	n/a
	Clear glass	565.75	n/a	565.75	n/a
	Brown glass	211.10	n/a	211.10	n/a
	Green glass	67.55	n/a	67.55	n/a
	Mixed glass	0.00	n/a	0.00	n/a
	Ferrous cans	162.50	n/a	162.50	n/a
	Non-comb non-comp rec other	731.24	n/a	731.24	n/a
Totals		18,972.10	2,515.26	18,972.10	2,515.26
Paper/cardboard		12,104.16	2,515.26	12,104.16	2,515.26
Plastic		1,117.84	0.00	1,117.84	0.00
Metals		1,014.37	n/a	1,014.37	n/a
Glass		844.41	n/a	844.41	n/a
Wood		3,891.32	0.00	3,891.32	0.00

Section B8. Least Cost Solution for Scenario B4

Table B.8. Materials diverted at separation options: Scenario B4

Materials diverted at separation facilities					
		Separation option			
Residential area		S1		Totals	Totals
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
RCCR	Old newsprint	7,445.72	0.00	**7,445.72**	**0.00**
	Old corrugated cardboard	1,524.28	0.00	**1,524.28**	**0.00**
	Office paper	1,027.00	0.00	**1,027.00**	**0.00**
	Phone books	192.56	0.00	**192.56**	**0.00**
	Books	513.50	0.00	**513.50**	**0.00**
	Old magazines	1,155.37	0.00	**1,155.37**	**0.00**
	Third class mail	1,604.68	0.00	**1,604.68**	**0.00**
	Other recyclable paper 1	2,310.74	0.00	**2,310.74**	**0.00**
	Other recyclable paper 2	1,925.62	0.00	**1,925.62**	**0.00**
	Other recyclable paper 3	1,412.12	0.00	**1,412.12**	**0.00**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
RCNR	Transparent HDPE	233.96	0.00	**233.96**	**0.00**
	Pigmented HDPE	24.63	0.00	**24.63**	**0.00**
	PET beverage bottles	184.70	0.00	**184.70**	**0.00**
	Other recyclable plastics 1	492.54	0.00	**492.54**	**0.00**
	Other recyclable plastics 2	1,231.35	0.00	**1,231.35**	**0.00**
	Other recyclable plastics 3	1,810.08	0.00	**1,810.08**	**0.00**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
RNNR	Ferrous metal cans	1,430.65	n/a	**1,430.65**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	800.38	n/a	**800.38**	n/a
	Aluminum other 1	184.70	n/a	**184.70**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	2,887.51	n/a	**2,887.51**	n/a
	Brown glass	1,077.43	n/a	**1,077.43**	n/a
	Green glass	0.00	n/a	**0.00**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
RCCN	Non-recyclable paper	n/a	2,567.49	n/a	**2,567.49**
	Food waste	n/a	2,275.53	n/a	**2,275.53**
RCNN	Non-recyclable plastics	n/a	1,308.75	n/a	**1,308.75**
	Miscellaneous	n/a	2,274.06	n/a	**2,274.06**
Totals		**29,469.48**	**8,425.82**	**29,469.48**	**8,425.82**
Paper/cardboard		**19,111.57**	**0.00**	**19,111.57**	**0.00**
Plastic		**3,977.25**	**0.00**	**3,977.25**	**0.00**
Metals		**2,415.72**	n/a	**2,415.72**	n/a
Glass		**3,964.94**	n/a	**3,964.94**	n/a
Other		n/a	**8,425.82**	n/a	**8,425.82**

Table B.8. (continued)

Materials diverted at separation facilities					
				Totals	Totals
Multi-family area		S2			
Sets	Items	Recyclables	Refuse to Fuel	Recyclables	Refuse to Fuel
		(Ton/year)	(Ton/year)	(Ton/year)	(Ton/year)
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.8. (continued)

Materials diverted at separation facilities					
Commercial area		**S2**		**Totals**	**Totals**
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
CCCN	Comb comp non-rec other	n/a	n/a	n/a	0.00
CCNN	Comb non-comp non-rec other	n/a	n/a	n/a	0.00
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**
Other		n/a	n/a	n/a	**0.00**

Section B9. Least Cost Solution for Scenarios C1 through C4

Table B.9. Materials diverted at separation options: Scenarios C1 through C4

Materials diverted at separation facilities					
				Totals	**Totals**
Multi-family area		**S2**			
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
MCCR	Old newsprint	595.66	0.00	**595.66**	**0.00**
	Old corrugated cardboard	121.94	0.00	**121.94**	**0.00**
	Office paper	82.16	0.00	**82.16**	**0.00**
	Phone books	15.40	0.00	**15.40**	**0.00**
	Books	41.08	0.00	**41.08**	**0.00**
	Old magazines	0.00	92.43	**0.00**	**92.43**
	Third class mail	0.00	128.37	**0.00**	**128.37**
	Other recyclable paper 1	0.00	184.86	**0.00**	**184.86**
	Other recyclable paper 2	0.00	154.05	**0.00**	**154.05**
	Other recyclable paper 3	0.00	112.97	**0.00**	**112.97**
	Other recyclable paper 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable paper 5	0.00	0.00	**0.00**	**0.00**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
MCNR	Transparent HDPE	18.72	0.00	**18.72**	**0.00**
	Pigmented HDPE	1.97	0.00	**1.97**	**0.00**
	PET beverage bottles	14.78	0.00	**14.78**	**0.00**
	Other recyclable plastics 1	39.40	0.00	**39.40**	**0.00**
	Other recyclable plastics 2	98.51	0.00	**98.51**	**0.00**
	Other recyclable plastics 3	0.00	144.81	**0.00**	**144.81**
	Other recyclable plastics 4	0.00	0.00	**0.00**	**0.00**
	Other recyclable plastics 5	0.00	0.00	**0.00**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
MNNR	Ferrous metal cans	114.45	n/a	**114.45**	n/a
	Other ferrous metal	0.00	n/a	**0.00**	n/a
	Aluminum cans	64.03	n/a	**64.03**	n/a
	Aluminum other 1	14.78	n/a	**14.78**	n/a
	Aluminum other 2	0.00	n/a	**0.00**	n/a
	Clear glass	323.40	n/a	**323.40**	n/a
	Brown glass	120.67	n/a	**120.67**	n/a
	Green glass	38.62	n/a	**38.62**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
Totals		**1,705.56**	**817.49**	**1,705.56**	**817.49**
Paper/cardboard		**856.24**	**672.68**	**856.24**	**672.68**
Plastic		**173.37**	**144.81**	**173.37**	**144.81**
Metals		**193.26**	n/a	**193.26**	n/a
Glass		**482.69**	n/a	**482.69**	n/a

Table B.9. (continued)

Materials diverted at separation facilities					
Commercial area		**S2**		**Totals**	**Totals**
Sets	**Items**	**Recyclables**	**Refuse to Fuel**	**Recyclables**	**Refuse to Fuel**
		(Ton/year)	**(Ton/year)**	**(Ton/year)**	**(Ton/year)**
CCCR	Old newsprint	544.97	0.00	**544.97**	**0.00**
	Old corrugated cardboard	8,918.16	0.00	**8,918.16**	**0.00**
	Office paper	2,012.21	0.00	**2,012.21**	**0.00**
	Phone books	83.84	0.00	**83.84**	**0.00**
	Third class mail	544.97	0.00	**544.97**	**0.00**
	Pallets	3,891.32	0.00	**3,891.32**	**0.00**
	Other recyclable paper 1	0.00	83.84	**0.00**	**83.84**
	Other recyclable paper 2	0.00	419.21	**0.00**	**419.21**
	Other recyclable paper 3	0.00	796.50	**0.00**	**796.50**
	Comb comp recyc other	0.00	1,215.71	**0.00**	**1,215.71**
	Mixed paper	0.00	0.00	**0.00**	**0.00**
CCNR	PET beverage bottles	40.21	0.00	**40.21**	**0.00**
	Mixed plastics	0.00	0.00	**0.00**	**0.00**
	Combust non-compost other	1,077.63	0.00	**1,077.63**	**0.00**
CNNR	Aluminum cans	120.63	n/a	**120.63**	n/a
	Clear glass	565.75	n/a	**565.75**	n/a
	Brown glass	211.10	n/a	**211.10**	n/a
	Green glass	67.55	n/a	**67.55**	n/a
	Mixed glass	0.00	n/a	**0.00**	n/a
	Ferrous cans	162.50	n/a	**162.50**	n/a
	Non-comb non-comp rec other	731.24	n/a	**731.24**	n/a
Totals		**18,972.10**	**2,515.26**	**18,972.10**	**2,515.26**
Paper/cardboard		**12,104.16**	**2,515.26**	**12,104.16**	**2,515.26**
Plastic		**1,117.84**	**0.00**	**1,117.84**	**0.00**
Metals		**1,014.37**	n/a	**1,014.37**	n/a
Glass		**844.41**	n/a	**844.41**	n/a
Wood		**3,891.32**	**0.00**	**3,891.32**	**0.00**

Appendix C

Life Cycle Inventory (LCI) of
Municipal Solid Waste Management Alternatives
Mass Flow Diagrams

5/20/1996 10:36:00 PM

I. Introduction

This document presents the mass flow diagrams for all waste stream components to be considered in the LCI modeling effort. The mass flow diagrams are a graphic representation of the manner in which waste can be managed and are used in the development of the mass flow equations. These mass flow equations will support the development of a solid waste economic analysis and the Life Cycle Inventory (LCI) analysis.

The economic analysis will focus on the cost of waste management as related to the public sector. It will include the cost of waste collection, transfer stations, MRFs, RDF plants, composting facilities and landfills. The economic optimization analysis will require cost coefficients for handling solid wastes. These coefficients will be generated by "preprocessors" which will output cost coefficients expressed in dollars per ton of the solid waste stream component managed at a given solid waste management node. For example, for the collection node, coefficients will be expressed in units of dollars expended per ton of the solid waste component transported.

The Life Cycle Inventory (LCI) analysis will examine the energy and resource usage and environmental releases associated with every solid waste stream component from "cradle to grave"; that is, from their generation, through their handling, separation, storage, processing at the source, collection, transfer, transport, treatment or transformation; and finally, disposal, reuse or remanufacturing and recycling. Each component of solid waste will require separate coefficients to identify its energy and resource usage and emissions at each solid waste management node. These coefficients will be generated by "preprocessors" which will output coefficients expressed in expended energy, resource usage and emissions expressed in appropriate units. For example, the expended energy coefficients will be expressed in units of utilized energy per ton of each solid waste component flowing into a node such as a landfill or MRF.

The coefficients from these preprocessors will be used in the development of an optimization model that will allow the user to develop solid waste management strategies that are optimized on a minimal cost or LCI parameter basis and constrained by various user defined factors such as desired recycling percentage. The mass flow equations will be used to constrain the optimization model to ensure conservation of mass flow at each model node.

II. Mass Flow Variables

It should be noted that the terms ‘residential’ and ‘multi-family dwellings’ are used in this document for simplicity and should not be considered to exclude other areas that may use the collection mode that usually applies to these types of dwellings. Any area that uses individual collection containers is considered ‘residential’ while any area that uses containerized collection is considered a ‘multi-family dwelling’. Throughout this document, the individual components of the waste stream that can flow through various nodes will be referred to by their variable names. These variable names are defined as follows:

1. Residential and multi-family dwelling waste consists of the following components:

Yard trimmings - Grass	YTG
Yard trimmings - Leaves	YTL
Yard trimmings - Branches	YTB
Old newsprint	ONP
Old corrugated cardboard	OCC
Office paper	OFF
Phone Books	PBK
Books	BOOK
Old Magazines	OMG
Third Class Mail	MAIL
Other recyclable paper 1 *	PAOT1
Other recyclable paper 2 *	PAOT2
Other recyclable paper 3 *	PAOT3
Other recyclable paper 4 *	PAOT4
Other recyclable paper 5 *	PAOT5
Non-recyclable paper	PANR
Food Waste	FW
Ferrous metal cans	FCAN
Other ferrous metal	FMOT
Non-recyclable ferrous metal	FNR
Aluminum cans	ACAN
Aluminum other 1 *	ALOT1
Aluminum other 2 *	ALOT2
Non-recyclable aluminum	ANR
Clear glass	GCLR
Brown glass	GBRN
Green glass	GGRN
Non-recyclable glass	GNR
Transparent HDPE	HDT

Pigmented HDPE	HDP
PET beverage bottles	PPET
Other recyclable plastics 1 *	PLOT1
Other recyclable plastics 2 *	PLOT2
Other recyclable plastics 3 *	PLOT3
Other recyclable plastics 4 *	PLOT4
Other recyclable plastics 5 *	PLOT5
Non-recyclable plastics	PLNR
Miscellaneous	MIS

2. Commercial Wastes Consist of the following components:

Old newsprint	ONP
Old corrugated cardboard.	OCC
Office paper	OFF
Phone Books	PBK
Third Class Mail	MAIL
Other recyclable paper 1 *	PAOT1
Other recyclable paper 2 *	PAOT2
Other recyclable paper 3 *	PAOT3
Pallets (wooden)	PAL
PET beverage bottles	PPET
Ferrous metal cans	FCAN
Aluminum cans	ACAN
Clear glass	GCLR
Brown glass	GBRN
Green glass	GGRN
Combustible compostable recyclable other *	CCRO
Combustible non-compostable recyclable other *	CNRO
Combustible compostable non-recyclable other *	CCNO
Combustible non-compostable non-recyclable other *	CNNO
Non-combustible non-compostable recyclable other *	NNRO

Non-combustible non-recyclable other * — NNNO

* These items allow the user to include recycling of additional components not specifically listed in each category.

III. Notation

In the following mass flow diagrams, the following notation will be used to identify mass flow nodes and product outputs:

1. Generation

   'G' will be used to refer to all generation

2. Collection alternatives

   Residential

   C0 - Collection of yard trimmings for aerobic composting
   C1 - Collection of mixed MSW in one truck prior to separation of
   any component.
   C2 - Collection of commingled recyclables (sorted at the point of collection by the collection crew)
   C3 - Collection of pre-sorted recyclables
   C4 - Collection of commingled recyclables (to be sorted at a MRF) (ONP in separate compartment)
   C5 - Collection of commingled recyclables and MSW (bagged separately) in a two compartment truck (ONP in separate compartment)
   C6 - Collection of commingled recyclables and MSW (bagged separately) in a three compartment truck (ONP in separate compartment)
   C7 - Collection of mixed MSW after removal of recyclables or yard waste.

C8 - Recyclables drop-off by the generator.
C9 - Collection of leaves using a leaf vacuum truck
C10 - Yard trimmings drop-off by the generator
C11 - Wet/Dry/commingled recyclables collection in separate compartments
C12 - Wet/Dry collection in separate compartments with recyclables collected via C2, C3 or C4.

Multi-family Dwellings

C13 - Multi-family collection of mixed MSW
C14 - Multi-family collection of pre-sorted recyclables (multiple bins)
C15 - Multi-family collection of commingled recyclables (two bins, ONP separate)
C16 - Multi-family collection of MSW after removal of recyclables via C14 or C15
C17 - Multi-family wet/dry/commingled recyclables collection in separate compartments
C18 - Multi-family wet/dry collection in separate compartments with commingled recyclables collected via C14 or C15.

Commercial

C19 - Collection of pre-sorted recyclables
C20 - Collection of mixed MSW (before or after recyclables removal)

3. Transfer Alternatives

TR1 - Transfer of mixed MSW
TR2 - Transfer of commingled recyclables (not in bags)
TR3 - Transfer of MSW and sorted recyclables (in separate bags, one compartment)
TR4 - Transfer of MSW and sorted recyclables (in separate bags, separate compartments)
TR5 - Transfer of pre-sorted recyclables

RT1 - Rail transfer of MSW from collection vehicles.

RT2 - Rail transfer of MSW from trains to haul vehicles at landfill D1.

RT3 - Rail transfer of MSW from trains to haul vehicles at landfill D3.

Note: In transfer stations TR3 and TR4, MSW (black bags) and recyclables (blue bags) will be separated and will flow out of the transfer stations to different locations as appropriate.

4. Separation alternatives - To occur at a MRF

S1 - Sorting of mixed refuse
S2 - Processing of pre-sorted recyclables collected via C2 and C3
S3 - Sorting of commingled recyclables collected via C4
S4 - Sorting of commingled recyclables collected as mixed waste and recyclables in color coded bags in a single compartment truck via C5
S5 - Sorting of commingled recyclables collected as mixed waste and recyclables in color coded bags in a double compartment truck via C6. Note that items normally excluded from MSW (couches, white goods, etc.) are ignored for this modeling effort.

5. Treatment alternatives

T1 - Aerobic composting of yard waste
T3 - Combustion with electric power generation
T5 - Refuse derived fuel (mixed MSW). Note that this facility would include preprocessing to remove materials normally excluded from RDF such as recyclable materials.
T6 - Backyard composting
T7 - Mixed refuse composting. Note that this facility would include preprocessing to remove materials normally excluded from composting such as white goods.
T8 - Anaerobic digestion. Note that this facility would include preprocessing to remove materials normally excluded from digestion such as white goods.

Note: Previous versions of this document included T2 and T4 alternatives (combustion with steam production and combustion with no energy recovery, respectively) These are not in common use and were deleted. Therefore, the numbering sequence for treatment alternatives is discontinuous

6. Disposal alternatives

D1 - Landfill

D2 - Ash Landfill
D3 - Enhanced Bioreactor

7. Product Outputs

Recyclables

Denotes the purchase of recyclables from houses and multi-family dwellings separated at a MRF, or recyclables in commercial waste that are specified by the user. Not only the cost, but the manner in which recyclables are processed after sale, is important to the model since different processes will result in different amounts of energy consumption and emissions.

Compost

Denotes compost product. The mass of compost produced will be used to calculate the revenue from compost.

Fuel

Denotes fuel from a RDF facility. Fuel as paper and/or plastic may also be generated from a MRF or the preprocessing end of a mixed waste composting facility.

Methane

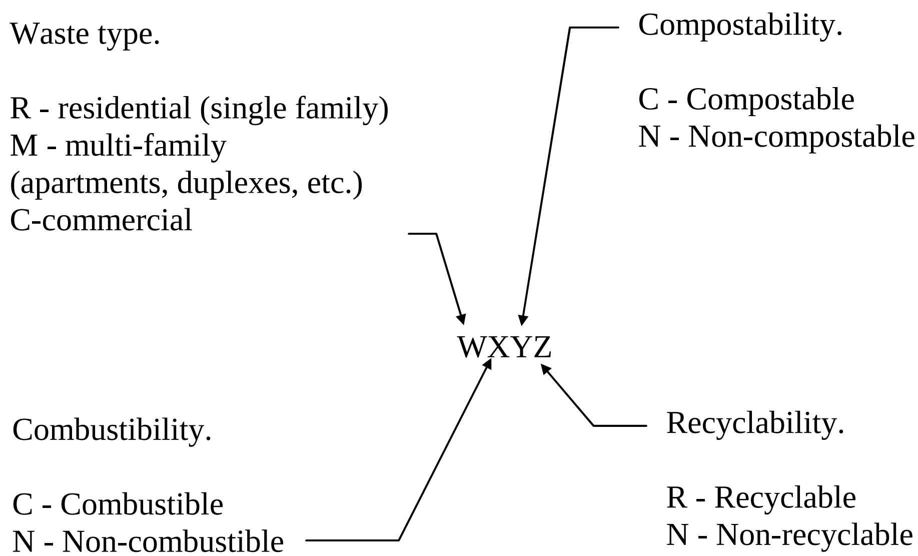
Denotes methane production from anaerobic digestion.

Scrap

Denotes scrap recyclables available in the ash output from a mixed MSW combustion facility which could be sold. A Magnet could be used to recover ferrous metal from the combustor ash. Glass and aluminum would always go with the ash to the ash landfill. Aluminum is not recoverable at this point since it is assumed that the combustion temperature would be in excess of the melting point of aluminum.

III. Definition of Sets

In the following set definitions and mass flow diagrams, the set names follow a defined pattern. Specifically, all set names will have 4 characters defined as follows:



SET DEFINITION	**SET NAME**
1. RESIDENTIAL WASTE (single family housing)	
YARD TRIMMINGS	
Yard trimmings - Leaves	**RYTL**
Yard trimmings - Grass Yard trimmings - Branches	**RYTO**

COMBUSTIBLE RECYCLABLES

COMPOSTABLE **RCCR**

Old newsprint
Old corrugated cardboard.
Office paper
Phone Books
Books
Old Magazines
Third Class Mail
Other recyclable paper 1
Other recyclable paper 2
Other recyclable paper 3
Other recyclable paper 4
Other recyclable paper 5
PMIX (Note 1, page 12)

See note 4 about paper, page 12.

