Appendix E

Description of RTI’s Municipal Solid Waste Decision Support Tool

Through cooperative research between the U.S. Environmental Protection Agency (EPA) and RTI International (RTI), a decision support tool was designed to assist local solid waste management personnel to understand the economics, resource consumption, and emissions associated with alternate solid waste management strategies. A brief description of the Municipal Sold Waste Decision Support Tool (MSW DST) is presented in the following section. 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 main elements of the MSW DST 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, results of the MSW DST 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. Figure 1 illustrates the functional elements that comprise the MSW DST, and 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 system captured by the MSW DST, our objective was to be as flexible as possible. However, given the large diversity of settings in which MSW is generated in the United States, development of a single system definition to address all situations will be unnecessarily complicated. Thus, there are likely to be situations where the tool cannot be applied.

The components of MSW to be included in the life cycle inventory (LCI) are 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 included in the tool is divided into three categories: residential waste, waste generated in multi-family dwellings, and commercial waste. In analyzing a specific solid waste management system, it is possible to consider different compositions for each type of waste. Lists of the components included within each category are presented in Table 1. In addition to individual components, the MSW DST allows for the recovery of combinations of components, such as the recovery of mixed paper for use as either pulp or fuel.

The unit operations included in the MSW DST are waste 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 was collected as part of this development of the MSW DST.

