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Application of Life-Cycle Management to Evaluate Integrated Municipal Solid Waste Management Strategies

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Notice

The information contained in this document has been developed as part of ongoing research funded by the U.S. Environmental Protection Agency under Cooperative Agreement No. CR823052 with the Research Triangle Institute. The results from this study are intended for use in evaluating the relative cost and environmental burdens of integrated municipal solid waste management strategies. The information and results from this study are not intended for use in making comparative assertions about the environmental preferability of alternative materials or products. Use of the methods or data presented in this documentation does not constitute endorsement or recommendation for use. This document is subject to review and modification prior to conclusion of the research. Mention of trade names or commercial products does not constitute endorsement or recommendation.

Abstract

Communities throughout the United States are struggling to develop efficient and cost-effective plans for managing their municipal solid waste (MSW). Today's MSW management systems often are complex and highly integrated systems that might include separate recyclables collection, recovery, composting, combustion, and disposal. Communities now must make complex decisions requiring an analysis of both cost and environmental burdens for these integrated systems. Despite the movement toward integrated systems, many of the existing techniques for analyzing the environmental and economic performance of MSW management systems focuses on the individual operations in isolation rather than as part of an integrated system.

To properly account for all of the environmental effects associated with integrated MSW management systems, planners must have tools that allow them to examine factors outside of the traditional MSW management framework of activities occurring from the point of waste collection to final disposal. This requires an examination of the "upstream" changes in resource use and pollutant generation from raw materials acquisition and manufacturing operations associated with recyclables recovery and transport. These upstream changes can be captured by taking a life cycle approach to MSW management.

The U.S. Environmental Protection Agency's (EPA's) Office of Research and Development, Air Pollution Prevention and Control Division, with cofunding from the U.S. Department of Energy, is working to apply life cycle concepts and tools to the analysis of MSW management systems in the United States. The research team for this project includes life cycle assessment (LCA) and solid waste management experts from Research Triangle Institute, North Carolina State University, the University of Wisconsin-Madison, Franklin Associates, and Roy F. Weston. In addition, groups of internal advisors and external stakeholders are active participants in this unique forum. The information and tools resulting from this research will help solid waste practitioners identify integrated MSW management strategies that minimize both cost and environmental burdens.

This document has been prepared to provide the reader with a general overview of the research goals and objectives and summary of major research components and outputs. More detailed information for specific research components is provided in supporting project documentation.

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Abbreviations and Symbols

BTU	British Thermal Unit
U.S. DOE	United States Department of Energy
DQG	Data Quality Goal
DQI	Data Quality Indicator
DST	Decision Support Tool
EIA	Energy Information Administration
FAL	Franklin Associates, Limited
GUI	Graphical User Interface
KWH	Kilowatt Hour
LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
NCSU	North Carolina State University
NERC	North American Electric Reliability Council
O&M	Operation and Maintenance
POTW	Publicly Owned Treatment Works
RCRA	Resource Conservation and Recovery Act
RDF	Refuse-Derived Fuel
RTI	Research Triangle Institute
SETAC	Society for Environmental Toxicology and Chemistry
TPD	Tons Per Day
U.S. EPA	United States Environmental Protection Agency
UW	University of Wisconsin - Madison
WTE	Waste-To-Energy Combustion

Key Terms and Definitions

Allocation: Technique for partitioning multiple inputs and outputs from a system.

Cost: Amount actually incurred for the provision of a product or service. Cost can include internal cost accrued by an organization, external costs accrued by society.

Data Quality Indicator: Measure which characterizes an attribute(s) of data or data sets.

Function: Performance characteristic of a system.

Functional Unit: Measure of performance of the main functional output of a system.

Integrated Waste Management: Interlinked stages of a system to collect, process, treat, and dispose of waste.

Life Cycle: Consecutive and interlinked stages of a system that extend from raw materials acquisition or generation of natural resources to final disposal.

Life Cycle Assessment: Compilation and evaluation, according to a systematic set of procedures, of the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the function of a product throughout its life cycle.

Life Cycle Impact Assessment: Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of environmental impacts based on a life cycle inventory analysis.

Life Cycle Inventory Analysis: Phase of life cycle assessment involving compilation, and quantification of inputs and outputs for a given product system throughout its life cycle.

Municipal Solid Waste: Waste generated in the residential, multifamily, and commercial sectors. Includes durable goods, nondurable goods, containers and packaging, food waste, and yard trimmings. Also includes ash from waste combustion. Excludes industrial process waste, sludge, construction and demolition waste, pathological waste, agricultural waste, mining waste and hazardous waste.

Price: Amount actually charged/paid for a product or service.

Key Terms and Definitions (Cont.)

Process Model: Mathematical representation of a unit process to calculate cost and environmental burdens as a function of the quantity and composition of the waste or material processed.

Raw Material: Primary or secondary recovered or recycled material that is used in a system to produce a product.

System: Collection of unit processes which, when acting together, perform some defined function.

Unit Process: Component of the system being studied that is a collection of operations which transforms inputs into outputs, such as manufacturing, waste collection, materials recovery, etc.