NON-COMPOSTABLE **RCNR**

Transparent HDPE
Pigmented HDPE
PET beverage bottles
Other recyclable plastics 1
Other recyclable plastics 2
Other recyclable plastics 3
Other recyclable plastics 4
Other recyclable plastics 5
PLMIX (Note 2, page 12)

NON-COMBUSTIBLE NON-COMPOSTABLE RECYCLABLES **RNNR**

Ferrous metal cans
Other ferrous metal

Aluminum cans
Aluminum other 1
Aluminum other 2

Clear glass

Brown glass
Green glass
GMIX (Note 2, page 12)

COMBUSTIBLE NON-RECYCLABLES

COMPOSTABLE **RCCN**

Non-recyclable paper (Note 1, page 12)
Food Waste

NON-COMPOSTABLE **RCNN**

Non-recyclable plastics (Note 2, page 12)

Miscellaneous

NON-COMBUSTIBLE NON-RECYCLABLES **RNNN**

Non-recyclable ferrous metal
Non-recyclable aluminum
Non-recyclable glass
Miscellaneous

2. MULTI-FAMILY (apartments, duplexes, etc.)

YARD TRIMMINGS

Yard trimmings - Leaves **MYTL**

Yard trimmings - Grass **MYTO**
Yard trimmings - Branches

COMBUSTIBLE RECYCLABLES

COMPOSTABLE **MCCR**

Old newsprint
Old corrugated cardboard.
Office paper

Phone Books
Books
Old Magazines
Third Class Mail
Other recyclable paper 1
Other recyclable paper 2
Other recyclable paper 3
Other recyclable paper 4
Other recyclable paper 5
PMIX (Note 1, page 12)

See note 4 about paper, page 12.

NON-COMPOSTABLE **MCNR**

Transparent HDPE
Pigmented HDPE
PET beverage bottles
Other recyclable plastics 1
Other recyclable plastics 2
Other recyclable plastics 3
Other recyclable plastics 4
Other recyclable plastics 5
PLMIX (Note 2, page 12)

NON-COMBUSTIBLE RECYCLABLES **MNNR**

Ferrous metal cans
Other ferrous metal

Aluminum cans
Aluminum other 1
Aluminum other 2

Clear glass
Brown glass
Green glass
GMIX (Note 2, page 12)

COMBUSTIBLE NON-RECYCLABLES

COMPOSTABLE **MCCN**

Non-recyclable paper (Note 1, page 12)
Food Waste

NON-COMPOSTABLE **MCNN**

Non-recyclable plastics (Note 2, page 12)

Miscellaneous

NON-COMBUSTIBLE NON-RECYCLABLES **MNNN**

Non-recyclable ferrous metal
Non-recyclable aluminum
Non-recyclable glass
Miscellaneous

3. COMMERCIAL WASTE

COMBUSTIBLE RECYCLABLES

COMPOSTABLE **CCCR**

Old newsprint
Old corrugated cardboard.
Office paper
Phone Books
Third Class Mail
Pallets (wooden)
Other recyclable paper 1
Other recyclable paper 2
Other recyclable paper 3
Combustible compostable
recyclable other (CCRO)
PMIX (Note 1, page 12)

See note 4 about paper, page 12.

NON-COMPOSTABLE	**CCNR**
PET beverage bottles PLMIX (Note 2, page 12) Combustible non-compostable recyclable other (CNRO)	
NON-COMBUSTIBLE RECYCLABLES	**CNNR**
Ferrous metal cans Aluminum cans	
Clear glass Brown glass Green glass GMIX (Note 3, page 12) Non-combustible non-compostable recyclable other (NNRO)	
COMBUSTIBLE NON-RECYCLABLES	
COMPOSTABLE	**CCCN**
Combustible compostable non-recyclable other (CCNO)	
NON-COMPOSTABLE	**CCNN**
Combustible non-compostable non-recyclable other (CNNO)	
NON-COMBUSTIBLE NON-RECYCLABLES	**CNNN**
Non-combustible non-recyclable other (NNNO)	

Notes: 1. The LCI model user will be able to define PMIX to consist of any or all members of sets **RCCR** and the non-recyclable paper component shown as a member of set **RCCN**. If the user includes non-recyclable paper as a part of PMIX, it would become a member of set **RCCR** and its flow would be the same as other members of the set shown in the following mass flow diagrams. This same note applies to sets **MCCR, MCCN, CCCR** and **CCCN**.

2. The LCI model user will be able to define PLMIX to consist of any or all members of sets **RCNR** and the non-recyclable plastic component shown as a member of set **RCNN**. If the user includes non-recyclable plastic as a part of PLMIX, it would become a member of set **RCNR** and its flow would be the same as other members of the set shown in the following mass flow diagrams. This same note applies to sets **MCNR** and **MCNN**.

3. The LCI model user will be able to define GMIX to consist of any or all glass members of set **RNNR**. If the user includes glass types in GMIX, those glass types will always flow as a single inseparable component in the following mass flow diagrams. This same note applies to sets **MNNR**.

4. For wet/dry collection options, the LCI model user will be able to define which recyclable paper types will be collected for composting (wet) and which types will be collected for other purposes such as recycling (dry). When included in the 'wet' fraction, a paper will be treated as compostable and would flow in the following mass flow diagrams as a part of set **RCCR**. When included in the 'dry' fraction, the paper would flow as a part of set **RCNR**. This same note applies to paper components of sets **MCCR/MCNR** and **CCCR/CCNR**.

IV. Mass Flow Diagrams

The following mass flow diagrams graphically depict the mass flows for each collection option described above. Included with each diagram is a table showing whether the members of each set described above can flow to each node and output for the collection option. Members of a set can flow to the node or output if the associated table entry is 'X'. If the set is not collected by the collection option, the set name will not appear in the table. If members of a set cannot flow to a node or output for the collection option, their associated table entry will be blank.

In all mass flow diagrams, square boxes denote nodes that masses can flow to. Items enclosed in ovals (such as Fuel) denote possible product outputs from the node to which they are connected.

In all mass flow diagrams, lines between nodes indicate mass flows. Typically, this mass is transported by truck. One exception is the lines between nodes RT1 and RT2. These lines depict rail transport.

Notes:

1. The electrical power output from combustion is not shown on the mass flow diagrams for simplicity. Power output is implicitly assumed for combustion in the diagrams.

2. The methane product output from enhanced bioreaction is not shown on the mass flow diagrams for simplicity. Methane output is implicitly assumed for enhanced bio-reation in the diagrams.

3. The lines in the following mass flow diagrams from mixed waste composting (T7) and anaerobic digestion (T8) to 'Fuel' reflect the possibility of pre-processing waste at these facilities to remove paper and/or plastic as a fuel prior to proceeding with the treatment process.

4. The following mass flow diagrams can be used in conjunction with the accompanying tables to determine if a given component of MSW can flow into and/or out of any defined node. However, it is important to keep in mind that although the possible flow paths for all members of a set are the same, all members of a set do not have to flow together. For example, old newsprint (ONP) and old corrugated cardboard (OCC) are both members of **RCCR** and can flow to all of the same locations; however, it would be possible for ONP to eventually flow to recyclables while OCC flowed to combustion or vice versa. Actual flow paths for each set component will be determined as a part of the model optimization.

5. In the following mass flow diagrams, flow never occurs from the mixed refuse transfer station (TR1) to mixed waste composting (T7) or anaerobic digestion (T8) since the assumption has been made that T7 and T8 facilities would be local rather than regional facilities and therefore would not be subject to the waste consolidation of a transfer station.

6. In the following mass flow diagrams, flow never occurs from the mixed refuse MRF (S1) to RDF (T5), mixed waste composting (T7) or anaerobic digestion (T8) since the assumption has been made that T5, T7 and T8 facilities would include pre-processing facilities to remove recyclables; therefore, flows from S1 to these nodes would be redundant.

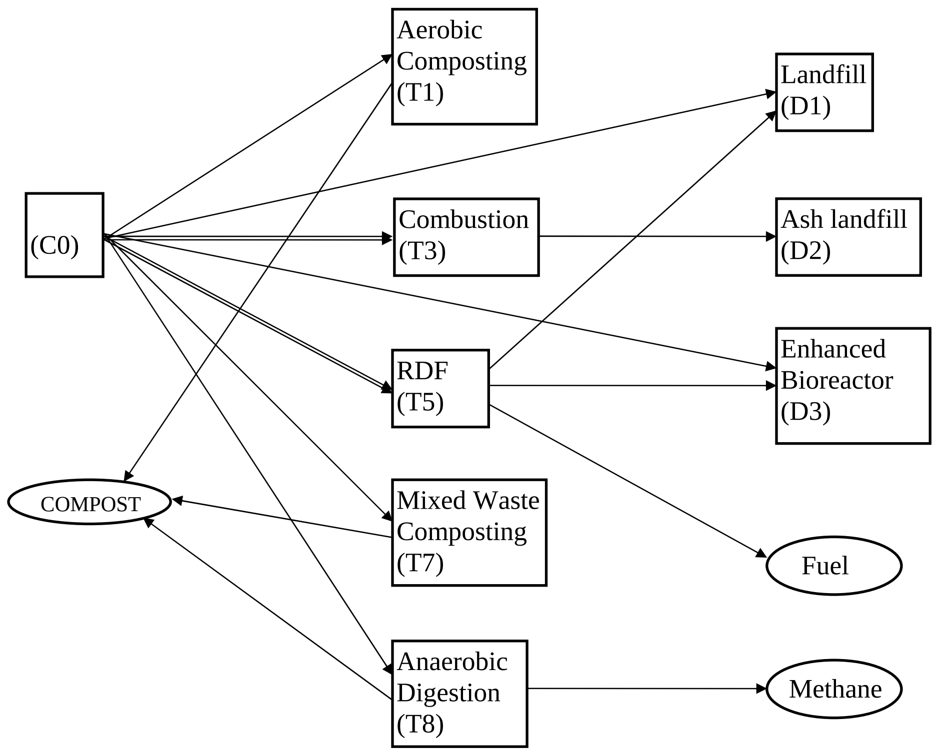
7. In the following mass flow diagrams, some flows into an enhanced bioreactor would seem to be inappropriate. For example, the residual from a commingled recyclables MRF would have little potential for methane production; however, this flow is shown as possibly going to an enhanced bioreactor landfill. The reason for these flows is to allow for the possibility that the model solution recommends only the construction of an enhanced bioreactor landfill without any conventional landfill. In

this case, residues with no methane potential would need to go to the enhanced bioreactor landfill.

8. In all diagrams for wet/dry collection options where rail haul is included, the flow lines from the collection end rail transfer station (RT1) to treatments such as mixed waste composting (T7) reflect the fact that collection vehicles would drop the dry fraction at RT1 and proceed to other treatment nodes with the wet fraction. Rail haul only occurs between RT1 and RT2.

9. In all diagrams for wet/dry collection options, all MSW components are shown as flowing to each possible treatment and disposal option. This is to take into account the fact that less than perfect wet/dry separation will be achieved by the generator. Therefore, some fraction of the intended contents of the wet containers will be placed into the dry containers and vice versa.

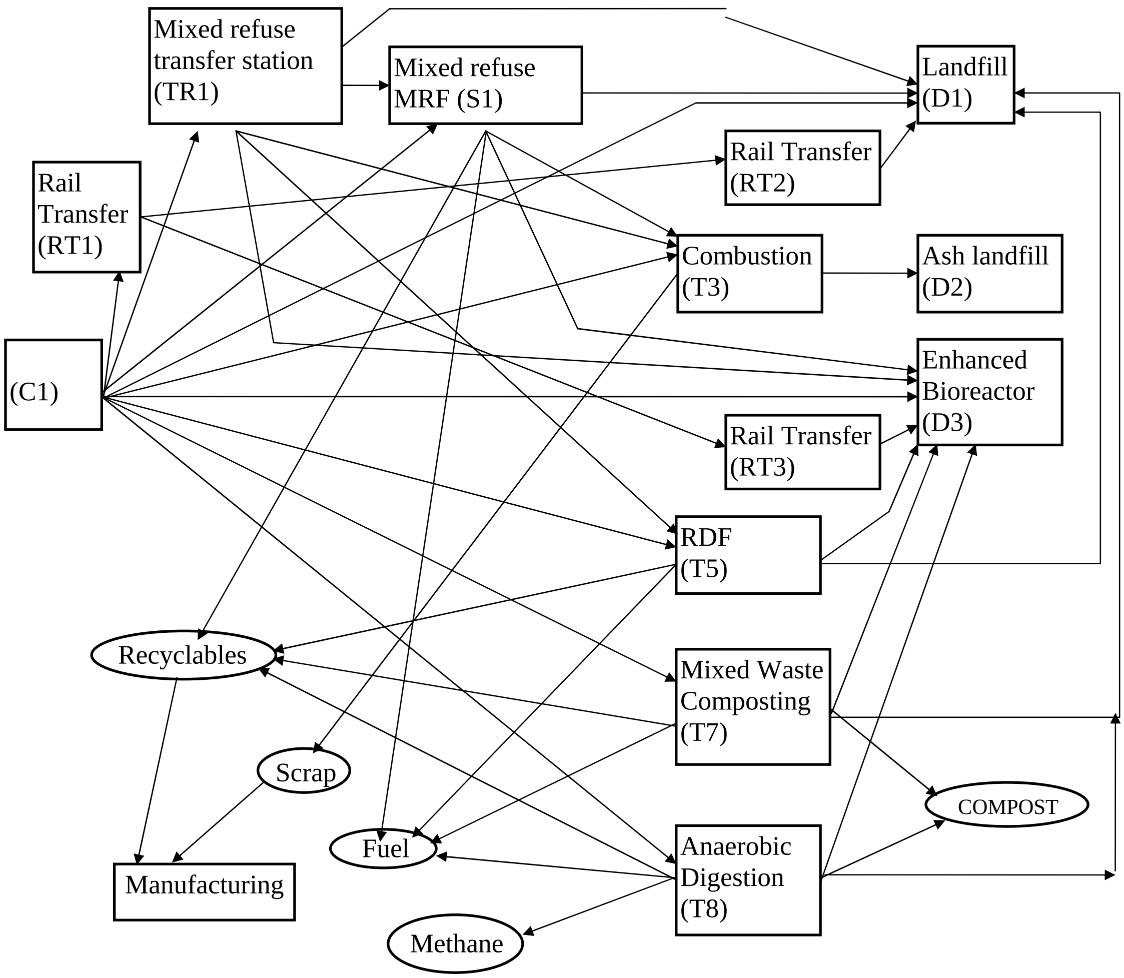
C0. Collection of yard waste from houses for aerobic composting (grass, leaves and branches)



SET	CAN ENTER NODE T1	T3	T5	T7	T8	D1	D2	D3	C	M	F
RYTL	X	X	X	X	X	X	X	X	X	X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X

Note:
D2 preprocessor should allow it to look like D1 or a haz. waste landfill as the user desires.

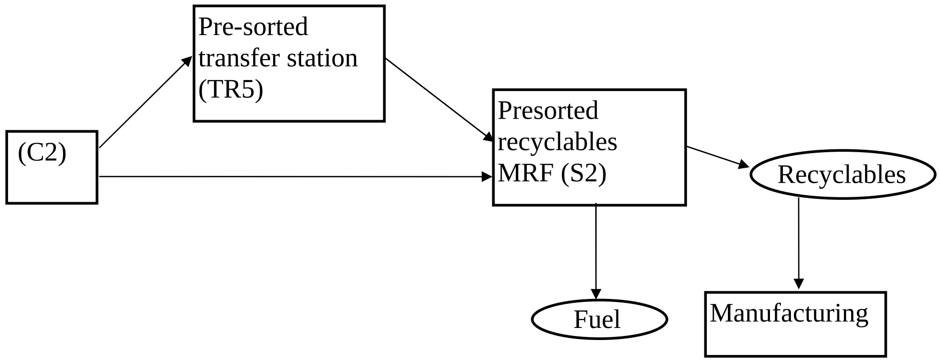
C1. Collection of mixed MSW from houses in a single compartment truck.



SET	CAN ENTER NODE																	
	TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
RYTL	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
RNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

C2. Commingled recyclables from houses sorted at point of collection.

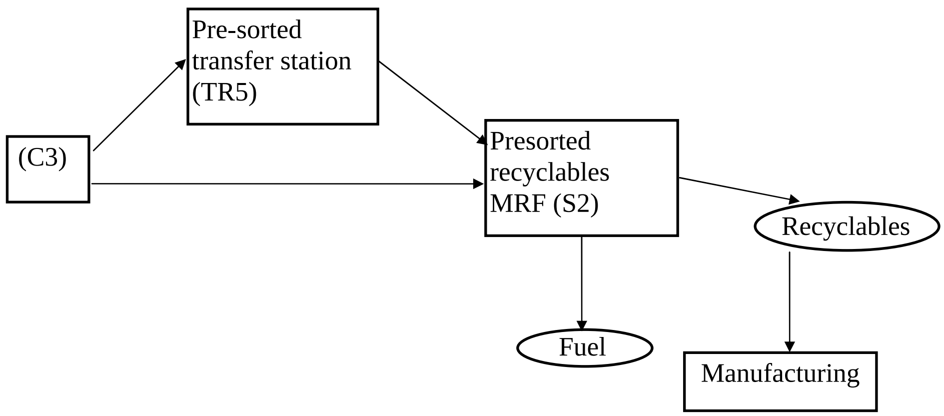


SET	CAN ENTER NODE				
	TR5	S2	F	R	MF
RCCR	X	X	X	X	X
RCNR	X	X	X	X	X
RNNR	X	X		X	X

Recyclability
Compostabilit
Combustibility
Type

See Note 10.

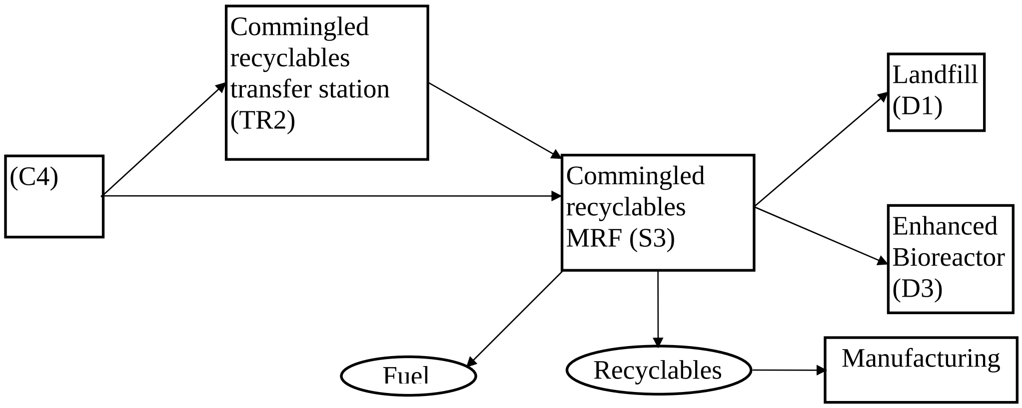
C3. Collection of pre-sorted recyclables from houses.