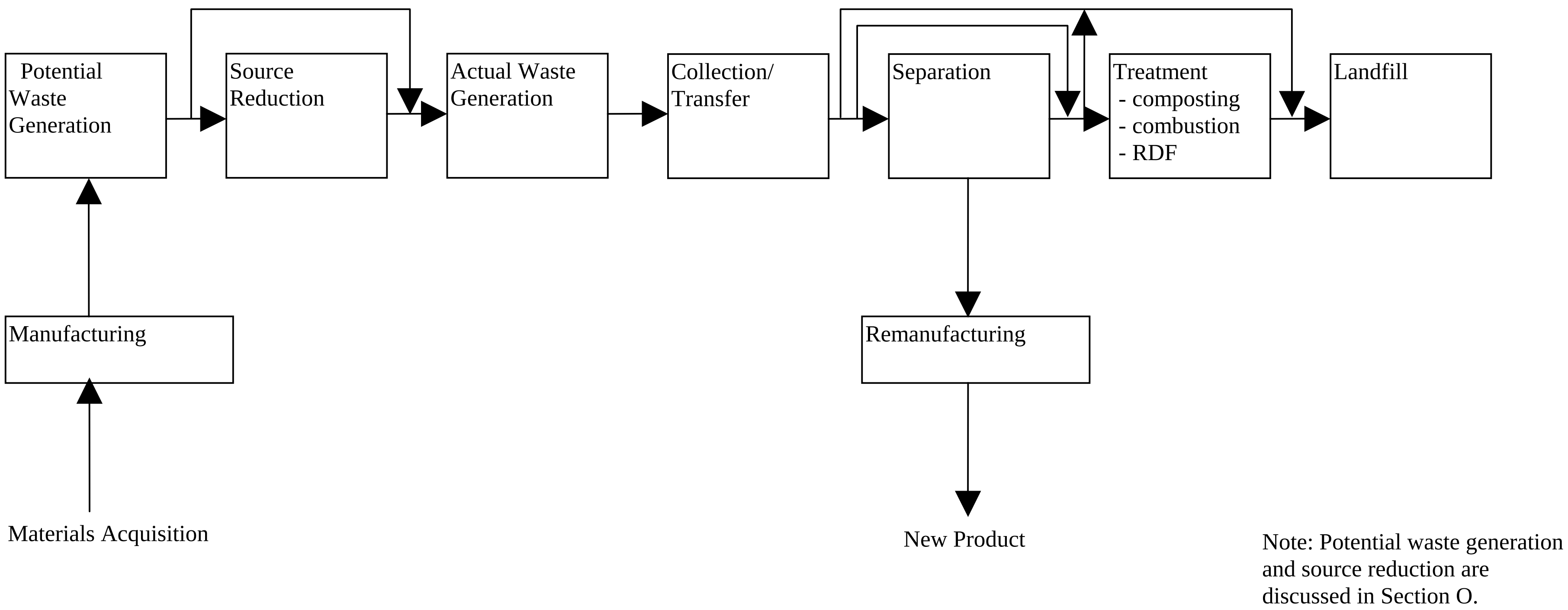
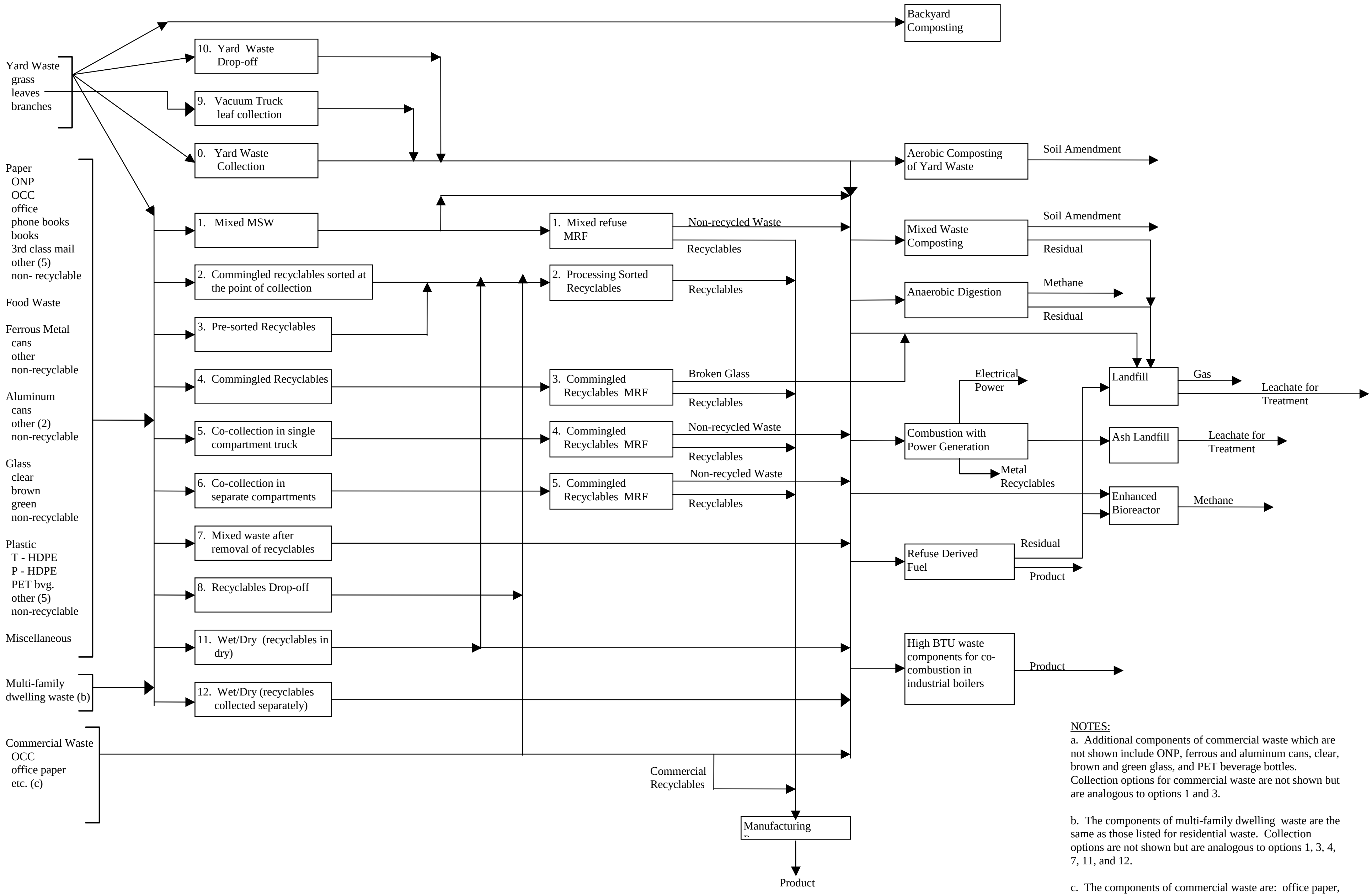


Figure -1 Functional Elements of the Life Cycle Analysis of Municipal Solid Waste Management Alternatives.