Executive Summary

Over $40 billion dollars are spent annually in the United States (U.S.) on MSW management. In 1999, more than 23 million tons of municipal solid waste (MSW) were generated in the United States by the public, businesses, and institutions. Frequently decisions are made about how to collect, transport, recycle/compost, and dispose of MSW without an adequate understanding of the economic and environmental implications. Decisions on how to best manage MSW can be contentious, expensive and impact ecosystems, and air and water sheds.

MSW consists of paper, plastic, glass, yard waste, food waste, and metals. Of the 23 million tons of MSW being managed in the U.S., 57% is landfilled, 21% is recycled, 7% composted, and 15% is combusted with energy recovery (EPA, 2002). There have been major changes in MSW management in the last few decades toward more integrated approaches and use of more advanced technology. How to best manage individual components may vary. Needs for rural regions may be different than those for large urban regions. Differences in hauling distances, processing, and avoided impacts must be considered throughout the life-cycle in order to find solutions that are more environmentally and economically efficient

In developing strategies for integrated MSW management, planners have a wide variety of available options to evaluate, from source reduction programs to different processes for collection, separation, treatment, and disposal. To examine the complex interrelationships of mass flows and associated costs, resource consumption, and environmental releases of integrated MSW management strategies, and identify optimal management solutions, it is necessary to quantify the costs and environmental aspects associated with each unit process included in the strategy (see McDougall et al., 2001).

When evaluating the environmental aspects of a particular MSW management strategy, planners should consider those burdens that occur outside of the traditional framework of activities from the point of waste collection to final disposal. For example, when waste management strategies focus on recycling options, it is important to consider the net environmental performance of these options including offsets in primary materials and energy production sectors. Similarly, when energy is recovered through combustion or landfills, the energy recovered will displace the production of fuels and generation of electricity from the utility sector. As illustrated in Figure ES-1, these types of tradeoffs may be captured by taking a life cycle approach.

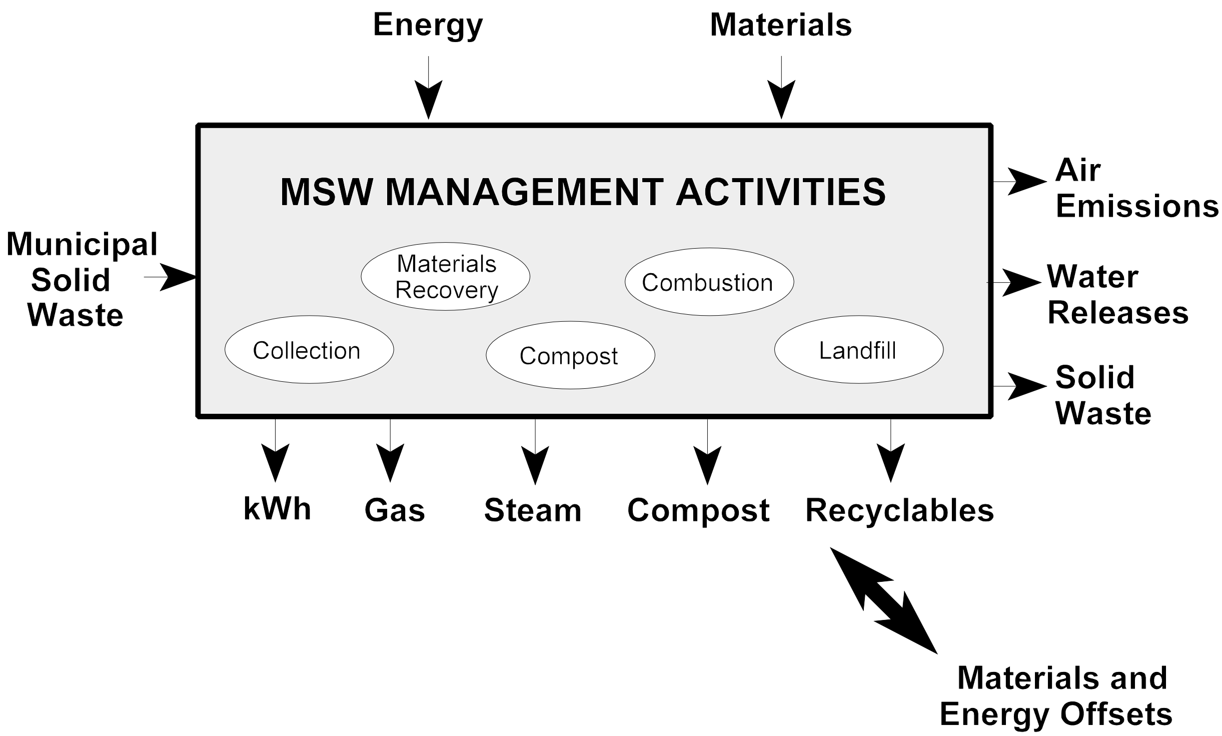


Figure ES-1. Functional Elements of the Municipal Solid Waste Life Cycle

To address and examine the interrelationship and tradeoffs of integrated MSW management strategies, RTI International and the U.S. EPA's Office of Research and Development, Air Pollution Prevention and Control Division, applied life cycle management concepts and tools to evaluate integrated MSW management systems in the U.S. RTI's research team for this effort included life cycle assessment (LCA) and solid waste management experts from North Carolina State University, the University of Wisconsin-Madison, Franklin Associates, and Roy F. Weston. In addition, project stakeholders from Federal, state, and local governments, industry, academia, and environmental advocacy organizations were very active participants in this effort.