	CAN ENTER NODE				
SET	TR5	S2	F	R	MF
RCCR	X	X	X	X	X
RCNR	X	X	X	X	X
RNNR	X	X		X	X

Recyclability
Compostabilit
Combustibility
Type

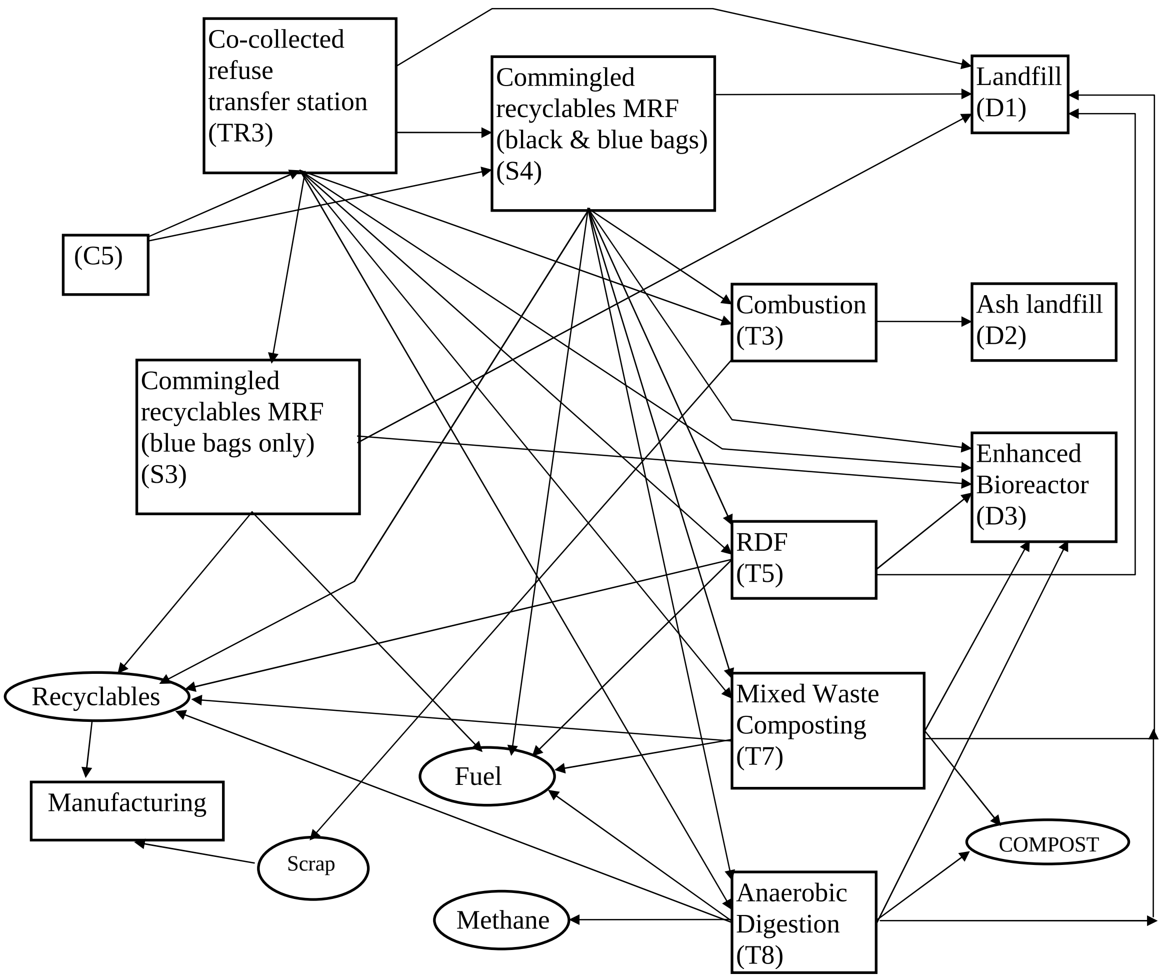
C4. Collection of commingled recyclables from houses sorted at a MRF (ONP in a separate compartment).



SET	CAN ENTER NODE						
	TR2	S3	D1	D3	F	R	MF
RCCR	X	X	X	X	X	X	X
RCNR	X	X	X	X	X	X	X
RNNR	X	X	X	X		X	X

Recyclability
Compostabilit
Combustibility
Type

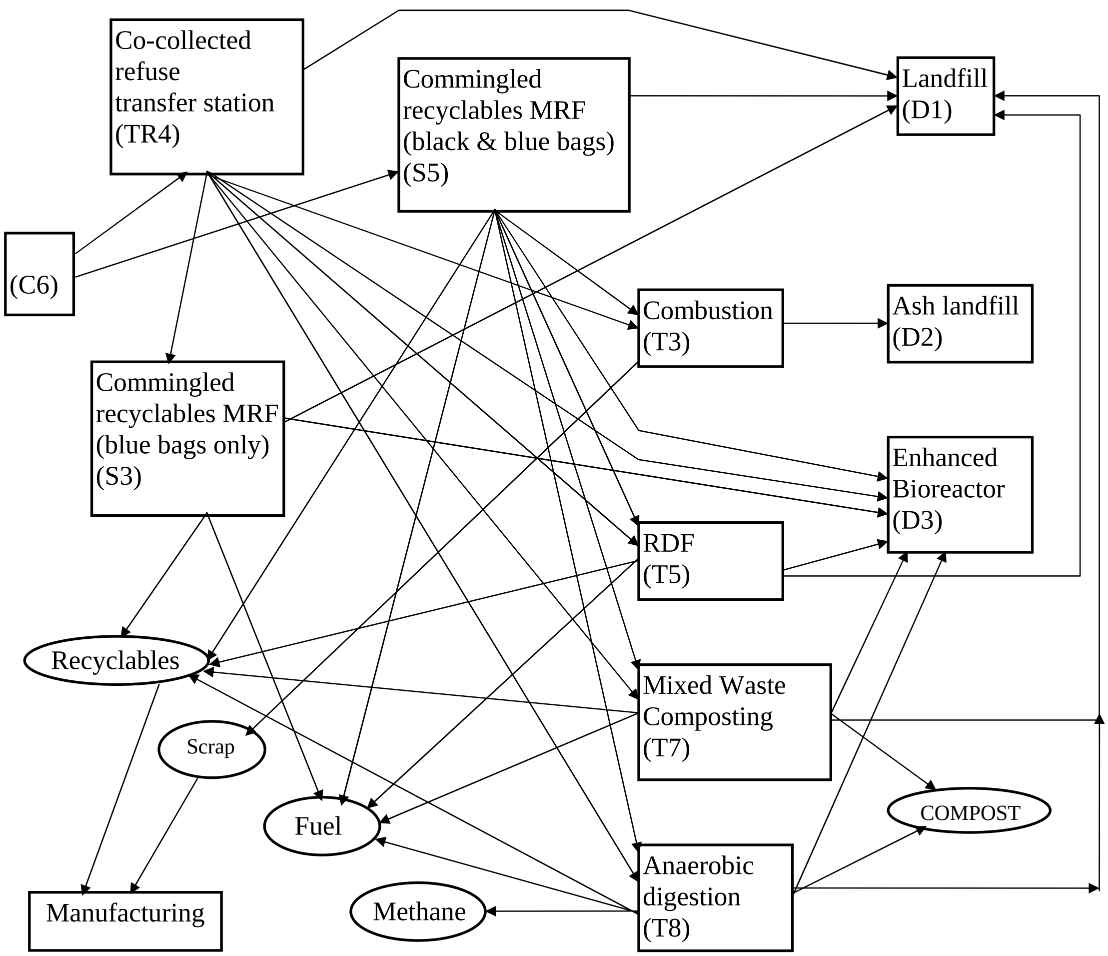
C5. Collection of commingled recyclables and MSW from houses in one single compartment truck (ONP in a separate compartment).



SET	CAN ENTER NODE															
	TR3	S3	S4	T3	T5	T7	T8	D1	D2	D3	MF	R	S	M	F	C
RYTL	X		X	X	X	X	X	X	X	X				X	X	X
RYTO	X		X	X	X	X	X	X	X	X				X	X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X			X	
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X		X	X	X	X	X	X	X	X				X	X	X
RCNN	X		X	X	X	X	X	X	X	X					X	
RNNN	X		X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

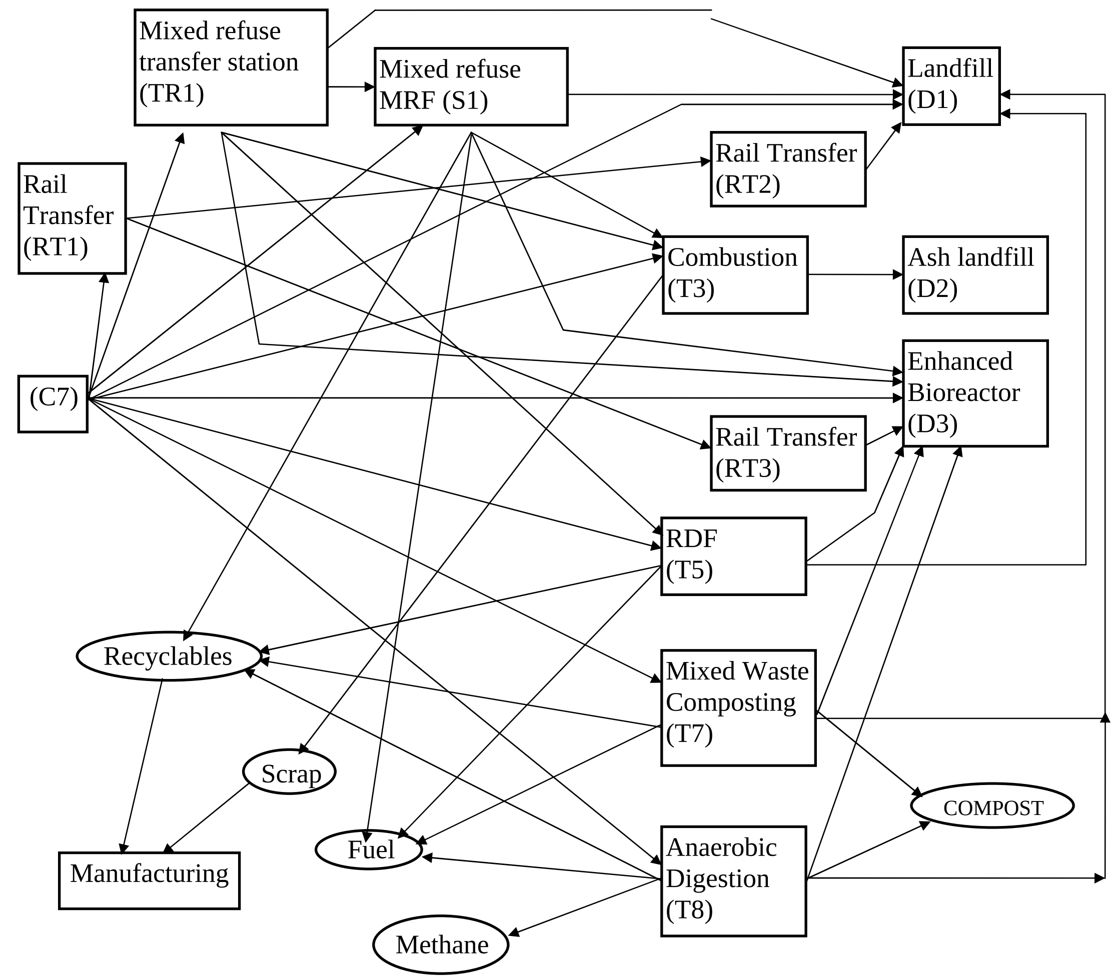
C6. Collection of commingled recyclables and MSW from houses in a double compartment truck (ONP in a separate compartment).



SET	CAN ENTER NODE														
	TR4	S3	S5	T3	T5	T7	T8	D1	D2	D3	MF	R	S	M	F	C
RYTL	X		X	X	X	X	X	X	X	X				X	X	X
RYTO	X		X	X	X	X	X	X	X	X				X	X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X			X	
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X		X	X	X	X	X	X	X	X				X	X	X
RCNN	X		X	X	X	X	X	X	X	X					X	
RNNN	X		X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

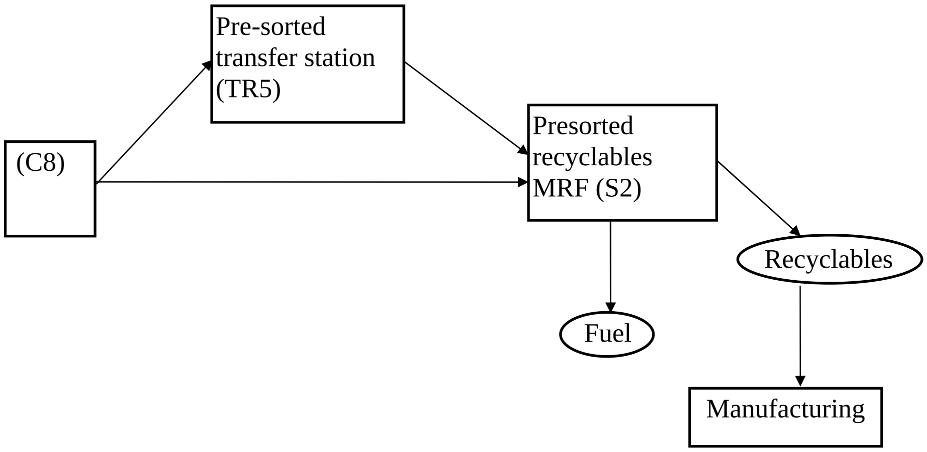
C7. Collection of mixed MSW from houses after removal of recyclables.



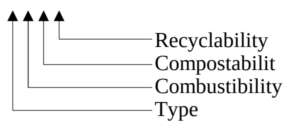
SET	CAN ENTER NODE TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
RYTL	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
RNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

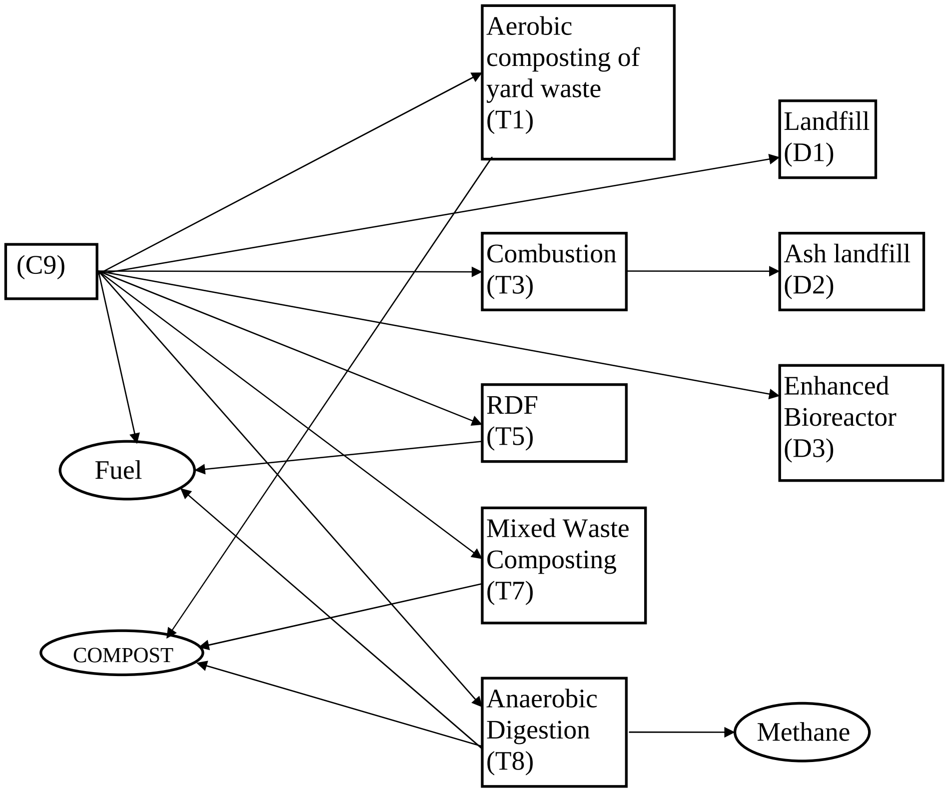
C8. Recyclables drop-off from houses and multi-family dwellings.



SET	CAN ENTER NODE TR5	S2	F	R	MF
RCCR	X	X	X	X	X
RCNR	X	X	X	X	X
RNNR	X	X		X	X
MCCR	X	X	X	X	X
MCNR	X	X	X	X	X
MNNR	X	X		X	X



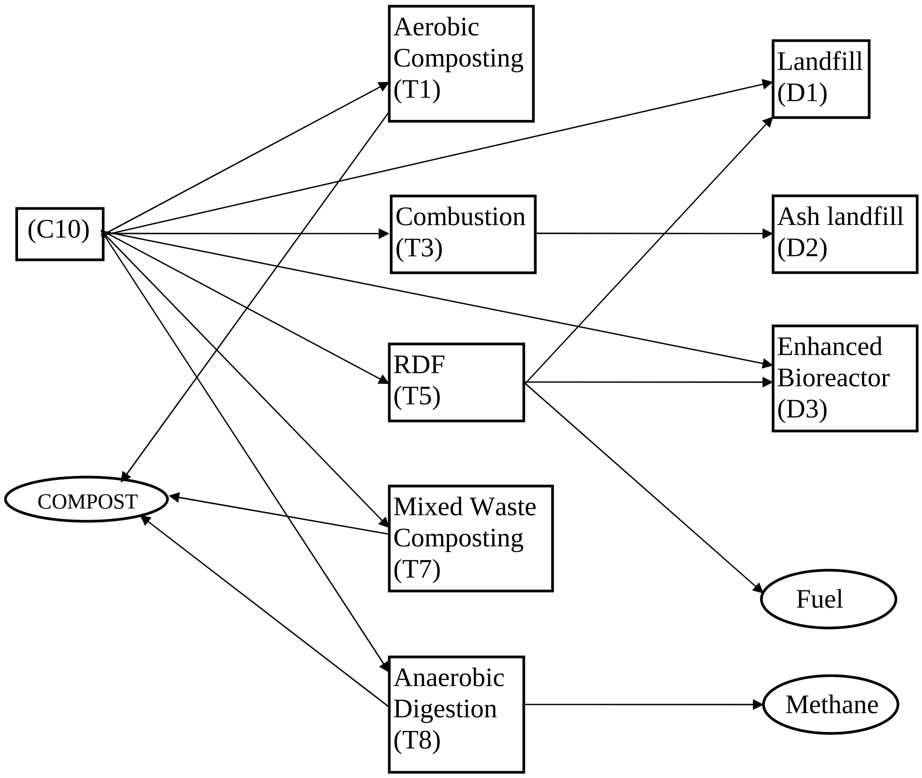
C9. Leaf Collection from houses in a Vacuum Truck



SET	CAN ENTER NODE									
	T1	T3	T5	T7	T8	D1	D2	D3	C	M	F
RYTL	X	X	X	X	X	X	X	X	X	X	X

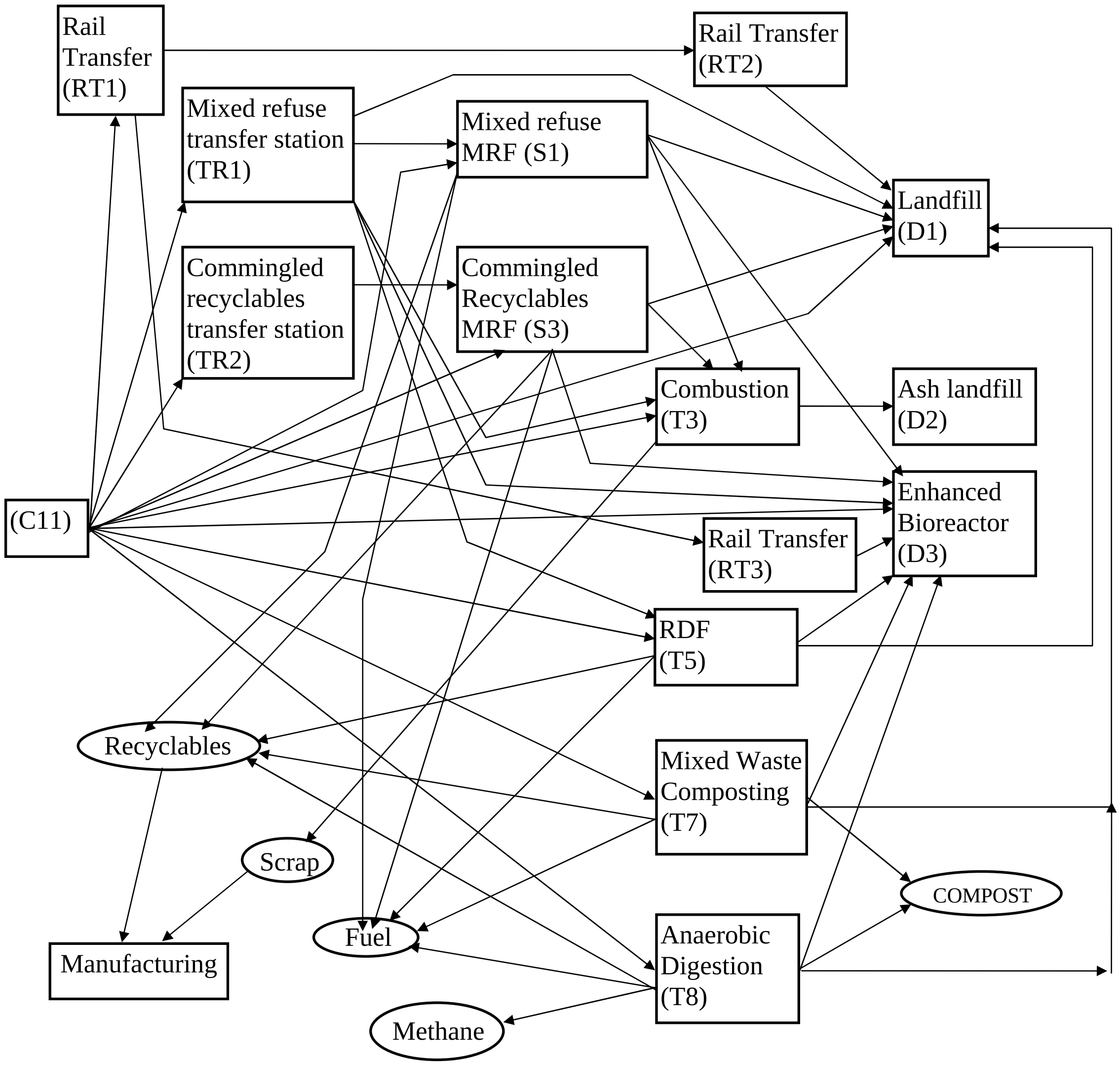
Note: If leaves flow to T5, they would not be mixed with the RDF feed but would be incorporated into the fuel product at the end of the process.