North Carolina State University, 1995

Figure 2 - Alternatives for Solid Waste Management

NOTES:

a. Additional components of commercial waste which are not shown include ONP, ferrous and aluminum cans, clear, brown and green glass, and PET beverage bottles. Collection options for commercial waste are not shown but are analogous to options 1 and 3.

b. The components of multi-family dwelling waste are the same as those listed for residential waste. Collection options are not shown but are analogous to options 1, 3, 4, 7, 11, and 12.

c. The components of commercial waste are: office paper, old corrugated containers, Phone Books, Third Class Mail, ferrous cans, aluminum cans, clear glass, brown glass, green glass, PET beverage bottles, newspaper, other recyclable (3), non-recyclables (3).

d. Transfer stations (truck and rail) are not shown due to space limitations. They are included in the system of alternatives.

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 multi-family 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 are included in the tool 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.

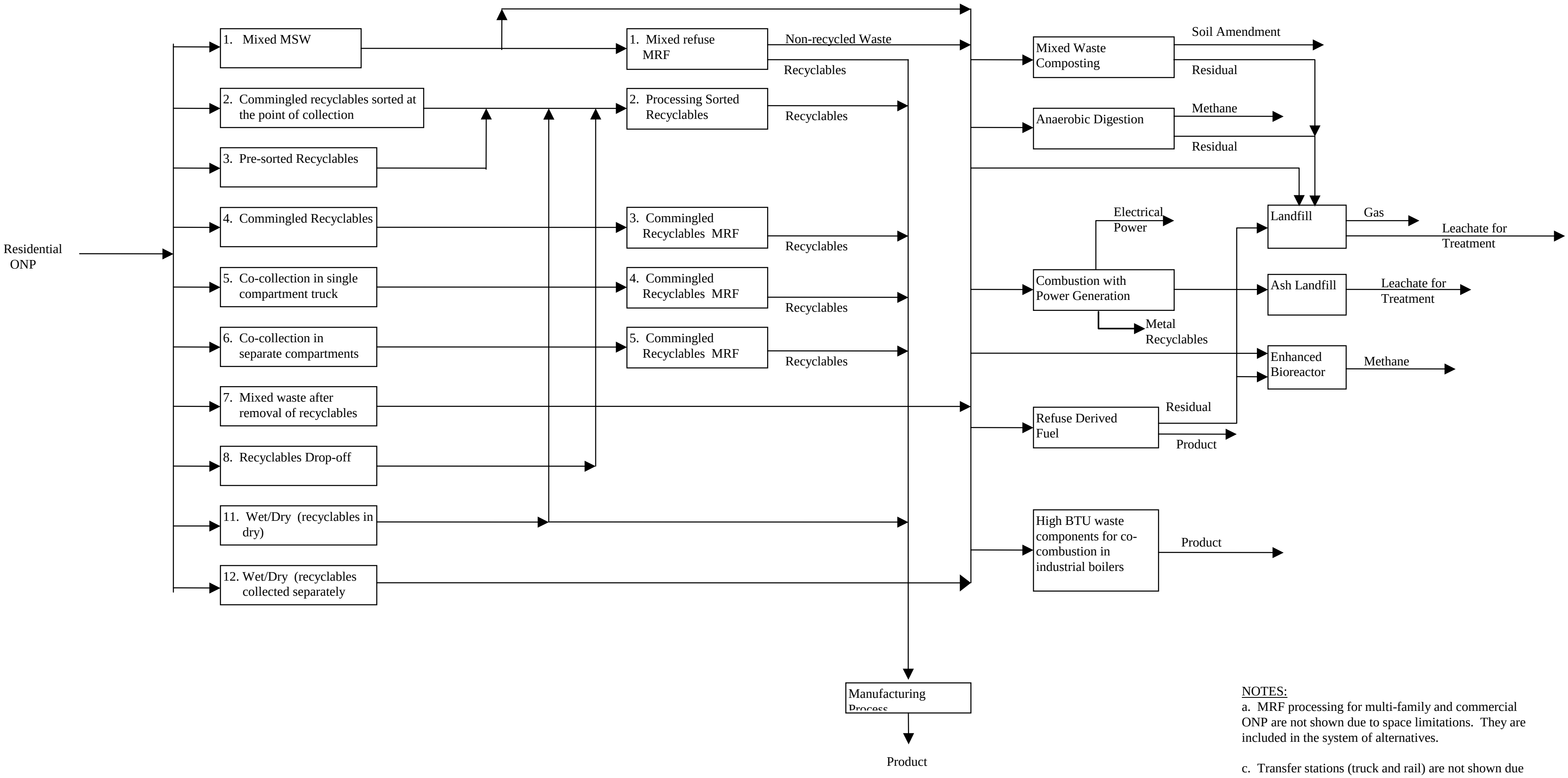
In MSW management strategies where recycling is utilized, recyclables will require processing in a materials recovery facility (MRF). The design of a MRF is dependent upon the manner in which refuse is collected and subsequently delivered to the MRF. Thus, the collection and recycling of MSW are interrelated, and this interrelationship is captured in the system. Eight different MRFs, each capable of recovering a set of recyclables from the applicable collection alternative, are considered in the MSW DST.