This research effort provides information and tools that will enable local governments and solid waste planners to examine cost and life-cycle environmental aspects for a large number of possible MSW management operations for 42 distinct MSW components. The primary outputs of this research include the following:

- **Life Cycle Inventory Database:** Data for individual waste management operations, materials production, and electrical energy generation are compiled in a publicly available computer database. The database allows users to search for data specific to unit processes, structures, equipment, or various life cycle inventory (LCI) parameters.

- **Municipal Solid Waste Decision Support Tool:** A computer-based decision support tool (MSW DST) to allow solid waste planners to enter site-specific data (or rely on supplied default data) for their community's waste quantity, composition, and other site-specific information to make screening level evaluations of alternative integrated MSW management strategies.

To ensure the applicability and usefulness of the research products to local governments and other solid waste planners, an inclusive review process for all research activities and documentation was employed. The review process included three different levels:

1. Internal project team and U.S. EPA and U.S. Department of Energy advisors.

2. Project stakeholders from U.S. government, industry, academia, and environmental organizations. A current listing of project stakeholders is included in Attachment 1 to this report.

3. External project peer reviews. Three separate peer reviewers were conducted and have included the following individuals:

    - David Allen, University of Texas at Austin
    - Robert Anex, University of Oklahoma
    - Kevin Brady, Demeter Environmental Inc.
    - Jürgen Giegrich, Ifeu- Institute
    - Allen Hershkowitz, Natural Resources Defense Council, Inc.
    - Gregory Keoleian, University of Michigan
    - Mitchell Kessler, TIA Solid Waste Management Consultants, Inc.
    - Jay Lund, University of California-Davis
    - Ruksana Mirza, Formerly with Proctor and Redfern, Ltd.
    - Debra Reinhart, University of Central Florida
    - Lynn Scarlett, Reason Foundation
    - Aarne Vesilind, Duke University and Bucknell University
    - Peter White, Proctor & Gamble
    - Steven Young, Five Winds International

This high level of involvement by project stakeholders and peer review committee members contributed greatly to the success of this project.

GOAL AND SCOPE DEFINITION

The overall goal defined for this study is to develop information and tools to evaluate the relative cost and life-cycle environmental aspects of integrated MSW management strategies. For instance, how do the cost and environmental aspects of a MSW management system change if a specific material (e.g., glass, metal, paper, plastic) is added to or removed from a community's recycling program? And, what are the tradeoffs in cost and environmental aspects if paper is recycled versus combusted or landfilled with energy recovery? Until this research effort, information was unavailable or incomplete for adequately evaluating alternative MSW management options to answer these types of questions.

The primary audience for this study and its outputs is local governments and solid waste planners. However, we anticipate that the information and tools developed through this study will also be of value to Federal agencies, environmental and solid waste consultants, industry, LCA practitioners, and environmental advocacy organizations.

The function of the system under study is to manage MSW. Therefore, the functional unit for this study is defined as the management of a given quantity and composition MSW from a defined region. All activities required to manage the MSW from the time it is sent out for collection to its ultimate disposition, whether that be in a landfill, compost that is applied to the land, energy that is recovered from combustion, or materials that are recovered and reprocessed into new products.

The individual components that comprise MSW include those defined by the U.S. EPA's Office of Solid Waste (U.S. EPA, 1997a). 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. The MSW components are listed in Table ES-1. Ash that is generated from the combustion of MSW is also included in the system, but is not included as part of EPA's definition of MSW. However, because waste combustion is included as a management option, the disposal of combustion ash must also be considered.

As shown in Table ES-1, the MSW stream is divided into three different waste generation sectors: residential, multifamily, and commercial. The rationale for this separation is that different waste generation rates, composition, collection and recycling alternatives, etc. may apply to different generation sectors.

The major unit processes included in the system are:

Waste Management:

- Collection
- Transfer Station
- Materials Recovery Facility (MRF)
- Combustion (with or without energy recovery)
- Composting (yard and mixed waste)
- Refuse-Derived Fuel (RDF) and Processed Refuse Fuel (PRF)
- Landfill (traditional, bioreactor,, and ash)

Other Operations:

- Electrical Energy
- Inter-Unit Process Transportation
- Materials Production (primary and secondary production processes)

For each of these unit processes, models were developed that utilize generic design and operating parameters in conjunction with resource use and emission factors to estimate cost and LCI parameters, based on the quantity and composition of incoming material. Because the composition of MSW can greatly affect the cost and environmental results for different management options, these “process models” also contain methodologies for allocating LCI and cost parameters to individual MSW components. The boundaries were made as consistent as possible across all process models.