C10. Yard Trimmings Drop-off from houses.



SET	CAN ENTER NODE										
	T1	T3	T5	T7	T8	D1	D2	D3	C	M	F
RYTL	X	X	X	X	X	X	X	X	X	X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X

C11. Wet/Dry/commingled recyclables collection from houses in separate compartments

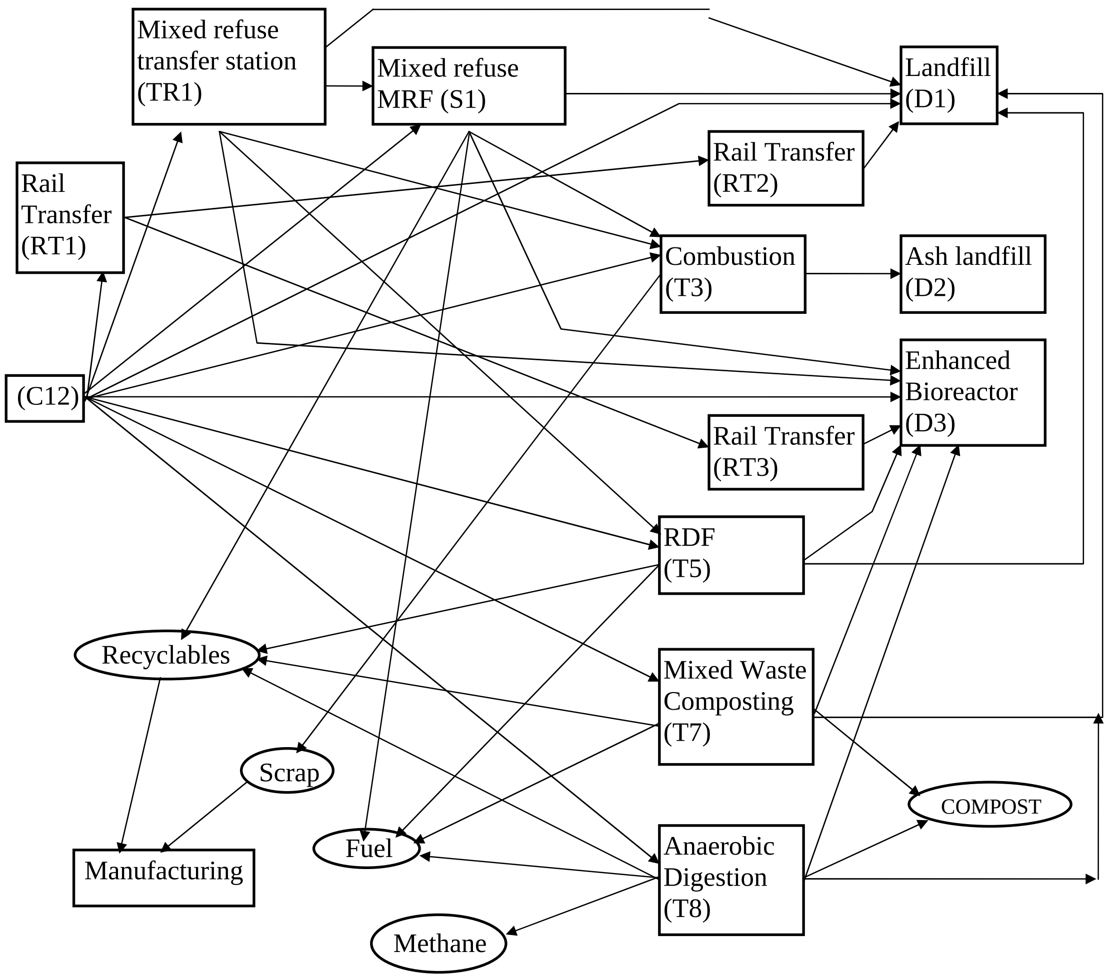


SET	CAN ENTER NODE TR1	TR2	RT1	RT2	RT3	S1	S3	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
RYTL	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCNN	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X		
RNNN	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

See notes 5 and 9

C12. Wet/Dry collection from houses in separate compartments with commingled recyclables collected separately.

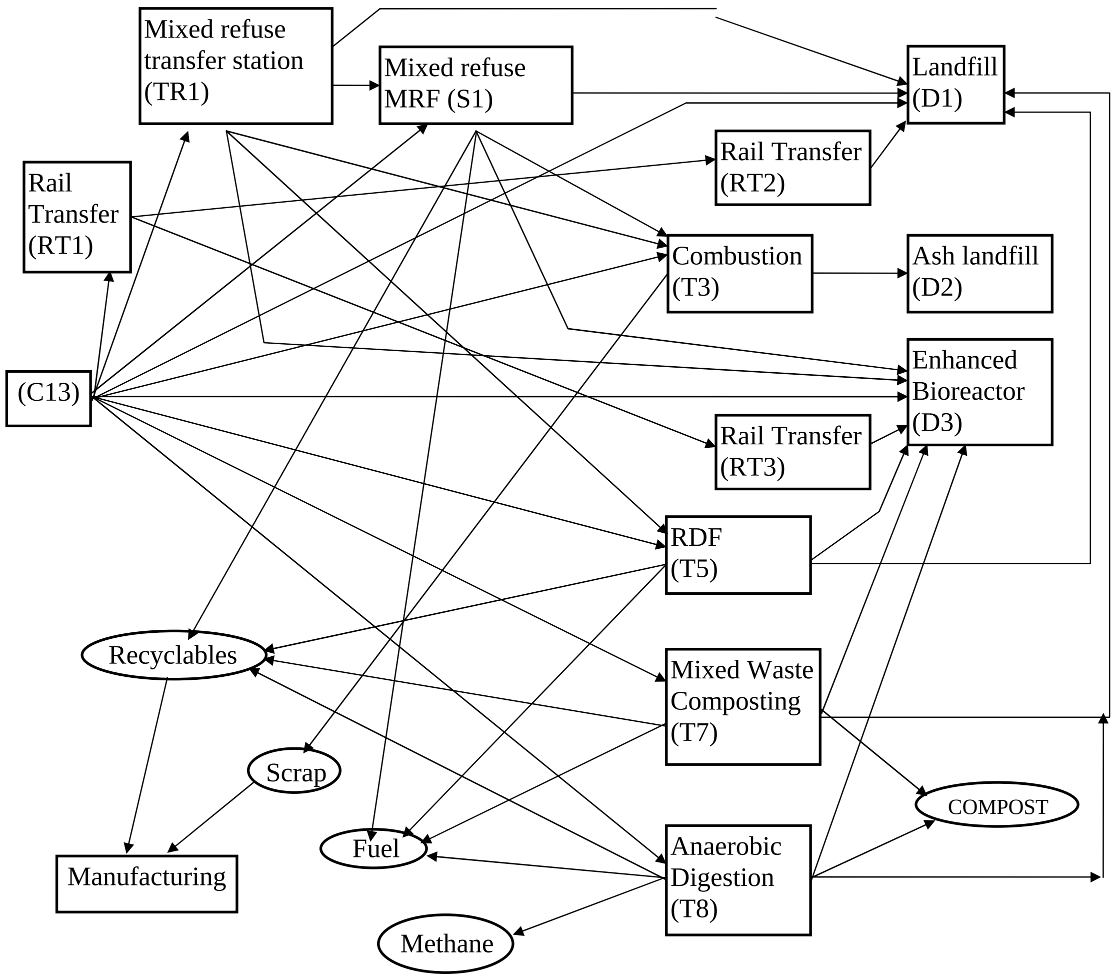


	CAN ENTER NODE																	
SET	TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
RYTL	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RYTO	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
RCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
RNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
RCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
RCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
RNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

See note 9.

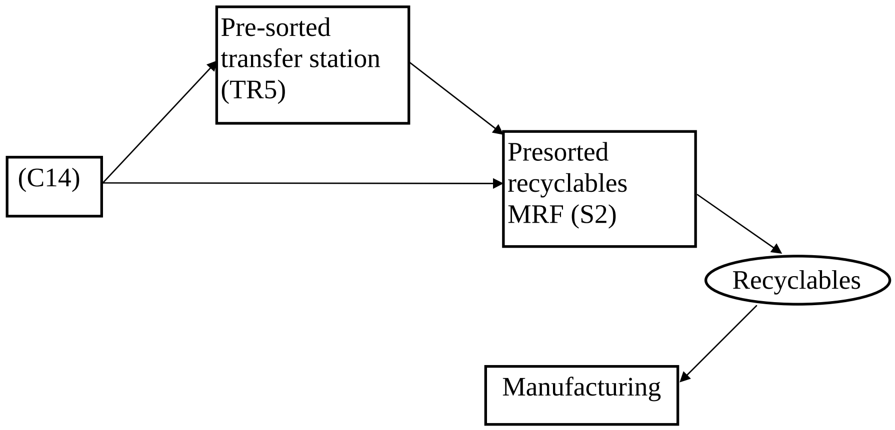
C13. Collection of mixed MSW from multi-family dwellings where containerized collection is required in a single compartment truck.



SET	CAN ENTER NODE																	
	TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
MYTL	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MYTO	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
MCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
MNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
MCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
MNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

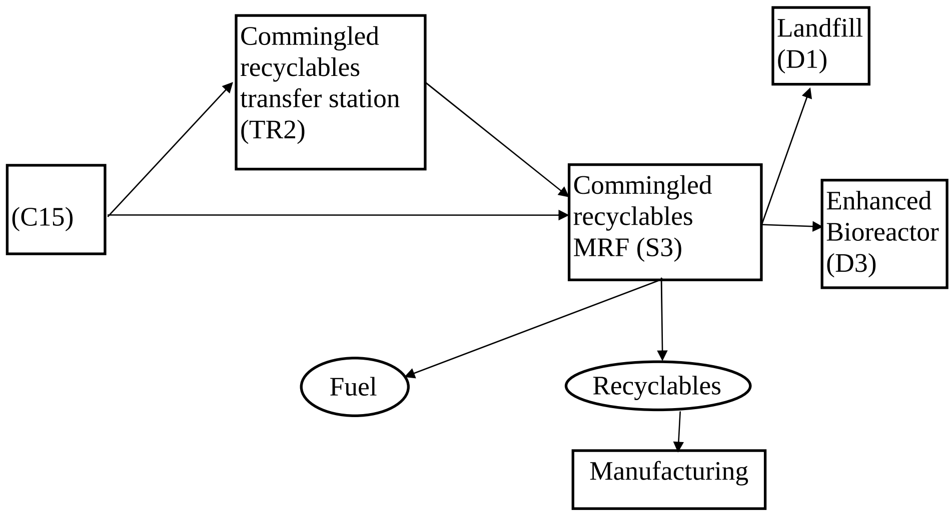
C14 - Collection of pre-sorted recyclables in container quantities from multi-family dwellings (multi-compartment bin)



SET	CAN ENTER NODE			
	TR5	S2	R	MF
MCCR	X	X	X	X
MCNR	X	X	X	X
MNNR	X	X	X	X

Recyclability
Compostabilit
Combustibility
Type

C15. - Collection of commingled recyclables in container quantities from multi-family dwellings (two compartment bin, ONP separate).

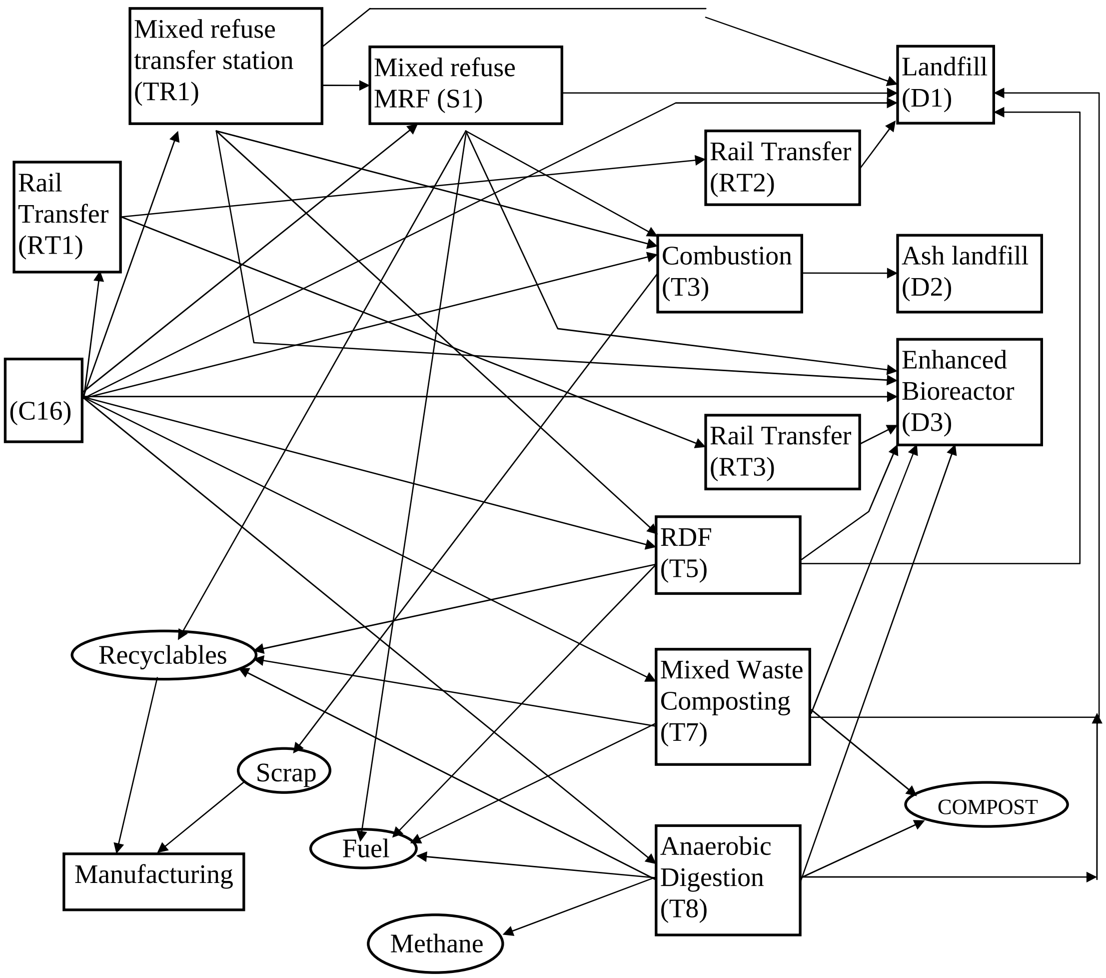


SET	CAN ENTER NODE						
	TR2	S3	D1	D3	F	R	MF
MCCR	X	X	X	X	X	X	X
MCNR	X	X	X	X	X	X	X
MNNR	X	X	X	X		X	X

Recyclability
Compostabilit
Combustibility
Type

Note: The mass entering D1 is an arbitrary % of all C15 mass

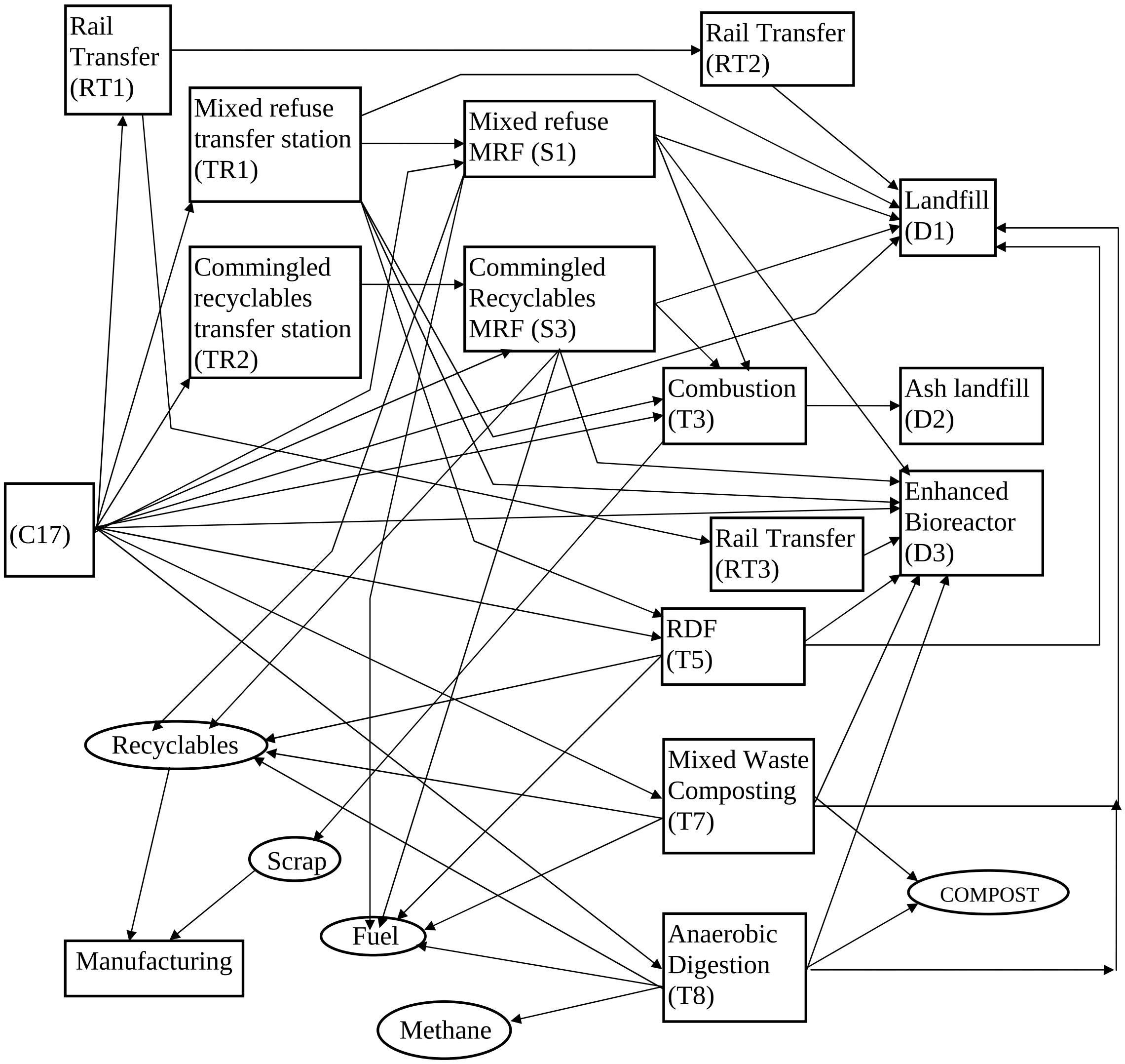
C16. - Collection of MSW from multi-family dwellings where containerized collection is required after removal of recyclables via C14 or C15.