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. The combustion process is assumed to have air pollution control devices that meet current regulations. In addition, two types of RDF are 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 is 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 are considered in the MSW DST; 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 are designed in accordance with relevant federal regulations with respect to liner design, leachate, and gas collection. A user is able to specify the liner design to be considered.

Finally, source reduction is considered in the MSW DST. 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 as an easy-to-use calculator.



NOTES:
a. MRF processing for multi-family and commercial ONP are not shown due to space limitations. They are included in the system of alternatives.

c. Transfer stations (truck and rail) are not shown due to space limitations. They are included in the system of alternatives.

Figure 2a - Waste Flow Alternatives for Residential Newsprint

North Carolina State University, 1995

Framework for MSW DST

The MSW DST includes several components, as illustrated in Figure 3. The tool is the primary mechanism through which the data gathered are to be integrated into the analysis of alternate waste management strategies. The underlying component of the overall tool is 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 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 that may be handled in all possible processes.

The next component of the MSW DST is the one that will be used to estimate the cost and life cycle factors corresponding to each waste management unit operation. We refer to this component as a process model. A process model was developed for each functional element presented in Figure 1, including waste generation, composition and characteristics, source reduction, collection, transfer station, separation (MRF), composting, combustion, RDF, and landfill or bioreactor. The objective of each process model is to utilize user input and default design information for the calculation of coefficients that describe the relationship between waste quantity and composition and a specific life cycle parameter, as well as cost. For example, in the collection process model, the user is asked to specify the collection frequency desired for a community and the distance from a collection route to a downstream facility (e.g., MRF, composting, incinerator, RDF plant, landfill). Based on such design information, the process model calculates coefficients for cost and life cycle parameters. This includes the cost for refuse collection in $/ton. In the cases of diesel fuel and particulate emissions, the process model calculates diesel consumption per ton of refuse collected and the pounds of particulate matter released from a collection alternative per ton of refuse collected. The process model then assigns costs, energy consumption, and emissions to the individual components of the waste stream that are identified in Section D. Where the user already has these data, they have the opportunity to input them directly and bypass the design component of a process model. Assignment of emissions to individual waste components is discussed further in Section B.1.

The next major component of the MSW DST is the optimization module. The user may choose to evaluate all feasible SWM strategies using the optimization module or simply use the tool as an accounting tool to simulate an existing SWM system. 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 life cycle inventory (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 is 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 that recycle a minimum of a specified fraction of the waste stream or utilize an existing process.

The MSW DST may also be used as an accounting tool. In this case, the user specifies the existing SWM system, and the tool computes the cost and LCI of the system.

The final component of the MSW DST is the user interface. This interface provides the user with a friendly platform through which to interact with the different components of the tool. It allows the user to view and edit process model data, provide site-specific information and constraints, and run the optimization module. The interface also provides a graphical display of the SWM system under consideration and allows the user to conduct "what-if" type analyses for user-input SWM scenarios.