The cost and main LCI data categories included in the study are:

Cost Categories:

- Capital cost
- Operating cost

LCI Categories:

- Energy consumption
- Air emissions
- Waterborne releases
- Solid waste

To compare alternative MSW management options, we used only parameters that are comparable across all management operations. For example, although data for dioxin/furan emissions for waste combustors were readily available, comparable data do not exist for MRF, composting, and landfill operations. Thus, we cannot make comparative assertions based on dioxin/furan emissions. There are 32 different cost and LCI parameters for which consistent data was available and these 32 parameters are presented in the MSW DST results.

Of the 32 parameters for which comparable data were available, 9 parameters were selected as initial parameters for optimization. These 9 parameters were selected based on discussion with project advisors and stakeholders and include:

- Cost
- Carbon monoxide
- Carbon dioxide - fossil (resulting from the combustion of fossil fuels)
- Carbon dioxide - biomass (resulting from the biodegradation or combustion of organic material)
- Electricity consumption
- Nitrogen oxides

- Particulate matter
- Sulfur dioxide

The remaining 23 air and water parameters that are tracked and reported in the MSW DST can be made optimizable in the future if desired. In addition, as data becomes available to enable comparisons of other parameters across unit processes, future versions of the MSW DST can be updated to include an expanded list of parameters.

SYSTEM BOUNDARIES

The system has largely been defined through the description of the functional elements and unit processes and the manner in which each will be treated. These elements and processes are outlined in detail in a system description document and summarized in the following section.

Boundaries for LCI Analysis

All activities that have a bearing on the management of MSW from collection through transportation, recycling, treatment, and disposal are included in the LCI. It is assumed that MSW enters the management system when it is set out or delivered to a collection site, whether it be a residential curbside, apartment collection site, or rural drop-off site. Thus, environmental aspects associated with the production of garbage bags and cans and recycling bins are *not* included in the LCI. Similarly, the transport of waste by residents to a collection point is *not* included in the LCI.

The functional elements of MSW management include numerous pieces of capital equipment from refuse collection vehicles to balers to major equipment at paper mills. Environmental aspects associated with operation of equipment and facilities are included in the LCI. For example, energy (fuel) that will be consumed during the operation of refuse collection vehicles is included in the LCI. In addition, electricity consumed for operation of the office through which the vehicle routes are developed and the collection workers are supervised is also included in the LCI. However, environmental aspects associated with the fabrication of capital equipment as well as the construction of facilities are *not* included in the LCI.

Where a material is recycled, the resources, energy, and environmental aspects associated with the manufacture of a new product are calculated, assuming a closed-loop recycling process, and included in the LCI results. These parameters are then compared against those from manufacturing the product using primary resources to estimate the net environmental savings (or addition burden). This procedure also applies to energy recovery from other unit processes including combustion, RDF, landfills.

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 is considered. For example, if biological oxidation demand (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, during its burial (e.g., bulldozer) and after its burial (e.g., gas collection and leachate treatment systems) in the landfill. Also, if compost is applied to the land, volatile and leachate emissions are considered.

Boundaries for Cost Analysis

The system boundaries for cost analysis differ from that of the LCI analysis and are designed to provide a relative comparison of cost among alternative MSW management options as incurred by the public sector. Capital and operating costs are included for waste collection, transportation, transfer stations, MRFs, composting, combustion, RDF, and landfills. In addition, costs are allocated to individual MSW components. For example, the result of the cost analysis can illustrate the additional capital and operating costs to a MRF for processing and storing glass.

Where recyclables are shipped from a MRF, the cost analysis ends where the public sector receives revenue (or incurs a cost) in exchange for the recyclables. The same procedure applies to the sale of RDF, landfill gas, or electricity from combustion. In addition, where waste is produced as part of a waste management facility, the cost of waste disposal or treatment is included in the cost analysis of that facility. For example, we include the cost of leachate treatment in our cost analysis of landfills. The cost analysis also includes the cost of training, educational, or other materials associated with source reduction or other aspects of MSW management.

The boundaries for the cost analysis include the cost of waste management that would be experienced by a local government such as the costs associated with collection, transport, recycling, treatment, and disposal. These costs are intended to provide a relative ranking of the different alternatives as part of a screening tool to narrow the range of options associated with integrated waste management.

There is no distinction between public and private sector costs. All waste management operations are assumed to occur in the public sector and therefore costs are calculated as though they are accruing to the public sector. The cost analysis is intended to reflect the full costs associated with waste management alternatives based on U.S. EPA guidance from *Full Cost Accounting for Municipal Solid Waste Management: A Handbook* (U.S. EPA, 1997b).

The boundaries for cost analysis do not include the costs associated with the manufacturing processes for different materials (i.e., aluminum, glass, paper, plastic, steel) or fuels production and electricity generation. These costs occur in the manufacturing and utility sectors and do not accrue to municipal or county governments. However, any revenues that are realized by the government body from the sale of recovered materials or fuels or electricity are included in the cost analysis.

TECHNICAL APPROACH FOR UNIT PROCESSES

As discussed in the previous section, the methodologies for LCI and cost analysis for each unit process are implemented in process models. Process models include sets of equations that utilize the default (or user input) facility design information to calculate all LCI and cost parameters based on the quantity and composition of waste entering each MSW management unit process. A summary of key assumptions and issues, and the status for each process model are provided in Table ES-2.