SET	TR1	RT1	RT2	RT3	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
	CAN ENTER NODE																
MYTL	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MYTO	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCCR	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
MCNR	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	
MNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
MCCN	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCNN	X	X	X	X	X	X	X	X	X	X	X				X		
MNNN	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

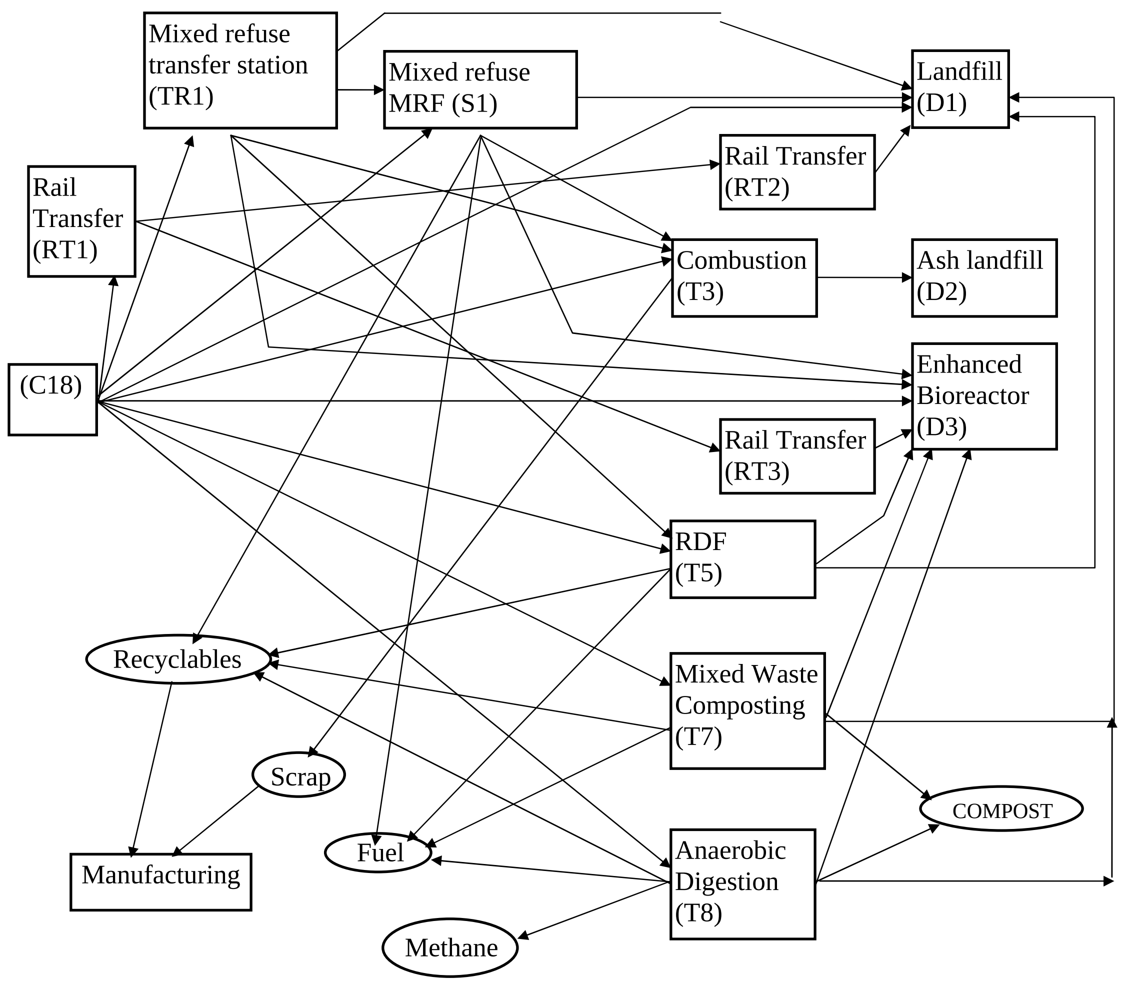
C17. Multi-family wet/dry/commingled recyclables collection in separate compartments



SET	CAN ENTER NODE																		
	TR1	TR2	RT1	RT2	RT3	S1	S3	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
MYTL	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X
MYTO	X	X	X	X	X	X	X	X	X	X	X	X	X	X					X	X
MCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
MCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
MNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
MCCN	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCNN	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X		
MNNN	X	X	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

C18. Multi-family wet/dry collection in separate compartments with commingled recyclables collected via C14 or C15.

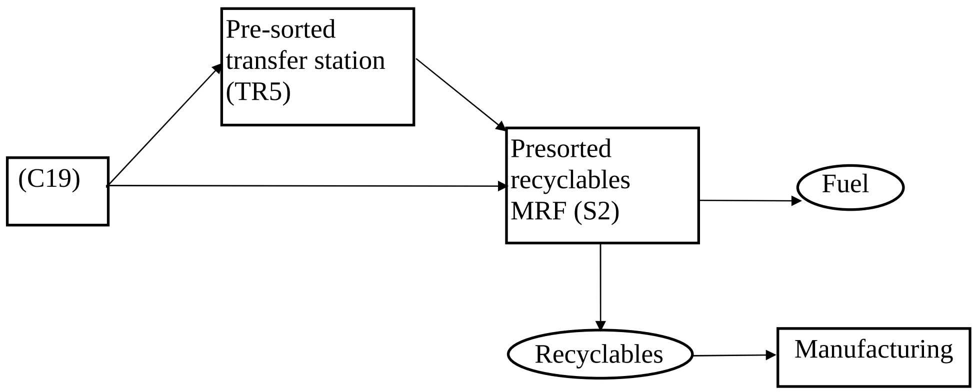


SET	CAN ENTER NODE TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
MYTL	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MYTO	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
MCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
MNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
MCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
MCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
MNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

See note 9.

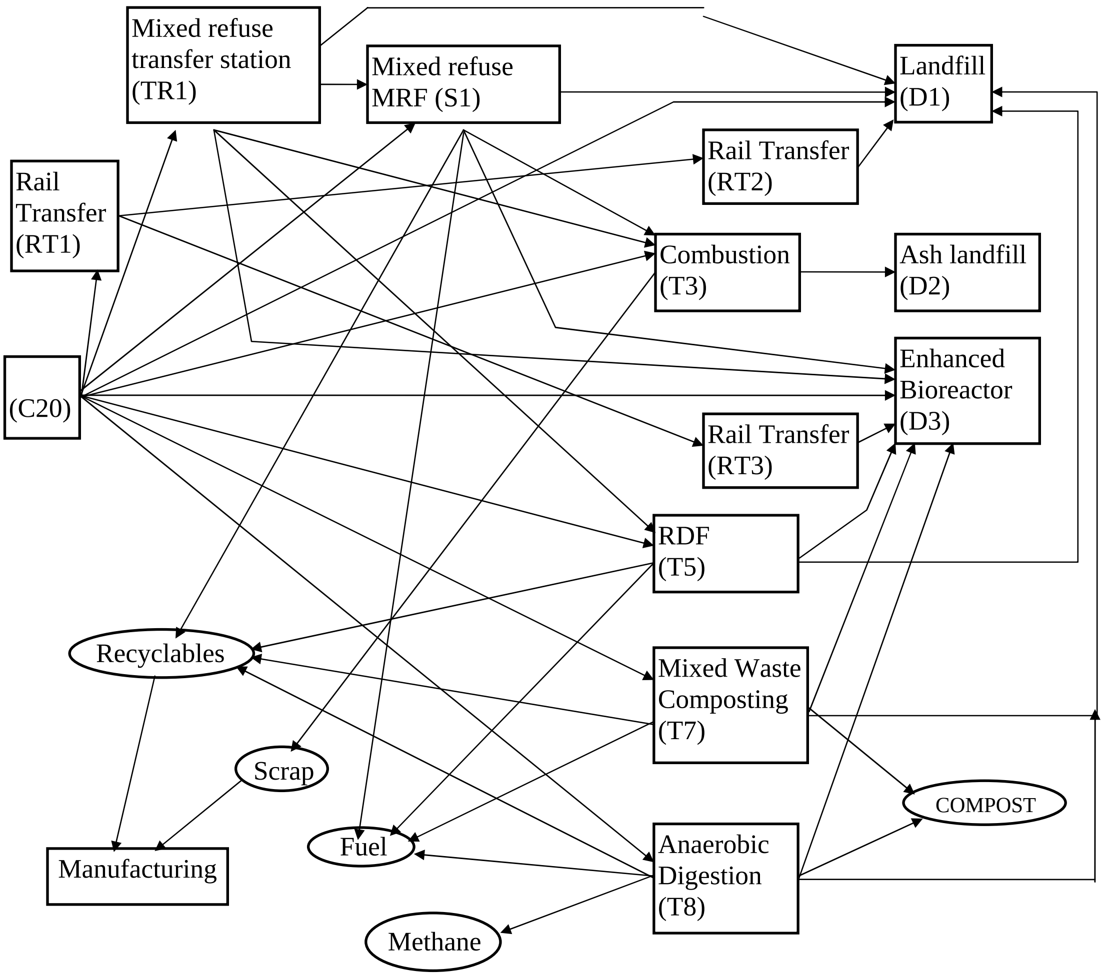
C19. - Collection of pre-sorted commercial recyclables.



SET	CAN ENTER NODE				
	TR5	S2	F	R	MF
CCCR	X	X	X	X	X
CNNR	X	X		X	X
CCNR	X	X	X	X	X

Recyclability
Compostabilit
Combustibility
Type

C20. - Collection of containerized commercial waste before or after removal of recyclables.



SET	CAN ENTER NODE																	
	TR1	RT1	RT2	RT3	S1	T3	T5	T7	T8	D1	D2	D3	MF	R	S	F	M	C
CCCR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
CCNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		
CNNR	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			
CCCN	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X
CCNN	X	X	X	X	X	X	X	X	X	X	X	X				X		
CNNN	X	X	X	X	X	X	X	X	X	X	X	X						

Recyclability
Compostabilit
Combustibility
Type

Appendix D

System Description for a Life-Cycle Inventory of
Municipal Solid Waste Management Alternatives

Morton A. Barlaz and Ranji Ranjithan
North Carolina State University

(7/22/95)

Executive Summary

The objective of this document is to define the boundaries of the solid waste management system to be included in the life-cycle assessment (LCA) of solid waste management alternatives. This system definition will serve as a guide for collection of the relevant data required for a life-cycle inventory. The boundaries are specified in terms of waste composition and generation rates, unit operations involved in solid waste management (collection, separation, composting, combustion, anaerobic digestion, refuse derived fuel and landfill), remanufacturing of products from recycled waste components, and the interrelationships between these unit operations. Figure 1 illustrates the functional elements which comprise the solid waste management system. The key unit operations in the system and the manner in which waste can flow between these processes are illustrated in Figure 2. The system boundary is specified with the objective of being as flexible as possible. However, given the large diversity of settings in which municipal solid waste (MSW) is generated in the U.S., development of a single system definition to address all situations would be unnecessarily complicated.

The components of MSW to be included in the life-cycle inventory (LCI) will be consistent with EPA's characterization of MSW. This definition includes waste generated in the residential, commercial, institutional and industrial sectors but excludes industrial process waste, sludge, construction and demolition waste, pathological waste, agricultural waste, mining waste and hazardous waste. Ash generated from the combustion of MSW will be included in the system. The MSW to be included in this system is divided into three categories: residential waste, waste generated in multifamily dwellings and commercial waste. In analyzing a specific solid waste management system, it will be possible to consider different compositions for each type of waste. Lists of the components included within each category are presented in Table 1 of the main document. In addition to individual components, the system will allow for the recovery of combinations of components such as the recovery of mixed paper for use as either pulp or fuel.

The unit operations to be included in the system include collection and transfer, separation (in material recovery facilities and drop-off centers), treatment (composting, combustion, RDF, anaerobic digestion), and burial. Data on the cost, energy and resource consumption, and pollutant emissions corresponding to individual processes within each unit operation will be collected as part of this project. A preliminary list of LCI parameters is included at the end of this Appendix D.

Several refuse collection options are defined for each waste generation sector. In the residential sector, options include the collection of mixed refuse, the collection of recyclables as either commingled recyclables or recyclables sorted by the collection crew or the waste generator, co-collection of refuse and recyclables in the same vehicle and wet/dry collection with recyclables either included with the dry components or collected in a separate truck. Collection alternatives for refuse generated in multifamily dwellings include the collection of mixed refuse, the collection of either commingled or presorted recyclables and wet/dry collection with recyclables either included with the dry components or collected separately. Collection options for the commercial sector include collection of both mixed refuse and presorted recyclables. Drop-off of recyclables at centralized facilities and dedicated yard waste collection are also considered.

Transfer stations serve as a central facility at which the collected waste is consolidated before shipment to a separation, treatment or disposal facility. Several types of transfer stations will be included in the system in order to receive waste from any of the aforementioned refuse and recyclable collection alternatives. In addition, rail transport is included for mixed refuse generated in the residential, multi-family or commercial sectors.

In MSW management strategies where materials recycling is utilized, recyclables will require processing in a materials recovery facility (MRF). The design of a MRF is dependent upon the manner in which refuse is collected and subsequently delivered to the MRF. Thus, the collection and recycling of MSW are interrelated and this interrelationship is captured in the system. Five different MRFs, each capable of recovering a set of recyclables from the applicable collection alternative, are considered in this system.

The recyclable material recovered from a MRF will ultimately be delivered to a remanufacturing process. The energy and resource consumption, and emissions corresponding to manufacturing a product from recyclable material (remanufacturing) will be considered in the system. In order to compare a remanufacturing process with manufacturing the same product from virgin material, the energy and resource consumption, and releases which apply to a virgin manufacturing process will also be considered.

Waste treatment options to be considered include combustion with energy recovery and conversion to electricity, composting of either mixed waste or yard waste, and anaerobic digestion. The combustion process will be assumed to have air pollution control devices which meet current regulations. In addition, two types of RDF will be considered. The first type of RDF facility will separate the refuse stream to recover a relatively high BTU fraction for use as a fuel. A second variation on the RDF theme will be referred to as co-combustion. Within this option, particular components of MSW are recovered for combustion in industrial boilers such as utility boilers and hog fuel boilers in the paper industry.

Three types of landfills will be considered in the system; one designed for the receipt of mixed refuse and operated to minimize water infiltration, a second designed for the receipt of combustion ash and a third designed for the receipt of mixed refuse and operated to enhance decomposition. All facilities will be designed in accordance with relevant federal regulations with respect to liner design, leachate and gas collection, etc. A user will be able to specify the liner design to be considered.

Finally, source reduction will be considered in the system. This represents a reduction in mass or toxicity of the waste stream. The effects of source reduction are unique to very specific components of the waste stream. A framework for analysis of source reduction is included in the system. However, data collection for source reduction options for industrial processes are beyond the scope of the project.

The ultimate product of this research will be a user friendly decision support tool designed to assist local solid waste management personnel to understand the economics, resource consumption and emissions associated with alternate solid waste management strategies. The decision support system will be supported by a data base with data on life-cycle inventory parameters for individual SWM unit operations. Together, the decision support tool and data base will allow the user to analyze their own solid waste management system and easily explore alternatives.

A. Introduction

The objective of this document is to describe the system and the system boundaries which will be used to conduct the life-cycle assessment (LCA) of municipal solid waste (MSW) management alternatives. This system description is a small but critical part of the overall project, the emphasis of which is the collection of data required for a life-cycle inventory of solid waste management (SWM) alternatives. The inventory analysis will be divided into a number of distinct SWM processes linked together as illustrated in Figure 1. These processes include waste generation, source reduction, collection and transfer, separation (MRFs and drop-off facilities), treatment (which may include composting, anaerobic digestion, combustion or RDF production) and disposal in a landfill or enhanced bioreactor. Remanufacturing is considered to the extent that a specific component of the waste stream is recycled. In this case, the inventory analysis will include both resource consumption and the emissions involved in the remanufacturing process, as well as the resource and emissions offset by virtue of using recycled versus virgin materials. While Figure 1 illustrates the functional elements which comprise the MSW system, the key unit operations in the system and the manner in which waste can flow between these unit operations are illustrated in Figure 2. As presented in Figure 2, there are many interrelationships between the separate unit operations. For example, decisions made with respect to waste separation influence downstream processes such as combustion. An example of waste management alternatives for one waste component is presented in Figure 2a. This figure illustrates the possible paths for old newsprint (ONP) through the system.

In defining the SWM system, our objective is to be as flexible as possible. However, given the large diversity of settings in which MSW is generated in the U.S., development of a single system definition to address all situations will be unnecessarily complicated. Thus, there are likely to be situations where this system definition cannot be applied.

The ultimate product of this research is an easy to use decision makers tool. This tool is a decision support system that will allow a user to perform a life-cycle inventory (LCI) based on locality specific data on MSW generation and management. The decision support system will be supported by a data base with data on LCI parameters for individual SWM unit operations. Work will proceed concurrently to collect the data required for analysis of site specific SWM scenarios and to develop the decision support system. A brief description of the overall decision support system is presented in the following section in order to facilitate review and evaluation of the system. Following this description, this document is structured to follow the order of the functional elements as presented in Figure 1, with the exception of source reduction which is presented after landfills. The discussion of system boundaries is presented in the final section by which time the reader will have a more complete understanding of the proposed system. Finally, a list of the life-cycle parameters to be considered for each unit operation is presented at the end of this Appendix D.

B. Framework for Decision Maker's Tool

The overall decision support system includes several components as illustrated in Figure 3. The decision support system is the primary mechanism through which the data gathered are to be integrated into the analysis of alternate SWM strategies. The underlying component of the overall system is the waste flow equations. These equations are a mathematical representation of the manner in which each waste component can and cannot flow through the system. For example, these equations will exclude the composting of waste components other than grass, leaves and branches in the yard waste composting unit operation. The potential flow paths for ONP are illustrated in Figure 2a. The waste flow equations represent all possible waste stream components which may be handled in all possible processes.

The next component of the decision support system is the one that will be used to estimate the cost and life-cycle factors corresponding to each SWM unit operation. We will refer to this component as a preprocessor. A preprocessor will be developed for each functional element presented in Figure 1, including waste generation, composition and characteristics, source reduction, collection, transfer station, separation (MRF), composting, anaerobic digestion, combustion, refuse derived fuel (RDF) and landfill or enhanced bioreactor. The objective of each preprocessor will be to utilize user input and default design information for the calculation of coefficients which describe the relationship between waste quantity and composition and a specific life-cycle parameter as well as cost. For example, in the collection preprocessor, the user will be asked to specify the collection frequency desired for a community and the distance from a collection route to a downstream facility (MRF, composting, incinerator, RDF plant, landfill, etc.). Based on such design information, the preprocessor will calculate coefficients for cost and life-cycle parameters. This would include the cost for refuse collection in $/ton. In the cases of diesel fuel and particulate emissions, the preprocessor would calculate diesel consumption per ton of refuse collected and the pounds of particulate matter released from a collection alternative per ton of refuse collected. The preprocessor will then assign costs, energy consumption and emissions to the individual components of the waste stream which are identified in Section D. Where the user already has these data, they will have the opportunity to input them directly and bypass the design component of a preprocessor. Assignment of emissions to individual waste components is discussed further in section B.1. A majority of the resources associated with this research project are oriented towards the collection and manipulation of the data required for the preprocessors.

The next major component of the decision support system is the optimization module. The user may choose to evaluate all feasible SWM strategies using the optimization module, or simply use the decision support system as an accounting tool to represent their existing SWM system. In order to identify an optimal SWM strategy with respect to a specific objective, it is necessary to (1) identify the objective and (2) systematically search all feasible SWM alternatives represented by the waste flow equations. The objective, which may be identified by the user, could be to minimize total cost, particulate matter emissions, or any other LCI parameter. The optimization module is then used to systematically search all potential waste management scenarios for the "best" SWM strategy with respect to the objective.

Site-specific information input by the user will be incorporated into the optimization module during the search for optimal SWM strategies. Thus, any strategy identified by the optimization module will meet site-specific constraints imposed by the user. For example, the optimization module can be constrained by the user to search for SWM strategies which recycle a minimum of a specified fraction of the waste stream or utilize an existing process.

The decision support system may also be used as an accounting tool. In this case the user would specify the SWM strategy under consideration and the decision support system would compute the cost and life-cycle inventory.

The final component of the decision support system is the user interface. This interface will provide the user with a friendly platform through which to interact with the different components of the decision support system. It will allow the user to view and edit preprocessor data, provide site-specific information and constraints, and run the optimization module. The interface will also provide a graphical display of the SWM system under consideration and allow the user to conduct "what-if" type analyses for user input SWM scenarios.

B.1 Assignment of Cost and Emission Factors to Individual Waste Components

A life-cycle inventory of MSW management alternatives requires that emissions and resource utilization be assigned for each MSW component in each unit operation. There are situations in the LCI where this will be problematic. Examples include emissions associated with the combustion of individual waste components and the contribution of individual components to leachate composition and gaseous emissions from landfills. While we are aware of this issue, the manner in which it will be addressed will be developed throughout years 1 and 2 as data are collected and analyzed. The overall approach to addressing this issue is as follows. First, there has been some recent research on the contributions of individual components to overall emissions during combustion. Where such data are available they will be used. Second, such data may be a high priority for measurement in year 2. Third, sensitivity analyses will be performed to evaluate where the results of the LCI are sensitive to the manner in which overall emissions are assigned to individual components. Where it is apparent that the appropriate data are not available and cannot be measured within the resource constraints of this project, simplifying assumptions will be made and identified in the project documentation.