Assignment of Cost and Emission Factors to Individual Waste Components

An LCI of MSW management alternatives requires that emissions and resource utilization be assigned for each MSW component in each unit operation. A unique feature of the MSW DST is that methodologies were developed to conduct this allocation of cost and life cycle parameters to each MSW component. For example, in the case of landfills, the landfill process model assigns leachate COD to individual components that reflect the relative biodegradability of a component. Thus, no COD is assigned to non-biodegradable components except plastics, which may release plasticizers.

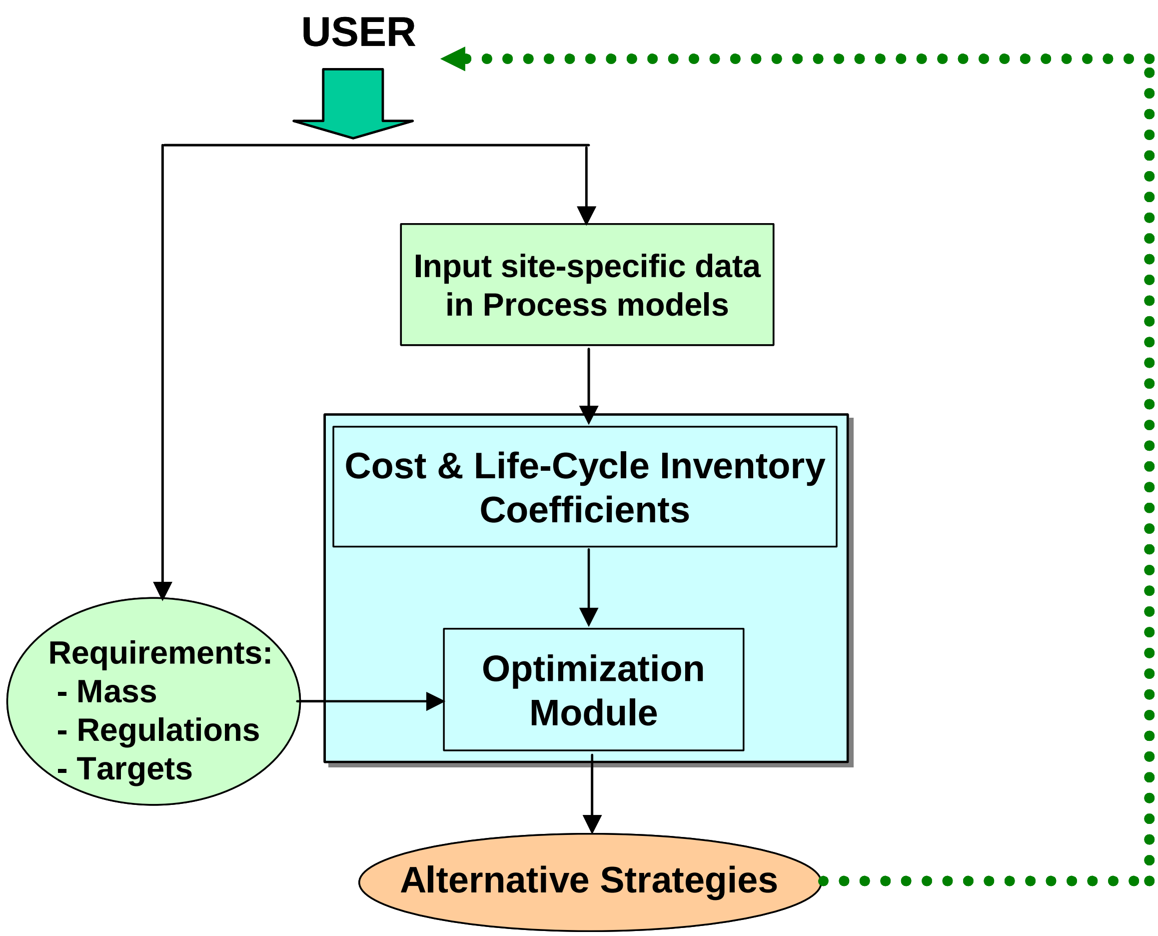


Figure 3 - Relationship between Data and Components of the MSW DST and the User.