The process models are linked in the MSW DST through a set of mass flow equations. The LCI and cost coefficients resulting from process models are used in the MSW DST to calculate the total system cost and environmental aspects for MSW management strategies. Summaries of the design and operating parameters and methods for LCI and cost analysis for each process model are published individually.

PRIMARY RESEARCH PRODUCTS

Through this project we are developing information and tools that enable solid waste planners to evaluate the relative cost and environmental aspects of integrated MSW management strategies. The project is providing this information and tools through three main research products: LCI database, MSW DST, and community case studies (see Thorneloe et al., 1998 for further information). Each of these products is summarized in the following section.

LCI Database

The life cycle database is being developed to provide LCI related information for all unit processes included in the system (see Thorneloe et al., 1998 for a summary of data being collected). The approach used to build this database is as follows. First, data from publicly available and private MSW and LCA studies, and other relevant sources, were collected and reviewed against the data quality goals and data quality indicators established for this project. The data quality assessment is based on upon, to the extent possible, guidelines from the International Standards Organization (ISO) 14040 (ISO, 1998). These existing data are being compiled into a database management system using commonly available software (Microsoft Access™).

The database management system was established to enable users to view environmental data for different aspects of waste management assessment. The main menu of the database is shown in Figure ES-2. Users can view LCI type data for energy production, equipment used in various waste management operations, general MSW properties (e.g., heating value), remanufacturing of recycled materials into new products, waste management data derived from the MSW DST and raw data collected from waste management operations.

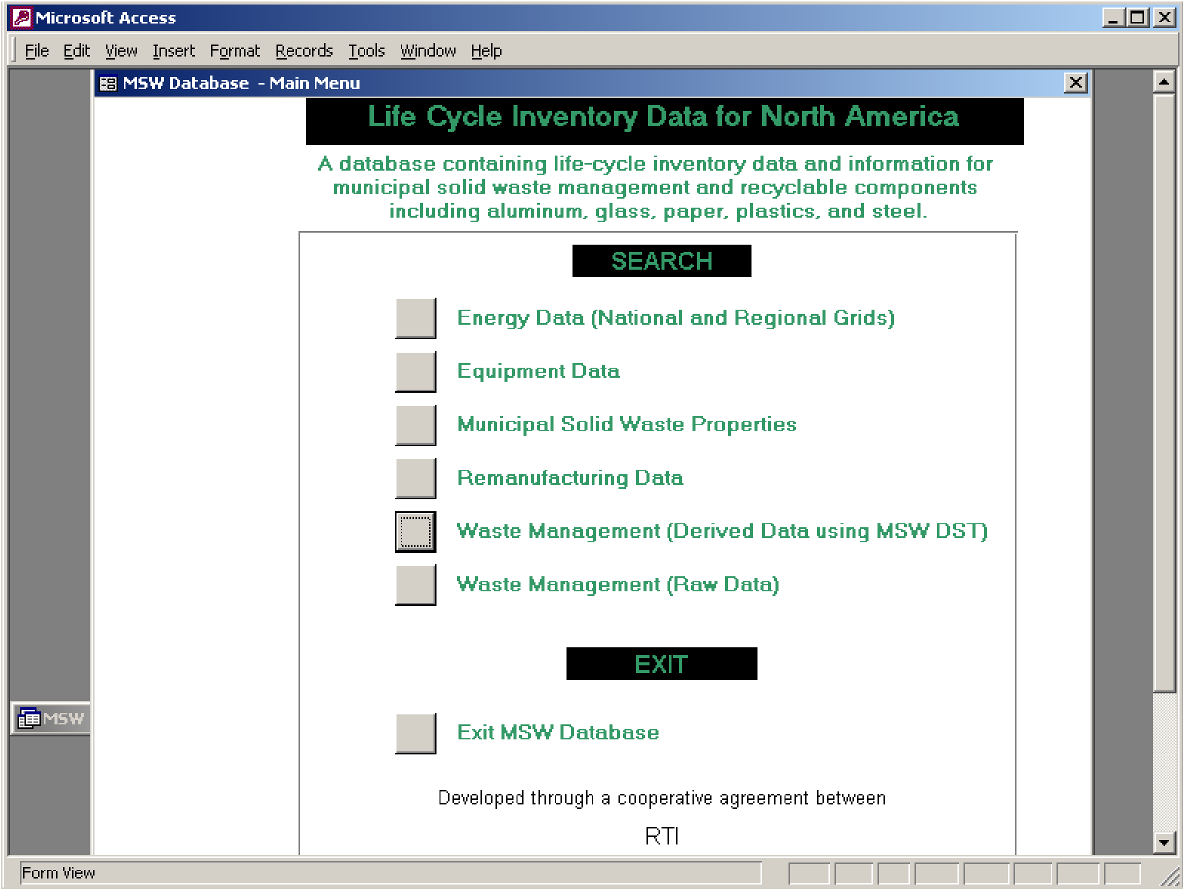


Figure ES-2. Main Menu of the LCI Database.