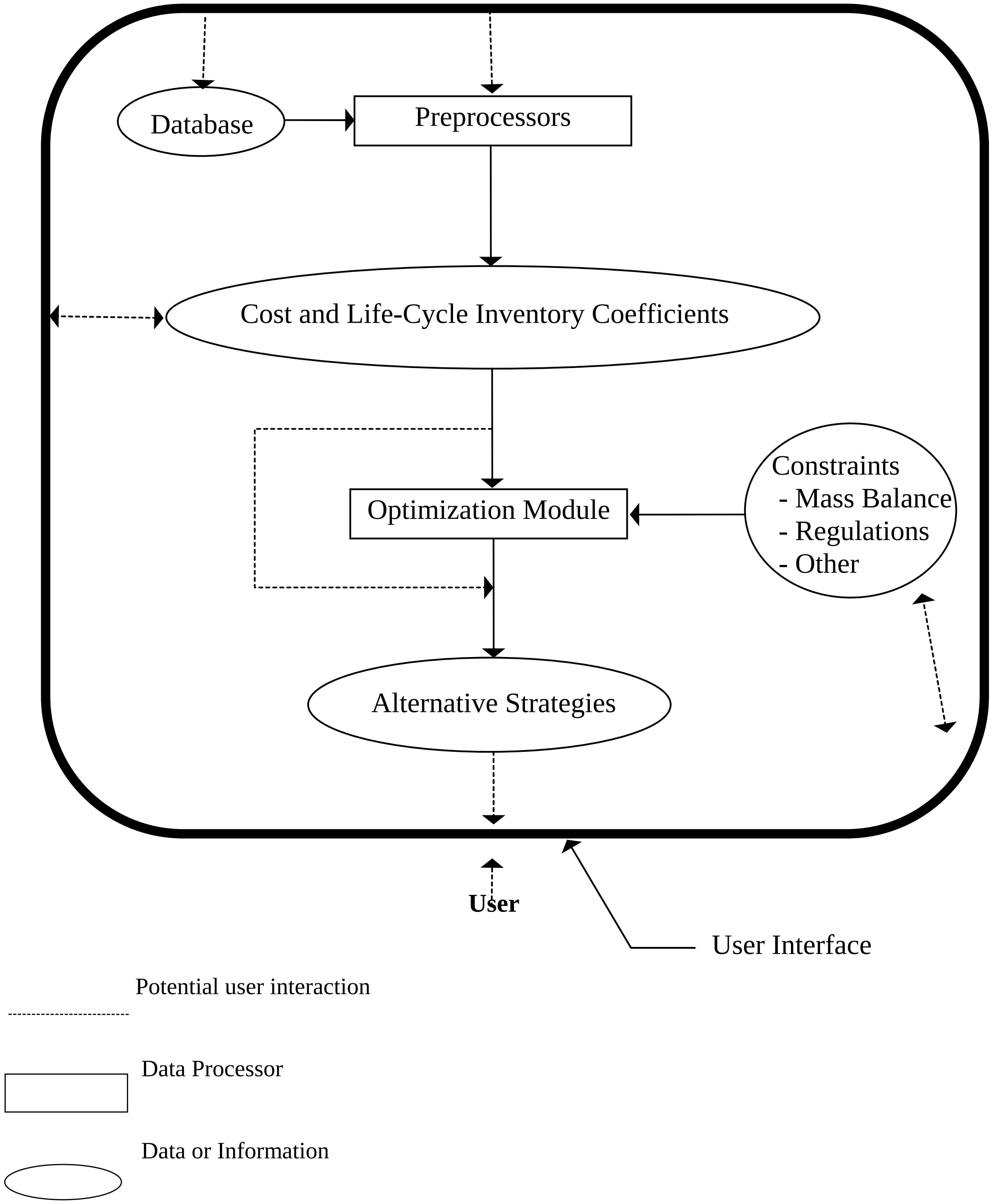


Figure 3 - Relationship between Data and Components of the Decision Support System and the User.

In the case of landfills, one potential solution for assignment of leachate COD to individual components would be to let the assignment reflect the relative biodegradability of a component. Recent research has documented the rapid anaerobic biodegradability of food and grass relative to paper. Thus, the COD contribution of the rapidly degradable components will be greater. In addition, no COD should be assigned to non-biodegradable components except plastics, which may release plasticizers.

C. Waste Generation

Our objective is to perform an LCI on management strategies applicable to wastes defined as MSW by EPA (USEPA 1994). This definition includes waste generated in the residential, commercial, institutional and industrial sectors but excludes industrial process waste, sludge, construction and demolition waste, pathological waste, agricultural waste, mining waste and hazardous waste. Ash generated from the combustion of MSW will be included in the system.

The MSW stream has been divided into three waste categories; residential, multifamily dwelling and commercial. The logic for this separation is that different collection and recycling alternatives apply to each category. The user will be asked to specify the fraction of the population from which waste is collected using collection alternatives appropriate for residential and multifamily dwelling waste as described in Section F. The third category of waste defined here is commercial waste which includes MSW generated in offices, institutions, industries, etc. Arrangements for the collection of this waste are typically handled by the waste generator and are unlikely to overlap with the collection of residential and multifamily dwelling waste. However, these wastes typically enter the same system that handles residential and multifamily dwelling waste at some point in their management.

The composition of waste from the residential, multifamily and commercial sectors will likely differ. In developing the LCI, the user will have the opportunity to input the waste generation rate and composition for each of the waste generation sectors. Default data will be provided for each category. We recognize that such data may be difficult for the user to obtain for commercial waste. However, the composition and generation rate for commercial waste is extremely site specific and default data are not likely to be reliable. Ideally, commercial waste generation factors could be provided by SIC code. Development of such factors is beyond the scope of this project. Should such factors be developed by others, the commercial waste component of the preprocessor could be modified to incorporate SIC codes.

D. Waste Composition

Municipal solid waste has been divided into individual components as listed in Table 1. The rationale for the selected components is described here. The residential and multifamily dwelling waste streams have been divided into 39 components. The components were selected to include those items which are most commonly recycled such as old newsprint (ONP) and HDPE milk and water containers. In addition, the categories have been selected to allow for flexibility by the addition of "other" categories. For example, five extra categories are allowed for "other paper." If the user wishes to consider the recycling of a paper component(s) not listed in Table 1, then the composition of that waste component can be entered as a non-zero value in a "paper-other" category. Similarly, if the user does not wish to consider recycling of a component, such as office paper from residential waste, then the user simply enters its composition as 0%. Five "other" categories have been added for plastics, two for aluminum and a single "other" category was added for ferrous metal in the residential and multifamily dwelling waste streams.

The waste components listed in Table 1 are the same for residential and multifamily dwelling waste. However, the user may enter different compositions for each waste component if desired. The commercial waste stream has been divided into 18 components. These components include the major recyclables in commercial waste based on national averages (office paper, old corrugated containers (OCC), pallets), materials which are commonly recycled (ferrous cans, aluminum cans, PET beverage bottles, container glass and newsprint), three "other" categories for recyclables and three “other” categories for non-recyclables.

While wastes are listed as individual components in Table 1, there are cases where wastes can be grouped together. The waste flow equations will be written to allow consideration of mixed color glass recycling in addition to recycling by individual color. Of course, recycling of mixed color glass would be dependent on the availability of a market. This is specified by the user who can input the revenue associated with mixed color glass in the MRF preprocessor. The user will also have the opportunity to remove from consideration mixed color glass recycling. Similarly, the user will have the opportunity to allow consideration of mixed paper or mixed plastic recycling. In the case of mixed paper and mixed plastic, the user will be required to specify whether the recyclables are used in remanufacturing or as a fuel.

The waste generation preprocessor will request the generation and composition data described in this and the previous section. This preprocessor will also contain default data on physical and chemical characteristics of each waste component such as density, BTU value and moisture content. These data will be used to calculate characteristics of the waste stream, such as moisture content and BTU value, as a function of waste composition.

Table 1 - Components of MSW to be Considered in the LCA[a]

Residential Waste

Yard Waste

1. grass[b]
2. leaves[b]
3. branches[b]
4. Food Waste

Ferrous Metal

5. cans
6. other ferrous metal
7. non-recyclables

Aluminum

8. cans

9/10. other - aluminum

11. non-recyclables

Glass

12. clear
13. brown
14. green
15. non-recyclable

Plastic

16. translucent-HDPE (milk/water containers)
17. pigmented-HDPE bottles
18. PET beverage bottles

19-24. other plastic

25. non-recyclable plastic

Paper

26. newspaper
27. office paper
28. old corrugated containers
29. Phone Books
30. Books
31. Old Magazines
32. Third Class Mail

33-37. other - paper

38. paper - non-recyclable

39 Miscellaneous

Multifamily Dwelling Waste

Yard Waste

1. grass[b]
2. leaves[b]
3. branches[b]
4. Food Waste

Ferrous Metal

5. cans
6. other ferrous metal
7. non-recyclables

Aluminum

8. cans

9/10. other - aluminum

11. non-recyclables

Glass

12. clear
13. brown
14. green
15. non-recyclable

Plastic

16. translucent-HDPE (milk/water containers)
17. pigmented-HDPE bottles
18. PET beverage bottles

19-24. other plastic

25. non-recyclable plastic

Paper

26. newspaper
27. office paper
28. old corrugated containers
29. Phone Books
30. Books
31. Old Magazines
32. Third Class Mail

33-37. other - paper

38. paper - non-recyclable

39. Miscellaneous

Commercial Waste

1. office paper
2. old corrugated containers
3. Phone Books
4. Third Class Mail
5. pallets
6. ferrous cans
7. aluminum cans
8. clear glass
9. brown glass
10. green glass
11. PET beverage bottles
12. newspaper

13-15 other recyclable

16-18 non-recyclables

Notes

a. Items without numbers represent broad waste categories. Items with numbers represent the proposed breakdown of MSW.

b. Yearly average compositions are required.

E. In-Home Recyclables Separation

The manner in which residential and multifamily dwelling waste are collected will influence resource consumption (e. g. water, electricity) in the home (or apartment). Several of the collection alternatives described in the following section include source separation of recyclables. Where a collection alternative involves the separate set out of recyclables, they may be rinsed for in-home storage prior to set out at curbside. Specifically, if recyclables are collected in options 2 through 6 described in the following section, then ferrous cans, aluminum cans, glass bottles, t-HDPE and PET beverage bottles may be rinsed. Water and energy use and wastewater production associated with this activity will be included in the inventory analysis.

F. Waste Collection

There are a number of options for the collection of refuse generated in the residential, multifamily dwelling and commercial sectors. The manner in which refuse is collected will affect the cost, resource utilization, emissions and design of both the collection operation and potential down stream processing facilities such as a MRF. The collection options which we propose to consider are presented in this section. The numbers given for each option are used throughout this document and appear in Figure 2. Alternatives for the collection of multifamily dwelling and commercial refuse are not individually presented in Figure 2 due to space limitations. The role of transfer stations is described in the following section.

Collection of Residential Refuse

Mixed Refuse Collection

1. Collection of mixed refuse in a single compartment truck with no separation of recyclables.

Recyclables Collection

2. Set out of commingled recyclables which are sorted by the collection vehicle crew at the point of collection into a multi-compartment vehicle.

3. Collection of recyclables presorted by the generator into a multi-compartment vehicle.

4. Collection of commingled recyclables in a vehicle with two compartments; one for ONP and one for commingled recyclables. We assume the ONP is separated by the waste generator.

Co-Collection

5. Collection of mixed refuse and recyclables in different colored bags for transport in a single compartment of a vehicle. Bags would then be sorted at a MRF. ONP would also be separated by the waste generator and transported in a separate compartment of the same vehicle.

6. Collection of mixed refuse and recyclables in different colored bags in separate compartments of the same vehicle. The refuse and recyclables would then be delivered to a MRF and the mixed refuse would be delivered to a combustion facility, composting facility, RDF plant or landfill. ONP would also be separated by the waste generator and transported in a separate compartment on the same vehicle.

Residuals Collection

7. If recyclables are collected in options 2, 3 or 4, then residual MSW is collected in a single compartment vehicle as in option 1.

Recyclables Drop-off

8. This alternative allows for the waste generator to bring recyclables to a centralized drop-off facility. This could also be a buy-back center.

Yard Waste Collection

0. Collection of yard waste in a single compartment vehicle. The user will be asked to specify whether waste is collected in bulk, in plastic bags which must be emptied prior to composting, or in biodegradable paper bags which need not be emptied. Of course, yard waste may also be collected as mixed refuse in options 1 or 7 unless a yard waste ban is specified by the user.

9. Dedicated collection of leaves in a vacuum truck.

10. This alternative allows for the waste generator to bring yard waste to a centralized composting facility.

Wet/Dry Collection

11. Wet/Dry collection with recyclables included with the dry portion. The user will be asked to specify whether various paper types are to be included in the wet or dry collection compartments.

12. Wet/Dry collection with recyclables collected in a separate vehicle. The user will be asked to specify whether various paper types are to be included in the wet or dry collection compartments.

Collection of Refuse and Recyclables from Multifamily Dwellings

Mixed Refuse Collection

13. Collection of mixed refuse from multifamily dwellings in a single compartment truck. The user will be required to specify the use of hauled or stationary containers.

Recyclables Collection

14. Collection of pre-sorted recyclables into multiple stationary or hauled containers.

15. Collection of commingled recyclables in a single bin for containers and a second bin for ONP.

Residuals Collection

16. If recyclables are collected in options 14 or 15, then residual MSW is collected in a single compartment vehicle as in option 13.

Wet/Dry Collection

17. Wet/Dry collection with recyclables included with the dry portion. The user will be asked to specify whether various paper types are to be included in the wet or dry collection compartments.

18. Wet/Dry collection with recyclables collected in a separate vehicle. The user will be asked to specify whether various paper types are to be included in the wet or dry collection compartments.

Collection of Commercial Waste

Recyclables Collection

19. Collection of presorted recyclables.

Mixed Refuse Collection

20. Collection of mixed refuse before or after recycling.

Multifamily dwelling waste may or may not be collected by the city in a manner similar to residential refuse collection. Whether this waste is collected by the city or a private contractor should not affect the LCI. Prior to execution of the decision support system, the user will be asked whether multifamily dwelling waste is collected by the city. If yes, then this waste will be analyzed as part of the collection preprocessor. If no, then this waste will be collected by a private contractor and the user will be asked to specify which, if any, components of MSW are recycled. Whether multifamily dwelling waste is collected by the city or the private sector, its life-cycle implications and costs will be included in the system. We assume that commercial waste and recyclables are collected by private contractors. The user will be asked to input the quantity and composition of commercial waste and the amounts of each material which are recycled. Commercial recyclables are assumed to be prepared for shipment to a remanufacturing facility in the private sector. The costs of commercial waste collection are borne in the private sector and not included in the system. However, the life-cycle implications of commercial waste and recyclable collection will be accounted for in the system.

G. Transfer Stations

Once refuse has been collected, there are a number of facilities to which it may be transported including a transfer station, MRF, combustion facility, RDF plant, composting facility, anaerobic digestion facility, landfill or enhanced bioreactor. Prior to describing the manner in which each of these processes is handled, the potential role of transfer stations is described.

The potential role of transfer stations is illustrated in Figures 4a to 4g. In Figure 4a, it is assumed that refuse is collected as mixed refuse (collection option 1). The waste may be transported to a transfer station, mixed refuse MRF, combustion facility, RDF plant, composting facility, anaerobic digestion facility, landfill or enhanced bioreactor. If the waste is brought to a transfer station, then the waste could subsequently be brought to any of these facilities. Waste flow down stream of a MRF, combustion facility, RDF plant, anaerobic digestion facility or composting facility plant is not illustrated in Figures 4a through 4g for simplicity. These flows are part of the system and are illustrated in Figure 2. A transfer

station handling mixed refuse will be referred to as Transfer Station 1. Different transfer station designs will be required dependent upon the type of waste processed.
Figure 4b illustrates the collection of commingled recyclables. These recyclables may be transported to either a transfer station (Transfer Station 2) or directly to a MRF designed to process commingled recyclables (MRF 3).

Figure 4c illustrates the role of a transfer station where refuse and recyclables are co-collected in a single compartment vehicle (collection option 5). In this case, refuse and recyclables could be delivered to either a MRF or to a transfer station. If the refuse and recyclables are delivered to a MRF, then the MRF also functions as a transfer station because the refuse must be removed from the facility to either a combustion facility, RDF plant, composting facility, anaerobic digestion facility, landfill, or enhanced bioreactor. Alternately, the refuse could be delivered to a transfer station (transfer station 3) for separation of the refuse and commingled recyclables.

Figure 4d illustrates the role of a transfer station in which refuse and recyclables are co-collected in a double compartment vehicle (collection option 6). Commingled recyclables and refuse may be transported to a transfer station (transfer station 4) where the recyclables and refuse are separated and transported to regional waste management facilities. In this case, the refuse would then be transported to a combustion facility, composting facility, anaerobic digestion facility, RDF plant, landfill or enhanced bioreactor and the recyclables would be transported to a MRF designed to process commingled recyclables (MRF-3). Alternately, the commingled recyclables and refuse may be transported to MRF-5 where the recyclables are processed and the refuse is transported to a combustion facility, RDF plant, composting facility, anaerobic digestion facility, landfill or enhanced bioreactor.

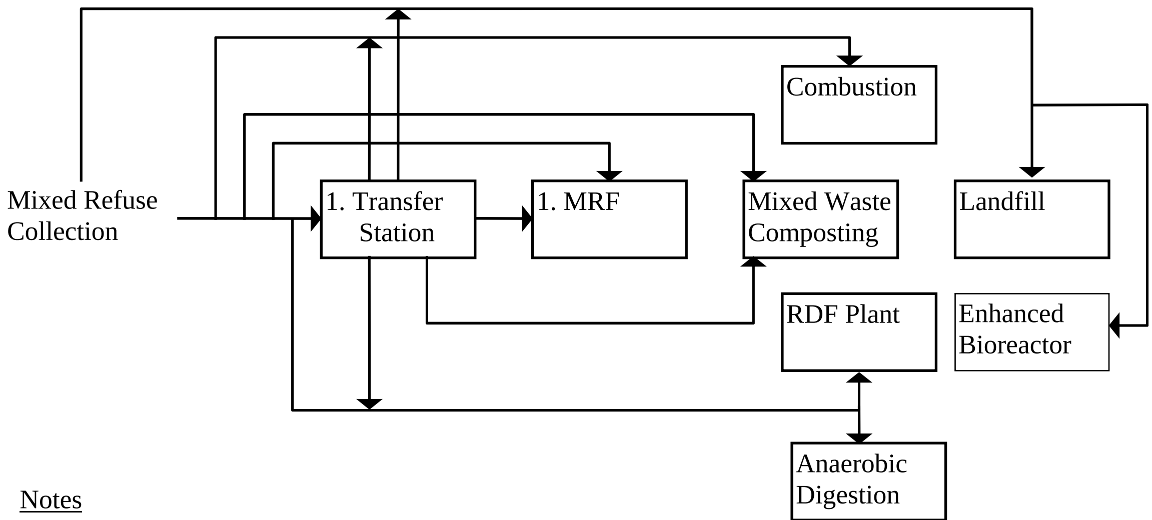
Figure 4e illustrates collection of presorted recyclables in collection options 2, 3 and 8. In these cases, recyclables could be transported either directly to a MRF designed to process presorted recyclables or to a transfer station (transfer station 5) followed by a MRF.

The alternate roles of transfer stations in the collection of residual MSW assuming separate collection of recyclables (collection option 7) are illustrated in Figure 4f. In this collection option, recycling has already occurred. Thus, the MSW is transported to a combustion facility, RDF plant, composting facility, anaerobic digestion facility, landfill or enhanced bioreactor either through or around a transfer station.

The transport of recyclables to and from drop-off facilities is illustrated in Figure 4g. Here, recyclables may be transported to a MRF designed to process presorted recyclables (MRF-2), either through or around a transfer station.

The final collection options involve yard waste including (a) the collection of yard waste in dedicated vehicles (option 0), (b) dedicated leaf collection in vacuum trucks (option 9) and yard waste drop-off (option 10). Transfer stations are not involved in these collection options. Finally, the system will include transport in rail cars. Mixed refuse and wet/dry collection options (options 1, 7, 11-13, 16-18 and 20) include transport to a facility designed to place the refuse in rail cars. This is illustrated in Figure 4h. Refuse transported in rail cars is directed to one of two receiving rail transfer stations. These receiving rail transfer stations are assumed to be adjacent to either a dry or enhanced bioreactor landfill.