Waste Generation

Our definition of MSW is consistent with wastes defined as MSW by EPA (U.S. EPA, 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 is also included in the MSW DST.

For waste generation, the MSW DST user can divide the waste stream into three waste categories: residential, multi-family dwelling, and commercial. The logic for this separation is that different collection and recycling alternatives apply to each category. The user is asked to specify the fraction of the population from which waste is collected, using collection alternatives appropriate for residential and multi-family dwelling waste, as described in Section F. The third category of waste defined here is commercial waste that includes MSW generated in offices, institutions, and industries. 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 multi-family dwelling waste. However, these wastes typically enter the same system that handles residential and multi-family dwelling waste at some point in their management.

The composition of waste from the residential, multi-family, and commercial sectors will likely differ. In developing the LCI, the user has the opportunity to input the waste generation rate and composition for each of the waste generation sectors. Default, national average data are provided for each category.

Waste Composition

The individual components of MSW that are included in the MSW DST are listed in Table 1. The rationale for the selected components is described here. The residential and multi-family dwelling waste streams have been divided into 39 components. The components were selected to include those items that are most commonly recycled, such as 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 zero percent. 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 multi-family dwelling waste streams.

The waste components listed in Table 1 are the same for residential and multi-family 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 and old corrugated containers [OCC]), materials that 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.

Although wastes are listed as individual components in Table 1, there are cases where wastes can be grouped together. The waste flow equations are 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 by inputting the revenue associated with mixed color glass into the MRF process model. The user also has the opportunity to remove from consideration mixed color glass recycling. Similarly, the user has 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 process model requests the generation and composition data described in this and the previous section. This process model also contains default data on physical and chemical characteristics of each waste component, such as density, BTU value, and moisture content. These data are used to calculate characteristics of the waste stream, such as moisture content and BTU value, as a function of waste composition.

In-Home Recyclables Separation

The manner in which residential and multi-family 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

Waste Collection

There are a number of options for the collection of waste generated in the residential, multi-family 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 downstream processing facilities, such as an MRF. The collection options that are included in the MSW DST 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 multi-family 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.

Table 1 - Components of MSW Considered in the MSW DST[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. ferrous cans
6. aluminum cans
7. clear glass
8. brown glass
9. green glass
10. PET beverage bottles
11. newspaper
12-14 other recyclable
15-17 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.

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 that 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 all paper components and the other for non-paper recyclables.

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 an MRF. All paper recyclables are collected in one bag, and non-paper recyclables are collected in a separate bag.

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 an MRF, and the mixed refuse would be delivered to a combustion facility, composting facility, RDF plant, or landfill. Commingled recyclables and mixed waste are collected in a three compartment truck – one compartment for mixed waste, one for paper recyclables, and the third compartment for non-paper recyclables.

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 Multi-family Dwellings

Mixed Refuse Collection

13. Collection of mixed refuse from multi-family 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 two compartment vehicle: one for non-paper recyclables and one for paper recyclables.

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 waste before or after recycling.

Multi-family 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 results. Prior to execution of the MSW DST, the user is asked whether multi-family dwelling waste is collected by the city. If yes, then this waste is analyzed as part of the collection process model. If no, then this waste is collected by a private contractor, and the user will be asked to specify which, if any, components of MSW are recycled. Whether multi-family dwelling waste is collected by the city or the private sector, its life cycle implications and costs is included in the system.

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.

Consider waste 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 an MRF, combustion facility, RDF plant, or composting facility or landfill. Different transfer station designs are required dependent upon the type of waste processed.

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.

In addition to over-road transfer, the MSW DST also includes rail transfer. Mixed refuse and wet/dry collection options include transport to a facility designed to place the refuse in rail cars. 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 conventional or bioreactor landfill.

Material Recovery Facilities

In MSW management strategies where recycling is utilized, recyclables require processing in an MRF. The design of an 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 MSW DST.