Data residing in the database is also used in the MSW DST, but database and MSW DST are *not* linked. Rather, the database is available as a stand-alone application that may be used as input data to other studies or models. If solid waste practitioners possess higher quality or more site-specific data than those provided in the database, users may add data to the database.

MSW DST

The MSW DST provides a user-friendly interface that allows users to evaluate the cost and environmental burdens of existing solid waste management systems, entirely new systems, or some combination of both based on user-specified data on MSW generation, constraints, etc. The processes that can be modeled include waste generation, collection, transfer, separation (MRF and drop-off facilities), composting, combustion and RDF production, and disposal in a landfill. Existing facilities and/or equipment can be incorporated as model constraints to ensure that previous capital expenditures are not negated by the model solution.

As illustrated in Figure ES-3, the decision support tool consists of several components including process models, waste flow equations, an optimization module, and a graphic user interface. The process models consist of a set of spreadsheets developed in Microsoft Excel. These spreadsheets use a combination of default and user supplied data to calculate the cost and life cycle coefficients on a per unit mass (ton) basis for each of the MSW components being modeled (see Table 1) for each solid waste management unit process (collection, transfer, etc.). For example, in the electric energy process model, the user may specify the fuel mix used to generate electricity in the geographic region of interest, or select a default grid. Based on this information and the emissions associated with generating electricity from each fuel type, the model calculates coefficients for emissions related to the use of 1 kWh of electricity. These emissions are then assigned to waste stream components for each facility that uses electricity and through which the mass flows. For example, MRFs use electricity for conveyors. The emissions associated with electricity generation would be assigned to the mass that flowed through that facility. The user will also have the ability to override the default data if more site-specific data are available.

The optimization module is implemented using a commercial linear programming solver called CPLEX. The model is governed by mass flow equations that are based on the quantity and composition of waste entering each unit process, and that intricately link the different unit processes in the waste management system (i.e., collection, transfer, recycling, treatment, and disposal options). The mass flow model constraints preclude impossible or nonsensical model solutions. For example, the mass flow constraints will exclude the possibility of removing aluminum from the waste stream via a mixed waste MRF and then sending the aluminum to a landfill. The user can identify the objective as minimizing total cost or LCI parameter (e.g., energy consumption). The optimization module uses linear programming techniques to determine the optimum solution consistent with the user-specified objective and mass flow and user-specified constraints. Examples of user-specified constraints might include the use of existing equipment/facilities and a minimum recycling percentage requirement.

The graphic user interface consists of a Microsoft Visual Basic routine that integrates the different components of the tool together to allow easy user manipulation of the spreadsheet models and the optimization module. It allows additional user constraints to be specified and provides a graphical representation of the solid waste management alternatives resulting from the optimization. Results
presented for the identified “optimal” solution include the annual per ton dollar cost, energy consumption, and pounds of various air, water, and solid waste releases. In addition, results can be viewed at the system, unit process, or MSW component levels.

Once the optimal solution is identified, the user is encouraged to use the modeling to generate alternatives (MGA) feature of the MSW DST. Using this feature, the user can start with the optimal solution and then identify alternate solutions that are only marginally suboptimal and are different to the maximum extent possible.