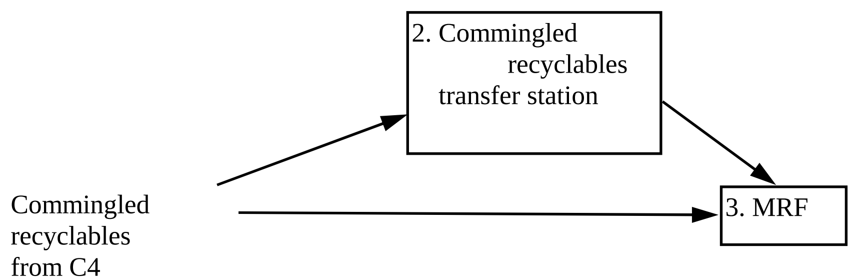
Figure 4a - Alternate Roles of a Transfer Station in Mixed Refuse Collection (Collection Option 1)



Notes
Lines which cross do not represent branches

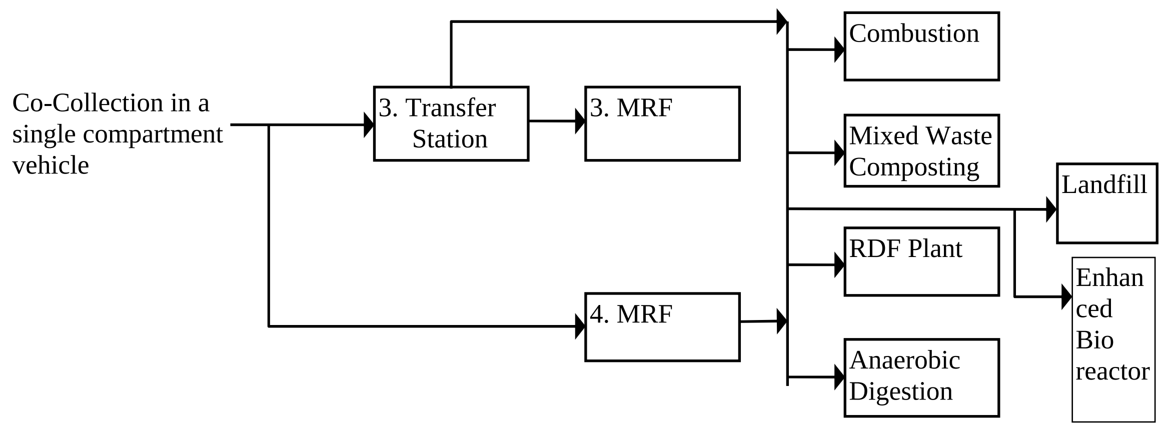
Waste transport downstream of MRF's, combustion facilities, composting and RDF plants is not shown for simplicity. These flows are considered in the system.

Figure 4b - Collection of Commingled Recyclables (Collection Option 4)



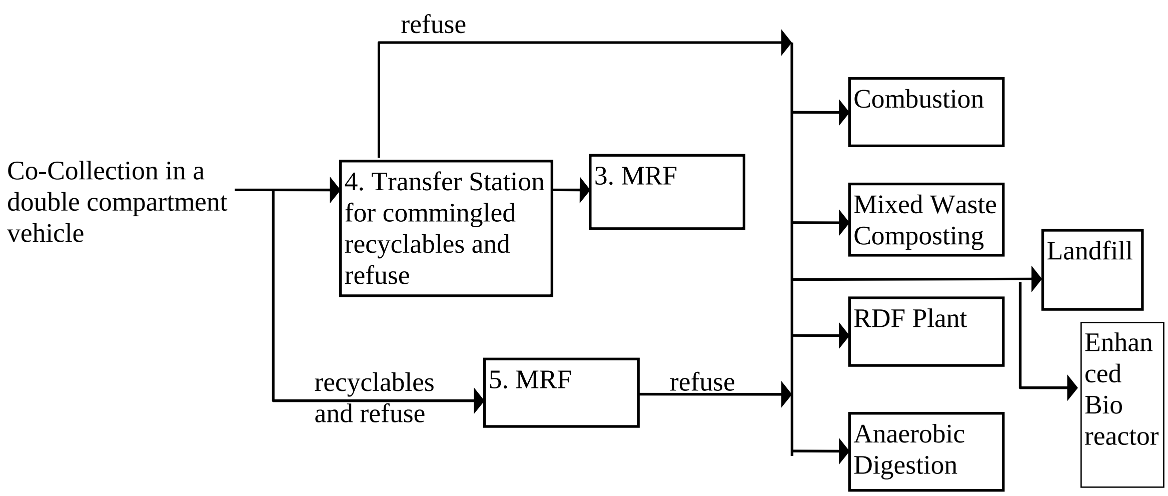
Note
Recyclables transport downstream of a MRF is not illustrated for simplicity. Transport of recyclables to a manufacturing facility is part of the system.

Figure 4c - Co-Collection in a Single Compartment Vehicle (Collection Option 5)



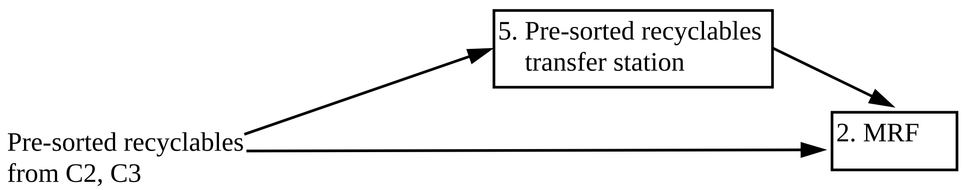
<u>Note</u>
Waste transport downstream of MRF's, combustion facilities, composting and RDF plants is not shown for simplicity. These flows are considered in the system.

Figure 4d - Co-Collection in a Double Compartment Vehicle (Collection Option 6)



<u>Note</u>
Recyclables transport downstream of a MRF is not illustrated for simplicity. Transport of recyclables to a manufacturing facility is part of the system.

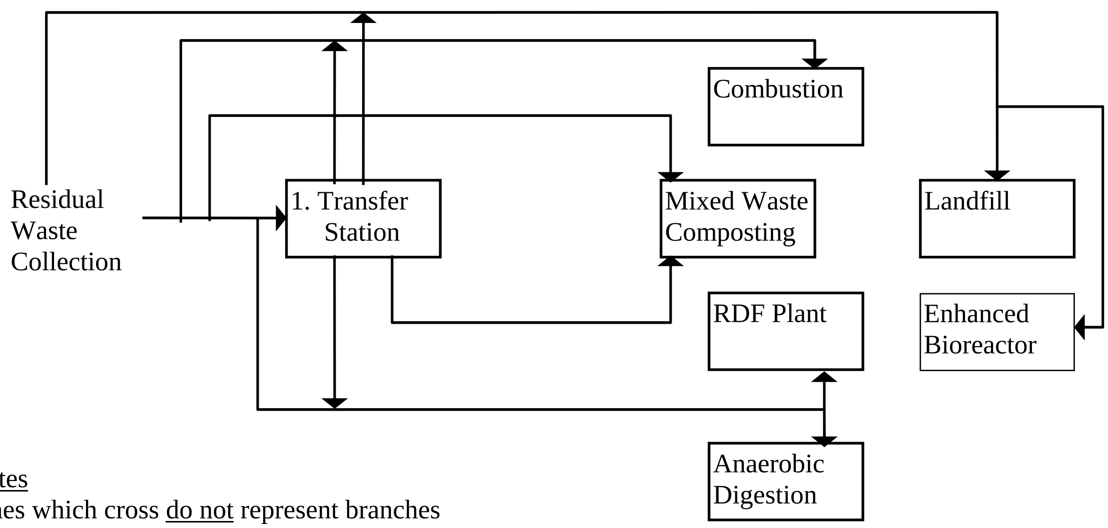
Figure 4e - Collection of Pre-sorted recyclables (Collection Options 2 and 3)



Note

Recyclables transport downstream of a MRF is not illustrated for simplicity. Transport of recyclables to a manufacturing facility is part of the system.

Figure 4f - Collection of Residential mixed waste (Collection Option 7)



Notes

Lines which cross do not represent branches

Waste transport downstream of MRF's, combustion facilities, composting and RDF plants is not shown for simplicity. These flows are considered in the system.

Figure 4g - Transport of Recyclables from a Drop-off Station
(Collection Option 8)

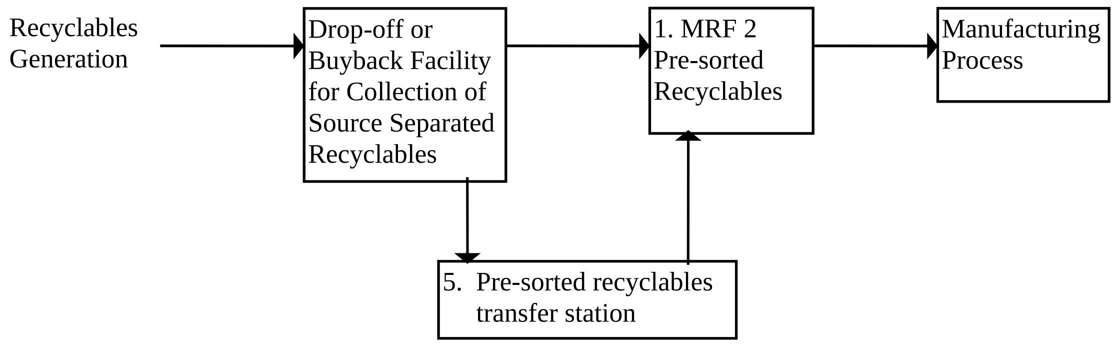
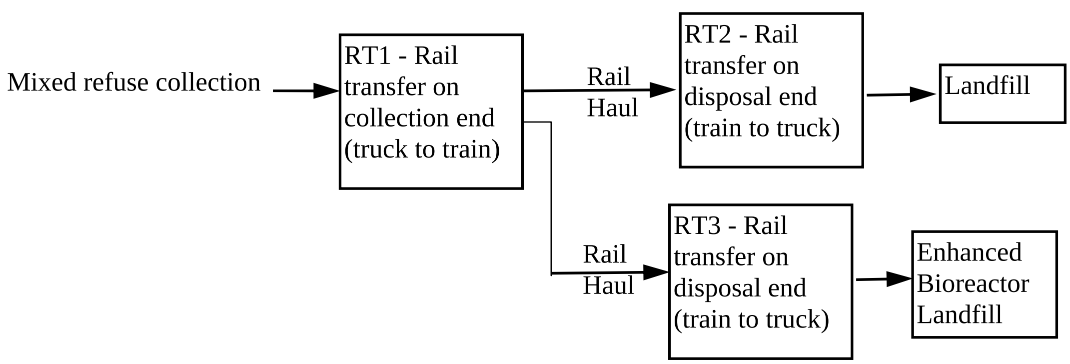


Figure 4h - Role of Rail Transfer Stations
(Collection Options 1, 7, 11-13, 16-18 and 20)



H. Material Recovery Facilities (MRFs)

In MSW management strategies where materials recycling is utilized, recyclables will require processing in a MRF. The design of a MRF is dependent upon the manner in which refuse is collected and subsequently delivered to the MRF. Thus, the collection and recycling of MSW are interrelated. These interrelationships are captured in the system.

The unique design features of each MRF will have an impact on their cost as well as parameters included in the LCI. Five distinct MRFs are considered in the system as described below. The components of MSW which can be recovered in each of the different MRFs are listed in Table 2. Table 2 also lists the components which can be accepted at a drop-off facility (collection option 8).

1. MRF 1 receives mixed refuse as collected in collection option 1 or 13.

2. MRF 2 receives presorted recyclables. Such recyclables could be generated in collection option 2, 3, 8, 14, or 19.

3. MRF 3 receives commingled recyclables as generated in collection option 4, 5, 6, 11, 15 or 17.

4. MRF 4 receives mixed refuse, commingled recyclables and ONP as delivered in a vehicle with one compartment for the mixed refuse plus recyclables and a second compartment for ONP (collection option 5). We will refer to black bags as the color bag containing refuse and blue bags as the color bag containing commingled recyclables.

5. MRF 5 receives commingled recyclables in blue bags and source separated ONP (collection option 6). The commingled recyclables are handled as in MRF 3. MRF 5 also serves as a transfer station for the mixed refuse present in a separate compartment of the vehicle.

Table 2 - List of Materials Which Can be Recycled at Each MRF Type

Recyclable Component	MRF 1	MRF 2	MRF 3	MRF 4	MRF 5	Drop-off or Buyback Center
Fe-cans	x	x	x	x	x	x
Al-cans	x	x	x	x	x	x
clear glass	x	x	x	x	x	x
brown glass	x	x	x	x	x	x
green glass	x	x	x	x	x	x
mixed color	x	x	x	x	x	x
glass	x	x	x	x	x	x
t-HDPE	x	x	x	x	x	x
p-HDPE	x	x	x	x	x	x
PET-bvg.	x	x	x	x	x	x
plastic-other	x	x	x	x	x	x
mixed plastics[a]	x	x	x	x	x	x
ONP	x	x	x	x	x	x
OCC						x
Phone Books		x	x	x	x	x
Books		x	x	x	x	x
Old Magazines		x	x	x	x	x
Third Class Mail		x	x	x	x	x
office paper		x	x	x	x	x
paper-other		x	x	x	x	x
mixed paper[a]	x	x	x	x	x	x

a. Includes "non-recyclable" plastics or paper.

Based on previous work, we have concluded that the MRFs described above are most cost effective when they include an automatic bag opener, a magnet for ferrous metal removal and an eddy current separator for aluminum can removal. All other sorting is performed manually. We propose to adopt these assumptions here, for purposes of developing MRF designs from which to estimate cost and LCI parameters. However, the user will have the opportunity to specify automated or manual equipment in certain cases.

The technology associated with MSW sorting in MRFs is evolving. This can be accommodated by allowing the user to bypass the design component of a preprocessor and input costs and LCI parameters directly. Five distinct MRFs are required as described above. However, they have many overlapping design features which will remain consistent between MRFs. The design for each MRF will be presented in year 2 as the preprocessors are developed.

I. Remanufacturing and Energy Recovery

The LCI analysis must account for all resources, energy and emissions associated with the recycling and reprocessing of a waste component. This section presents the conceptual framework to be used to account for resource expenditures and potential savings due to the use of recycled materials. In management strategies where some portion of the MSW is recycled, the recyclables will ultimately be delivered to a facility for remanufacturing. Separation will occur during collection, or at a MRF or other waste management facility. Energy and resources will be expended to deliver recyclables to a remanufacturing facility. At the facility, additional energy and resources will be expended to convert the recyclables to a new product. The total amount of energy required to recover the recyclable from the waste stream and convert it to a new product will be included in the inventory analysis. This energy is termed E_r. In addition, the amount of energy required to produce a similar amount of product from virgin material will be calculated. This energy is termed E_v. The net amount of energy (E_n) expended (or saved) to recycle a material will then be calculated as the difference between E_r and E_v ($E_n = E_r - E_v$.)

While energy has been used here as an example, a similar calculation will be performed for all life-cycle parameters involved in the remanufacturing process such as carbon dioxide and other air emissions, wastewater pollutants, and solid waste, etc. This calculation assumes that a product manufactured using recycled materials is indistinguishable from the same product manufactured with virgin materials. Although not shown in Figure 5, ONP which is not recycled would be disposed by combustion, conversion to RDF, composting or a landfill as illustrated in Figure 2.

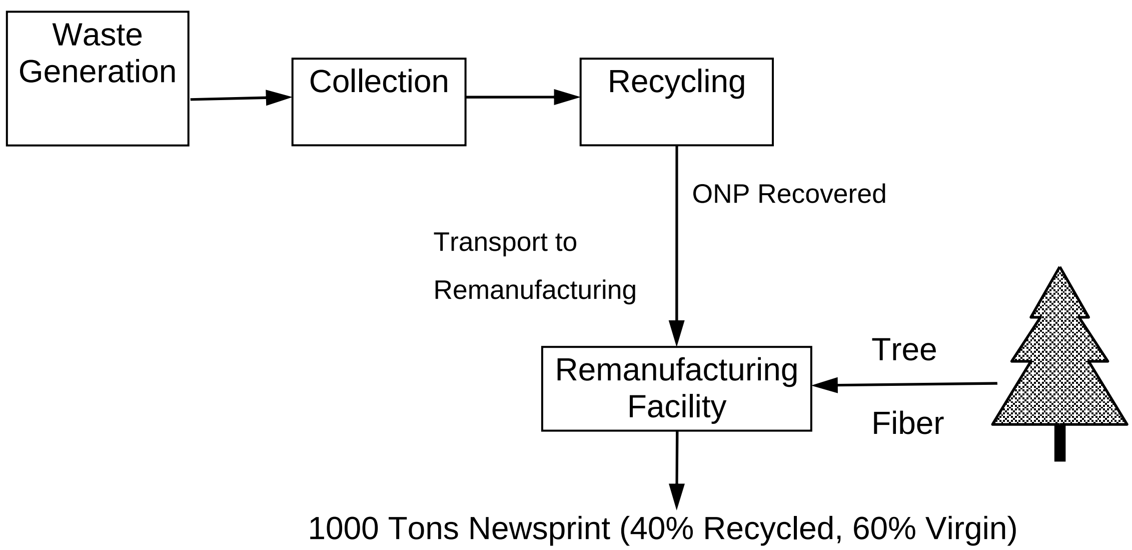
The calculation described above is illustrated conceptually for ONP in Figure 5. Figure 5 shows the flow diagram which accounts for the total energy required to produce and deliver to consumers 1000 tons of newsprint (as newspapers). As can be seen in Figure 5, newsprint is not produced from 100% recycled material; some virgin material is mixed with the recycled fiber.

In order to develop the life-cycle inventory, an assumption must be made with respect to which remanufacturing process is utilized for a recyclable. In the case of ONP, the major use is the production of new newsprint. However, some ONP is used in other applications (container board, cellulose insulation, animal bedding, etc.). For each recyclable, it will be necessary to collect data on remanufacturing processes in order to complete the LCI. Data collection efforts will focus on the major remanufacturing process for each recyclable. Additional remanufacturing processes will be included in the decision support system so that if resources are available to collect data on more than one remanufacturing process, the system will have the capacity to incorporate it into the analysis.

In addition to recycled materials, an offset will also be required in management strategies where energy is recovered from the direct combustion of MSW, the combustion of RDF or landfill gas. The conceptual framework described above may be applied here as well. Energy recovered from the MSW will be credited to that management strategy. In calculating emissions reductions associated with energy recovery, we will assume the ‘saved’ energy resulted from fossil fuel (coal, oil or natural gas) and not from hydro or nuclear power.

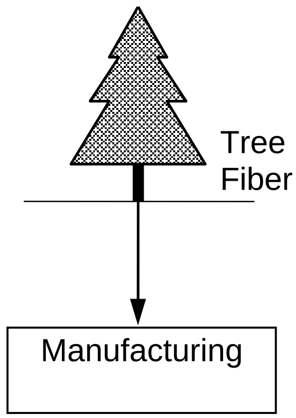
Figure 5
Illustration of Framework for Calculation of
Life Cycle Effects Including Remanufacturing for Recycled
Newsprint

A. Calculation of E_r



E_r = Total energy required to produce 1000 Tons of newsprint using recycled material, from collection through new product production.

B. Calculation of E_v



E_v = Total energy required to produce 1000 Tons of newsprint from virgin material.

Includes energy from growth of trees through final product.

1000 Tons Newsprint (100% Virgin)

J. Composting

Composting is the aerobic biodegradation of organic matter and is considered as a treatment alternative. We propose to consider composting of either yard waste or mixed waste. Yard waste composting may occur in either a centralized municipal facility or in a generator's backyard. Here, we consider a centralized composting facility. Backyard composting will be considered in Section O on source reduction.

We propose to consider two alternatives for yard waste composting; a low and medium technology facility. The major difference between these two facilities is the degradation rate of the yard waste as influenced by the turning frequency. The detention times are assumed to be 540 and 270 days for the low and medium technology facilities, respectively and can be modified by the user. Turning is accomplished with either a front end loader once per year (low) or a windrow turner 25 times per year (medium). Again, these parameters can be modified by the user. Other major differences between the low and medium technology facilities include water addition, post process screening and the potential to treat leachate. The type of facility to be considered will be a user input parameter. Branches will be shredded prior to composting in both the low and medium technology facilities. Neither facility includes an automated air supply system.