The unique design features of each MRF will have an impact on their cost, as well as parameters included in the LCI. Distinct MRFs are considered in the system as described below. The components of MSW that can be recovered in each of the different MRFs are listed in Table 2. Table 2 also lists the components that 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 non-paper recyclables, and paper recyclables, as delivered in a vehicle with one compartment (Collection Option 5). We refer to black bags as the color bag containing refuse and blue bags as the color bag containing commingled recyclables.
5. MRF 5 receives non-paper recyclables and paper recyclables in separate blue bags (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.
6. A front-end MRF to a mixed waste composting facility. This MRF is at the front end of a mixed waste composting facility, i.e., the material recovery operations precede composting operations. The MRF is similar to a mixed waste MRF, but includes provisions for additional sorting to remove contaminants from mixed waste that affect the composting product.

7. A front-end MRF to a refuse-derived fuel (RDF) facility. This MRF is at the front end of an RDF facility, i.e., material recovery operations precede RDF operations. The MRF is similar to a mixed waste MRF, but does not include a magnet and eddy current separator for recovery of ferrous cans and aluminum. These waste components are recovered in the RDF facility.

Table 2 - List of Materials Which Can be Recycled at Each MRF Type

Recyclable Component	MRF 1 Mixed Refuse	MRF 2 Presorted Recyclables	MRF 3 Commingled Recyclables	MRF 4 Co-collection Single Comp.	MRF 5 Co-collection Double Comp.	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	X				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 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 adopted these assumptions for the MSW DST for purposes of developing MRF designs from which to estimate cost and LCI parameters. However, the user has the opportunity to specify automated or manual equipment in certain cases.

The technology associated with MSW sorting in MRFs is evolving. Modeling new MRF technologies is accommodated by allowing the user to bypass the design component of the MRF process model and directly inputting costs and LCI parameters. However, they have many overlapping design features that will remain consistent between MRFs.

Remanufacturing and Energy Recovery

The MSW DST accounts for all resources, energy, and emissions associated with the recycling and reprocessing of a waste component. This section presents the conceptual framework used in the MSW DST 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 an 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 ($E_n = E_r - E_v$.)

Although 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. 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 that 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 percent recycled material; some virgin material is mixed with the recycled fiber.

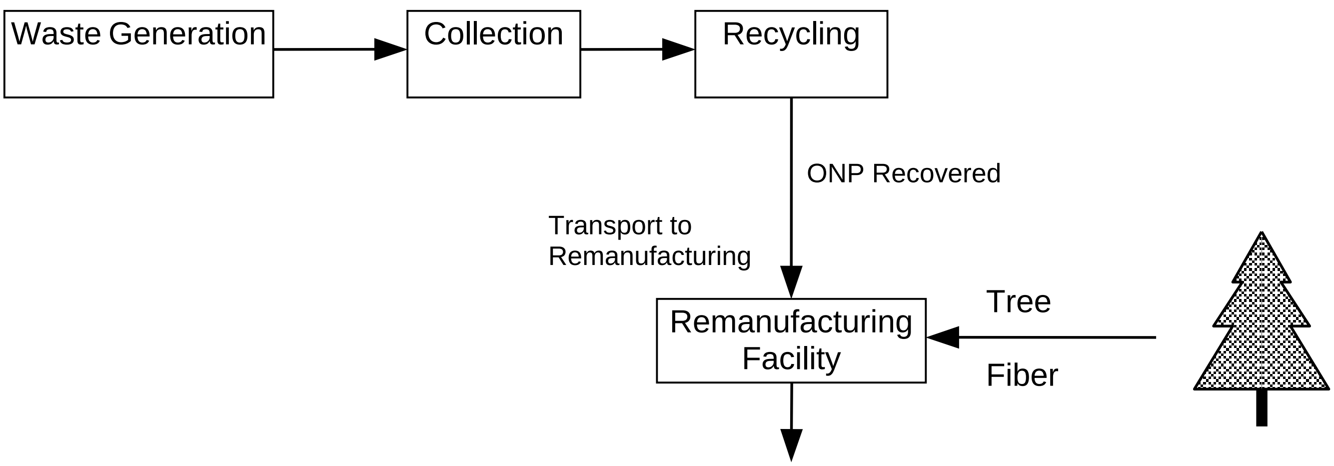
In order to develop the LCI, an assumption must be made with respect to which remanufacturing process is utilized for a recyclable. In the case of ONP, the major use is the production of new newsprint. However, some ONP is used in other applications (e.g., container board, cellulose insulation, animal bedding). For each recyclable, it was necessary to collect data on remanufacturing processes in order to complete the LCI.