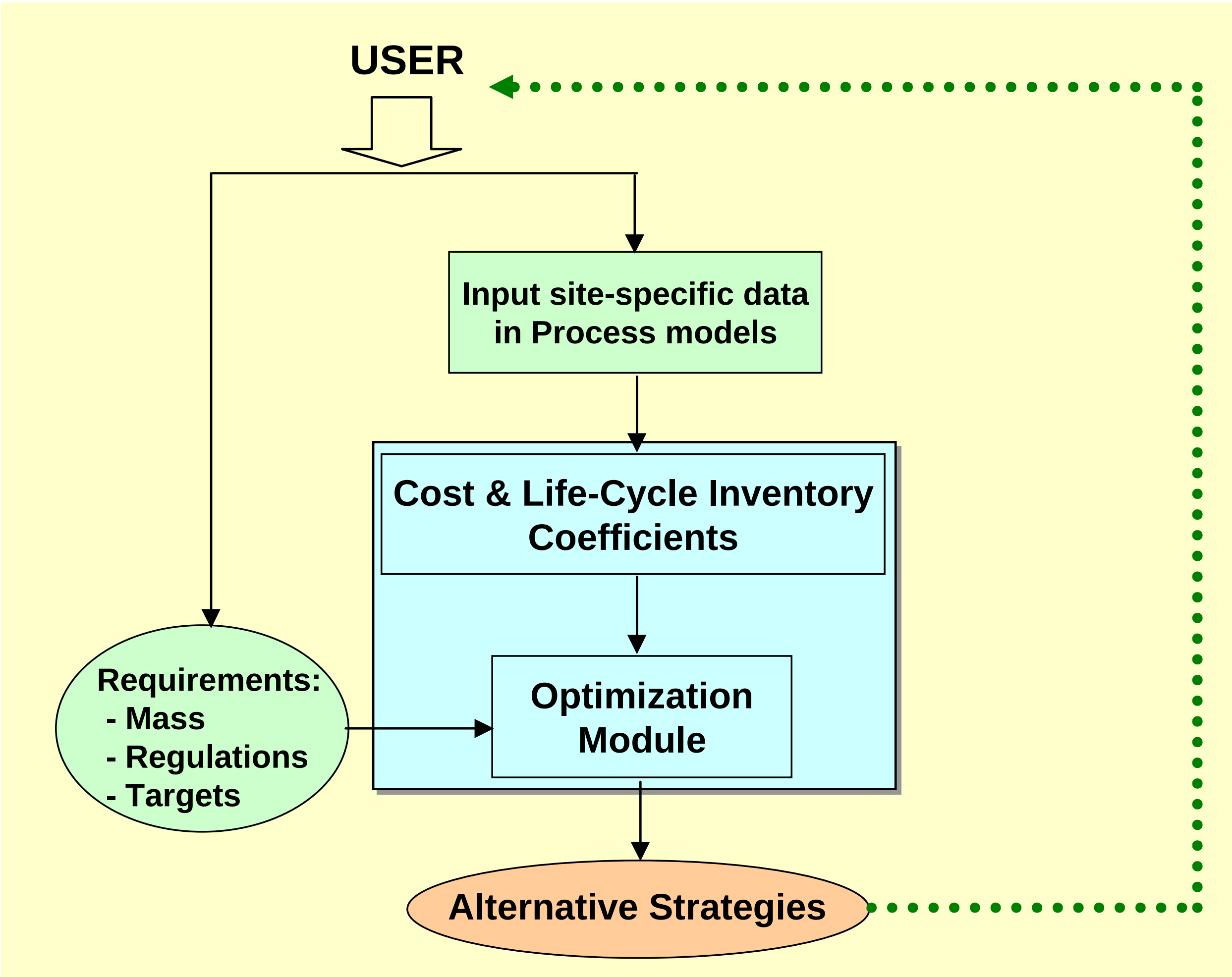


Figure ES-3. Components of the MSW DST

For example, the user may look at the least cost solution and have some concern about its political viability. Using the MGA feature, the user could then ask the MSW DST to search for solutions that are no more than an allowable increase in cost, for example 10% more expensive than the least cost solution. The MSW DST will then generate a solution that is different from the "optimal" solution but still attractive with respect to cost.

Community Case Studies

The MSW DST is being used in case study applications with a variety of local communities and States. These studies are providing cost and environmental information about alternative waste management strategies to these assist these groups in developing waste management plans and policies. The case studies also are enabling the research team refine the methods and data used in the MSW DST as well as the user interface to the MSW DST. Some examples of the issues being analyzed with the MSW DST for these different groups and studies are as follows:

- Lucas County, Ohio was developing a 15 year plan for their solid waste management system. They felt their current waste operations are not cost effective and ignore pollution and life-cycle implications. The analyses and results of this case study helped them in the development of integrated, cost-effective, and environmentally preferable plans and targeting opportunities for improving recycling.

- Anderson County, South Carolina evaluated the cost and environmental implications of implementing a residential curbside recycling program for the more densely populated areas of the county as well as setting up a yard waste composting program. The results of the study assisted the County in determining the most cost effective strategies for implementing the programs.

- The U.S Navy in the Pacific Northwest used the MSW DST to develop and implement an improved solid waste management plan to reduce cost, increase recycling rates, and ensure that environmental goals were being met. With the closing of smaller local landfills and with the transporting of waste by rail to a larger regional site, the Navy evaluated subsequent changes in cost, energy consumption, and environmental releases. In order to identify more cost-effective and environmentally preferable solutions to a more regional approach for integrated waste management, the Navy also evaluated options that would combine waste from nearby communities.

- The State of Wisconsin is investigating the environmental benefits of State-wide recycling programs. We are using the MSW DST to analyzing how changes in levels of State mandated recycling goals can potentially affect environmental burdens. We are also analyzing how landfill tip fee surcharges can affect the role of recycling. The results of this study will assist the State in deciding what solid waste strategies should be used in the future to meet environmental improvement goals.

- The Integrated Waste Services Association, in conjunction with the Municipal Waste Management Association, used the MSW DST tool to evaluate the effect of improvements in waste management technologies on greenhouse gas emissions in the United States during the past 25 years. Results indicate that although the amount of MSW has doubled, emissions have decreased due to adoption of integrated waste management programs and recycling, better control of landfill gas, and use of energy resulting from waste to energy and landfill gas to energy.

Chapter 1
Introduction

Most applications of life-cycle assessment (LCA) have generally focused on the evaluation of the environmental performance for a defined product system, while holding constant or altogether neglecting the mode of solid waste management. White et al. (1995) describe the application of LCA whereby the product system is held constant and the evaluation is done on the performance of alternatives for solid waste disposal. This concept has been implemented in programs throughout the world that are applying LCA concepts and methods to the evaluation of integrated municipal solid waste (MSW) management strategies. In evaluating such strategies, planners have a wide variety of available processes for waste collection, separation, treatment, and disposal to evaluate. Combining these processes in integrated systems forms complex interrelationships of mass flows with associated energy and resource consumption and environmental releases. Examining these interrelationships, and identifying optimal management solutions, can be accomplished by taking a life-cycle approach, as illustrated in Figure 1-1. Unlike traditional product LCAs which begin with raw materials extraction, our system begins with MSW generation and considers the inputs and effects to all life cycle stages resulting from the management of MSW.