Yard waste may be delivered in collection vehicles or dropped off by the waste generator. In addition, leaves may be delivered in vacuum trucks. If yard waste is delivered in bags, then the user will be asked to specify whether the bags are biodegradable, in which case they will not require emptying, or non-biodegradable, in which case they will need to be emptied and the bags will represent a residual. Yard waste may also be delivered in bulk.

The design of the mixed waste composting facility will be based on mechanical aeration. This facility will include preprocessing of the inlet waste stream to remove non-compostable recyclables such as metal, plastic and glass as well as non-compostable non-recyclables. The waste flow equations will be written so that paper may or may not be removed in the preprocessing step.

K. Combustion

Combustion represents a treatment alternative in which the volume of MSW requiring burial is significantly reduced. We will consider a facility in which MSW is burned with subsequent energy recovery in the form of electricity. Facilities in which energy is not recovered as well as facilities in which energy is recovered as steam are excluded from the system. The logic for this selection is that the majority of combustion facilities constructed today include energy recovery as electricity.

The cost, energy production and emission functions for a combustion facility will be developed on the basis of BTU of input waste per day as opposed to tons per day which is more standard. In so doing, we are able to link the cost and energy yield of combustion to waste composition. The BTU value of the waste input to a combustion facility will be calculated from default data on the BTU value of individual waste components and the composition of waste entering the facility. Thus, if the BTU value of MSW changes, the effect will be incorporated into estimates of potential energy recovery. This will allow comparison of the relative net benefits of recycling and combustion with energy recovery in the optimization module.

In order for a combustion facility to be feasible, a critical mass of refuse is required. The critical mass will be set up as an input parameter so that (1) a SWM alternative with an unacceptably small combustion facility is not proposed and (2) future changes in technology resulting in a change in the critical mass can be incorporated in the system. The combustion facility will include appropriate air pollution control equipment to meet current regulations.

L. Refuse Derived Fuel (RDF) and Co-Combustion

In addition to combustion as discussed in the previous section, two alternatives for recovery of the energy value of MSW will be considered in the SWM system, RDF and co-combustion. In the system described here, RDF production refers to the separation of MSW into a product stream with a relatively high BTU value and a residual stream with a relatively low BTU value. Of course, the efficiency of the separation of MSW into these streams will be less than 100%. There are many variations on the RDF theme including the production of shredded refuse for direct combustion, and the production of pellets for shipment over longer distances. The most common RDF processes will be identified in future work so that one or more generic RDF plant designs can be developed. These designs will be used as the basis for a preprocessor in which cost, energy and emission factors are developed.

The division between an RDF plant and a MRF is not entirely distinct as metals separation typically occurs in an RDF plant. Thus, if RDF is part of an MSW management strategy, then it would probably not be necessary to remove tin cans separately. Similarly, an eddy current separator at an RDF plant would eliminate its need at a MRF. As more information is developed on RDF plants, we will propose the manner in which the interrelationship between an RDF plant and a MRF will be handled.

Another manner in which energy can be recovered from MSW is by the combustion of particular components of the stream in industrial boilers. This could include utility boilers, hog fuel boilers in the paper industry and the like. The system allows for the recovery of a mixed waste paper stream and a mixed waste plastics stream during recycling. One or both of these streams could be used as fuel for an industrial boiler. This will be referred to as RDF although it will not necessarily include a separate facility.

M. Anaerobic Digestion

Anaerobic digestion of MSW could occur in either a reactor or by operation of a landfill with leachate recycle for enhanced refuse decomposition and methane production. Here we refer to digestion in a reactor. The facility will include preprocessing of the inlet waste stream to remove non-degradable recyclables such as metal, plastic and glass as well as non-degradable non-recyclables. The waste flow equations will be written so that paper may or may not be removed in the preprocessing step.

N. Landfills

Three types of landfills will be considered in the system; one designed for the receipt of mixed refuse and operated to minimize water infiltration, a second designed for the receipt of combustion ash and a third designed for the receipt of mixed refuse and operated to enhance decomposition. All landfills will be designed according to RCRA Subtitle D and Clean Air Act standards. However, through the preprocessor, the user will have the opportunity to specify either a more lenient or stricter design with respect to the liner and cover systems. The first landfill will be operated as a dry landfill. The system will include both gaseous and liquid emissions from the landfill. The user will be required to specify whether gas is flared, recovered for energy, vented to the atmosphere or allowed to diffuse out of the landfill. This information, coupled with data on landfill gas production, will be used to estimate atmospheric emissions. Estimates will also be developed for the amount of leachate requiring treatment. This leachate will be treated in an off-site treatment facility. Energy and emissions associated with leachate treatment will be considered in our inventory analysis.

Municipal waste combustion ash will be directed to a landfill designed to accept ash. Even when a community utilizes combustion, there will be some material which should not be routed to a combustion facility and also times when it is out of service. Thus, we expect that the design for an ash landfill will include a relatively small section designed for the receipt of mixed refuse. A third landfill will be designed with leachate recycle to enhance refuse decomposition, methane production and leachate treatment. As above, the system will include both gaseous and liquid emissions. The user will be required to specify whether gas is flared or recovered for energy. This information, coupled with data on landfill gas production, will be used to estimate atmospheric emissions.

O. Source Reduction

As illustrated in Figure 1, source reduction represents the difference between potential and actual waste generation. Source reduction represents a reduction in mass or toxicity. Source reduction may lead to reductions in other LCI parameters such as COD production or particulate emissions. The effects of source reduction are unique to very specific components of the waste stream. The conceptual framework for modeling source reduction is described first, followed by examples of how it could be applied.

With reference to Figure 1, the box entitled source reduction represents a series of multipliers that adjust the waste generation rate resulting from a source reduction program. These numbers are multiplied by the waste quantities in the potential waste generation box to calculate actual waste generation. Source reduction will include a series of multipliers, with unique values for changes in waste mass and each life-cycle parameter. These multipliers will be set up as individual input parameters in a preprocessor so that where the user has data on a specific process, it can be used. Collection of data on specific industrial processes for evaluation of source reduction is beyond the scope of this project.

Source reduction is generally applied to very specific components of the waste stream. Examples might include a lighter napkin with equivalent absorbency, or a napkin produced by an alternative manufacturing process which reduces waste production. Napkins are not one of the waste components listed in Table 1. Rather than divide the waste stream into the individual components which make up MSW in order to specifically include napkins, we have provided additional "dummy waste components" in the waste composition data input section. These dummy variables could be used in the same way as the "paper-other" category. That is, if a user wishes to focus on napkins, then the user would consider one of the dummy variables to be napkins. The user could then enter the appropriate multipliers in the source reduction preprocessor to account for mass and other life-cycle parameter reductions (or increases) associated with the production of a different napkin. If a waste were to be converted from a non-recyclable to a recyclable form, then its composition would have to be considered as part of one of the recyclable components identified in Table 2. If this is inappropriate, then the preprocessor would require modification.

A simple example of the source reduction preprocessor is its application to backyard composting. Here, yard waste which is composted by the waste generator does not enter the MSW collection system. A multiplier in the source reduction preprocessor would be used to reflect the decreased mass of yard waste in MSW. Yard waste not collected would not require energy for collection or further processing in a centralized composting facility. However, there are life-cycle implications associated with backyard composting and these will be accounted for in a dedicated preprocessor. The backyard composting preprocessor would account for emissions associated with biodegradation as well as emissions associated with the use of a chipper for size reduction of branches. In the preprocessor, the user will have to specify the fraction of backyard compost systems where a chipper is utilized.

P. Summary of System Boundaries

The system has largely been defined through the description of the functional elements and unit operations as discussed in this document and the manner in which each will be treated. In general, we will evaluate all data which have a bearing on the inventory analysis from materials acquisition through waste disposal or remanufacturing. Where a material is recycled and a new product is produced, the resources, energy and emissions associated with production of the new product as well as those saved by using a recycled material instead of a virgin material will be considered. This concept also applies to energy recovery from combustion as described in more detail in Section I and in Figure 5.

In considering remanufacturing, we will evaluate life-cycle parameters from the recovery of a raw material through its conversion to a product. Where petroleum is a raw material, the analysis would include all activity beginning with recovery of petroleum from the earth. Where energy is required in a process, the energy associated with production of the energy (precombustion energy) and the wastes associated with energy production will be considered. Where trees are utilized, resources associated with growing and harvesting the tree will be considered.

The functional elements of MSW management include numerous pieces of capital equipment from refuse collection vehicles to balers to major equipment at paper mills. Resources are associated with the fabrication of capital equipment as well as the construction of a new facility. In theory, these resources should be considered in the inventory analysis. This may be particularly relevant in evaluation of waste management strategies which suggest the construction of a new facility, such as a MRF, or the purchase of new refuse collection vehicles. While inclusion of capital equipment appears to be theoretically correct, it introduces additional complexity which may not be necessary. The amortized purchase price of a facility or a piece of equipment will be used as a screen to evaluate the importance of its inclusion in the inventory analysis. Where the amortized capital cost of a piece of equipment is low relative to the non-labor cost to operate it, we will assume that the resources involved in fabrication of the equipment are insignificant. It is difficult to identify cases where capital equipment and facility construction can or cannot be neglected ahead of time and issues such as this will be brought out for discussion by the internal advisory board as they arise.

A second type of resource that may be neglected is the energy associated with the operation of a facility's infrastructure, or "overhead" energy. For example, energy will be expended for the operation of refuse collection vehicles. We expect that a much smaller amount of energy will be expended for operation of the office through which the vehicle routes are developed and the collection workers are supervised. Our hope is to obtain estimates of this "overhead" energy based on utility bills. If this energy is less than 5% of the energy utilized by the collection vehicles, then it will be neglected unless standard overhead energy consumption factors are available. This will save the project the resources required to estimate such energy more precisely and will not affect the quality of the project output.

Another system boundary is that at the waste treatment and disposal end of the system. Where liquid wastes are generated which require treatment, the energy associated with their treatment will be considered. For example, if BOD is treated in an aerobic biological wastewater treatment facility, then energy is consumed to supply adequate oxygen for waste treatment. If a solid waste is produced which requires burial, energy will be consumed in the transport of that waste to a landfill and its burial in the landfill.

1. System Boundary for Economic Analysis

In this section we propose that the system boundary for the economic analysis differs from that used for the inventory analysis. We propose that our economic analysis focus on the cost of waste management as experienced by the public sector. Thus, the economic analysis will include the cost of waste collection, transfer stations, MRFs, composting facilities, combustion, RDF plants and landfills. In addition, where a waste is produced as part of a waste management facility, the cost of waste treatment will be included in the economic analysis of that facility. For example, we will include the cost of leachate treatment in our economic analysis of landfills. The economic system boundary will also include the cost of educational or other materials associated with source reduction or other aspects of solid waste management. The boundary will be drawn at the points where waste is buried and recyclables are shipped to a downstream processor. For example, if recyclables were shipped from a MRF, the economic analysis would end where the public sector received revenue (or incurred a cost) in exchange for recyclables. The same analysis would apply to the sale of RDF or electricity. The user must be cautioned that there are situations where the revenue realized from the sale of a recyclable is artificially high. This has occurred in the past where a manufacturer has taken steps to encourage the recycling of a material by offering an artificially high price. Such situations may arise when recycling of a waste component not typically recycled begins. This situation would not be expected to persist for a period of several years.

One cost to be excluded from the economic analysis is the cost of remanufacturing. However, we feel that this cost is reflected in the price paid to a community for recyclables or electricity. Another cost to be excluded is the cost associated with the collection and processing of waste generated in the private sector. As described in Section F, we assume that waste generated in the commercial sector is collected by private haulers at the expense of the waste generator. If this waste is transported to a facility operated in the public sector, then a tipping fee will be paid to reflect the cost of waste management at that facility. Thus, the cost of commercial waste disposal is not charged to the public sector. Nevertheless, it is important to account for commercial waste as its mass is likely to be a significant component of total waste generation and it will affect the size of various facilities.

The user will have the option to enter costs directly into the preprocessor or provide sufficient design information for the preprocessor to estimate costs. Where costs are estimated by the preprocessor, we propose to estimate costs in the absence of an allowance for profit. The user will then be given the opportunity to specify a profit margin if the user expects that a waste management unit operation will not be operated in the public sector. The calculated cost will then be adjusted upwards prior to its use in the optimization module.

In summary, by focusing on costs incurred in the public sector, the analysis will be of most use to local officials responsible for development of strategies for solid waste management.

Q. References

USEPA, 1994, "Characterization of Municipal Solid Waste in the United States: 1992 Update, EPA/530-R-94-042.

Inventory Analysis Worksheets

Each unit operation presented in Figure 1 will require information on a number of life-cycle parameters. Work has begun to identify which specific parameters should be considered for each unit operation. These parameters have been identified on individual worksheets for collection, transfer stations, MRFs, composting, RDF, combustion, anaerobic digestion and landfills. An inventory worksheet has not been developed for remanufacturing because it will be specific for each recyclable and new product.

Each worksheet includes a section for consumption and a second section for releases. Consumption includes energy, water and raw materials. Energy is divided into energy required for the process and energy associated with facility operation and maintenance. As discussed in Section P, if the energy for facility operation and maintenance is low, it will be neglected. Releases are divided into gaseous, liquid and solid wastes. Releases will occur as a result of specific process operation as well as due to energy consumption. Thus, release factors will be developed to relate total energy consumption to the release of specific gaseous, liquid and solid wastes. Categories to be considered in the inventory include notes identifying the source of an emission or resource consumption.

These worksheets must be considered as preliminary as there are issues which have been identified but not yet resolved. For example, we have yet to address how to account for the emission of toxic organic gases. Can they be lumped together as volatile organic carbon or treated individually? This question is specifically applicable to landfill gas and leachate.

Components of LCA for SWM Process:

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	
natural gas	
propane	
gasoline	
diesel	
fuel oil	
Facility operation & maintenance *	
Water	
Process operation	
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	
Facility operation & maintenance *	
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	
- fuel use	
electricity	
gas	
propane	
diesel	
fuel oil	
Facility operation & maintenance *	
Waterborne	
Process operation	
- process related	
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	
Facility operation & maintenance *	

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: Collection

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	
natural gas	
propane	
gasoline	
diesel	collection vehicles
fuel oil	
Facility operation & maintenance *	electricity, gas and oil: shop and office O&M
Water	
Process operation	truck washing
Facility operation & maintenance *	shop and office O&M
Other (raw materials)	
process-specific material	oil and other engine fluids
Facility operation & maintenance *	batteries, belts, tires, paint, grease, etc. office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	
- fuel use	
electricity	emissions depend on source of power
gas	
propane	
diesel	truck exhaust: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for shop and office O&M, heating and ac
Waterborne	
Process operation	
- process related	truck washing: BOD,COD,soilds, oils and grease
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	oil and other engine fluids
- process related MSW	
Facility operation & maintenance *	truck O&M: tires, belts, batteries, engine fluids office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: Transfer Station

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	compactor, scale
natural gas	
propane	rolling stock
gasoline	
diesel	rolling stock, trucks
fuel oil	
Facility operation & maintenance *	elec: shop & office O&M, heating & ac, steam cleaning
Water	
Process operation	dust control, cleaning
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	
Facility operation & maintenance *	shop and office O&M office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	
- fuel use	
electricity	emissions depend on source of power
gas	
propane	from rolling stock: HC,CO,CO_2,NOx - complete list?
diesel	from rolling stock & trucks: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for shop and office O&M, heating and ac
Waterborne	
Process operation	
- process related	
Facility operation & maintenance *	wash water: BOD,COD,total suspended solids, oils and grease
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	
Facility operation & maintenance *	from shop and machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: MRF

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	conveyors,balers,magnets,eddy current separators,glass crusher,pneumatic
electricity	conveyors, bag openers,shaking screen, scales, air compressors, trommel
natural gas	
propane	rolling stock
gasoline	
diesel	rolling stock
fuel oil	
Facility operation & maintenance *	elec: shop & office O&M, heating & ac, steam cleaning
Water	
Process operation	floor cleaning
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	bale wire, disinfectant
Facility operation & maintenance *	machine fluids, hydraulic fluids office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	
- fuel use	
electricity	emissions depend on source of power
gas	
propane	from rolling stock: HC,CO,CO_2,NOx - complete list?
diesel	from rolling stock: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for shop and office O&M, heating and ac
Waterborne	
Process operation	
- process related	wash water: BOD,COD,total suspended solids, oils and grease
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	
Facility operation & maintenance *	from shop and machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: RDF

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	conveyors,magnet,eddy current seprator, pneumatic conveyor,
electricity	shaking screen, scales, air compressors, trommel, shredder, compactor
natural gas	
propane	rolling stock
gasoline	
diesel	rolling stock
fuel oil	
Facility operation & maintenance *	elec: shop & office O&M, heating & ac, steam cleaning
Water	
Process operation	floor cleaning
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	disinfectant
Facility operation & maintenance *	machine fluids, hydraulic fluids office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	dust
- fuel use	
electricity	emissions depend on source of power
gas	
propane	from rolling stock: HC,CO,CO_2,NOx - complete list?
diesel	from rolling stock: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for shop and office O&M, heating and ac
Waterborne	
Process operation	
- process related	wash water: BOD,COD,total suspended solids, oils and grease
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	
Facility operation & maintenance *	from shop and machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: Yardwaste Compost Facility

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	scale, bag openers
natural gas	
propane	front end loaders
gasoline	
diesel	front end loaders, grinders, windrow turners
fuel oil	
Facility operation & maintenance *	elec: office O&M, heating & ac
Water	
Process operation	water addition
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	bags
Facility operation & maintenance *	machine O&M office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	CO_2, NOx, N_2O (others? - list not complete)
- fuel use	
electricity	emissions depend on source of power
gas	
propane	
diesel	from equipment: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for office O&M, heating and ac
Waterborne	
Process operation	
- process related	BOD, phenols, nitrates, ammonia, herbicides, insecticides
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	plastic bags, product with residue (such as insecticides & herbicides)
Facility operation & maintenance *	from machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: Incineration

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	motor
natural gas	supplemental fuel for combustion
propane	rolling stock
gasoline	
diesel	rolling stock
fuel oil	supplemental fuel for combustion
Facility operation & maintenance *	elec: office O&M, heating & ac
Water	
Process operation	washing, use in scrubber and spray dryer
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	chemicals, limestone, catalysts, NH_3
Facility operation & maintenance *	machine O&M office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	NOx,dioxin & furans,HC,particulates,Cd,Pb,Hg,SOx,HCl,CO (extensive list in AP42 Tables 2.1-1 through 2.1.-12)
- fuel use	
electricity	emissions depend on source of power
gas	
propane	from rolling stock: HC,CO,CO_2,NOx - complete list?
diesel	atm releases from combustion will be included in process related releases
fuel oil	atm releases from combustion will be included in process related releases
Facility operation & maintenance *	from electricity for office O&M, heating and ac
Waterborne	
Process operation	
- process related	waste water from scrubber: BOD,COD,total suspended & dissolved solids
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	ash, sludge
- process related MSW	
Facility operation & maintenance *	from machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.

Components of LCA for SWM Process: Landfill

LCA Component	SWM PROCESS:
Consumptions	
Energy	
Process operation	
electricity	scale
natural gas	
propane	
gasoline	
diesel	earth movers, compactors, front end loaders
fuel oil	
Facility operation & maintenance *	elec: office O&M, heating & ac
Water	
Process operation	dust control, for vegetation at closure
Facility operation & maintenance *	
Other (raw materials)	
process-specific material	
Facility operation & maintenance *	machine O&M office supplies (neglect or use a fraction of capital facility)
Releases	
Atmospheric	
Process operation	
- process related (i.e. landfill gases, combustion gases)	CO_2, CH_4, NOx, N_2O, NMOC & VOC (or more specific composition of NMOC & VOC?)
- fuel use	
electricity	emissions depend on source of power
gas	
propane	
diesel	from equipment: HC,NOx,CO,CO_2,SOx,particulates,CH_4,N_2O
fuel oil	
Facility operation & maintenance *	from electricity for office O&M, heating and ac
Waterborne	
Process operation	
- process related	collected storm water runoff, BOD, COD, total dissolved solids, Fe, Pb, Cd, NH_3, VOC - (VOC and leachate composition?)
Facility operation & maintenance *	
Solid waste	
Process operation	
- process related non-MSW	
- process related MSW	plastic bags
Facility operation & maintenance *	from machine O&M: used engine fluids, grease, machine parts office waste

* Facility O&M related components will be treated as fractions of process related (capital) components.
These fractions can be set based on energy consumption rates or cost information.
Components with small fractions (e.g., < 5%) will be neglected.