In addition to recycled materials, an offset is 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, the MSW DST assumes 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

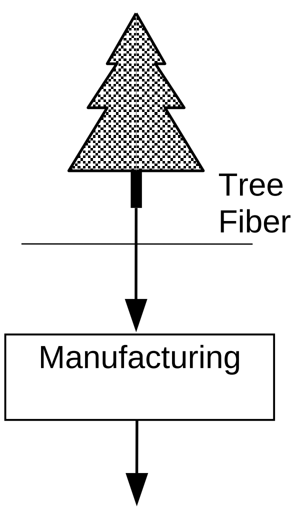
A. Calculation of E_r



1000 Tons Newsprint (40% Recycled, 60% Virgin)

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)

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, the MSW DST considers a centralized composting facility. Backyard composting will be considered in Section O on source reduction.

The MSW DST includes 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 is 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 is 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 is based on mechanical aeration. This facility includes 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 are written so that paper may or may not be removed in the preprocessing step.

Combustion

Combustion represents a treatment alternative in which the volume of MSW requiring burial is significantly reduced. The MSW DST considers 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 were developed on the basis of BTU of input waste per day, as opposed to tpd, which is more standard. In so doing, we were able to link the cost and energy yield of combustion to waste composition. The BTU value of the waste input to a combustion facility was 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 is incorporated into estimates of potential energy recovery. This allows 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 is 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 also includes appropriate air pollution control equipment to meet current regulations.

Refuse Derived Fuel and Co-Combustion

In addition to combustion as discussed in the previous section, two alternatives for recovery of the energy value of MSW are included in the MSW DST: RDF and co-combustion. 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 percent. 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 were identified and, in the future, one RDF plant design could be developed.

The division between an RDF plant and an MRF is not entirely distinct because 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 an MRF. As such, the MSW DST allows for the user to model an up-front MRF to the RDF plant.

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 MSW DST 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 is referred to as RDF, although it will not necessarily include a separate facility.

Landfills

Three types of landfills are included in the MSW DST: one designed for the receipt of mixed waste and operated to minimize water infiltration (conventional landfill), a second designed for the receipt of combustion ash (ash landfill), and a third designed for the receipt of mixed refuse and operated to enhance decomposition (bioreactor landfill). All landfills are designed according to RCRA Subtitle D and Clean Air Act standards. However, through the process model, the user has the opportunity to specify either a more lenient or stricter design with respect to the liner and cover systems.

The first landfill is operated as a dry landfill. The MSW DST includes both gaseous and liquid emissions from the landfill. The user is 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, is used to estimate atmospheric emissions. Estimates are also developed for the amount of leachate requiring treatment. This leachate is assumed to be treated in an off-site treatment facility. Energy and emissions associated with leachate treatment are also considered in the tool.

Municipal waste combustion ash is directed to a landfill designed to accept ash. Even when a community utilizes combustion, there will be some material that should not be routed to a combustion facility and also times when it is out of service. Thus, the design for an ash landfill includes a relatively small section designed for the receipt of mixed refuse. A third landfill is designed with leachate recycle to enhance refuse decomposition, methane production, and leachate treatment. As above, the MSW DST includes both gaseous and liquid emissions. The user is required to specify whether gas is flared or recovered for energy. This information, coupled with data on landfill gas production, is used to estimate atmospheric emissions.

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 is 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 includes a series of multipliers, with unique values for changes in waste mass and each life cycle parameter. These multipliers are set up as individual input parameters in a process model 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 was not part of the development of the MSW DST.

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 that 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 that 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 process model 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 process model would require modification.

A simple example of the source reduction process model is its application to backyard composting. Here, yard waste that is composted by the waste generator does not enter the MSW collection system. A multiplier in the source reduction process model is 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 are accounted for in a dedicated process model. The backyard composting process model 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 process model, the user has to specify the fraction of backyard compost systems where a chipper is utilized.