The RTI International and the U.S. Environmental Protection Agency's (U.S. EPA's) Office of Research and Development applied LCA concepts and tools to evaluate the cost and environmental performance of integrated MSW management systems in the U.S. RTI's research team for this effort included LCA and solid waste management experts from North Carolina State University, the University of Wisconsin-Madison, Franklin Associates, and Roy F. Weston.

1.1 WHY TAKE A LIFE CYCLE APPROACH TO MSW MANAGEMENT?

A life-cycle perspective encourages waste planners to consider the environmental aspects of the entire system including activities that occur outside of the traditional framework of activities from the point of waste collection to final disposal. For example, when evaluating options for recycling, it is important to consider the net environmental benefits (or additional burdens) including any potential displacement of raw materials or energy. Similarly, when electricity is recovered through the combustion of waste or landfill gas, the production of fuels and generation of electricity from the utility sector is displaced.

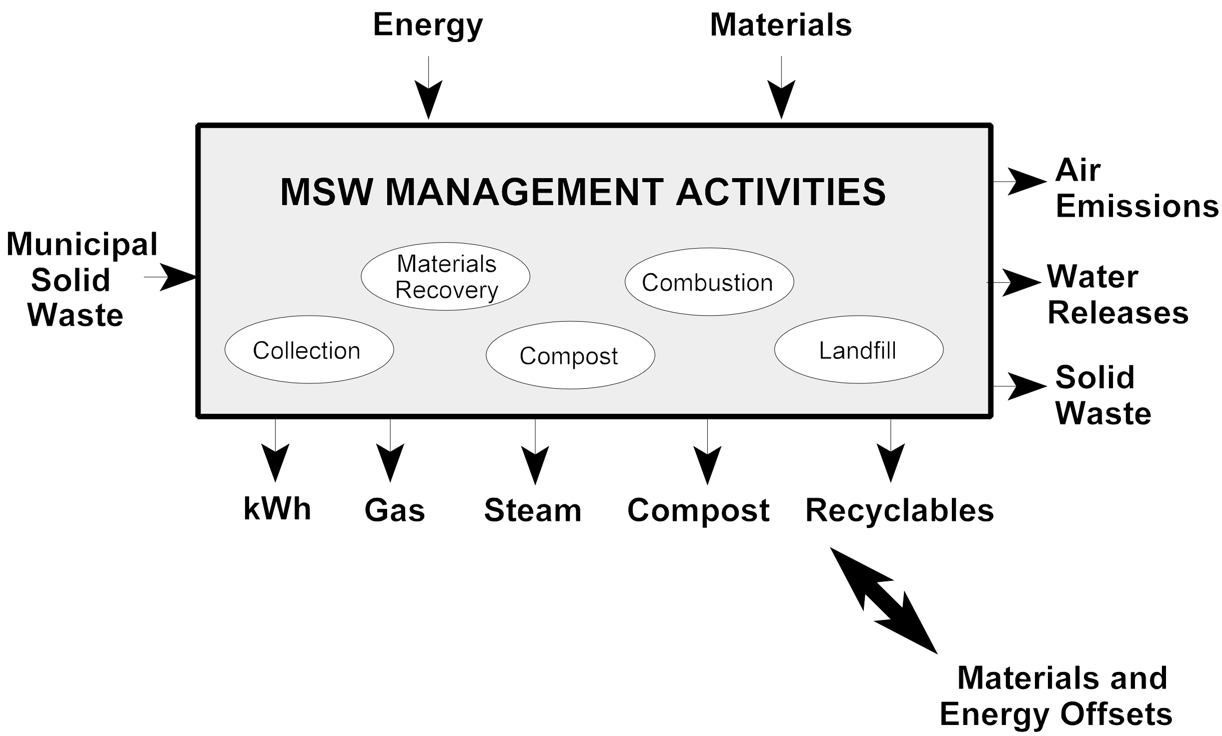


Figure 1-1. Illustration of the MSW Life Cycle.

1.2 HOW DOES THIS RESEARCH HELP TO ANALYZE MSW MANAGEMENT STRATEGIES?

This research provides information and tools that will enable local governments and solid waste planners to examine cost and environmental aspects for a large number of possible MSW management operations for 42 distinct MSW components. The primary outputs of this research will include the following:

- **Municipal Solid Waste Decision Support Tool (MSW DST):** is being designed to allow MSW planners to enter site-specific data (or rely on the default data) to compare alternative MSW management strategies for their communities' waste quantity and composition and other constraints. This enables users to evaluate cost, energy consumption, and environmental emissions for a large number of possible MSW management operations including MSW collection, transfer, separation (MRF and drop-off facilities), composting, combustion, and landfill disposal.

Using A Life-Cycle Approach to Study Solid Waste Management Systems

RTI has applied the MSW DST with communities, States, and other solid waste management organizations. These case studies are providing cost and environmental information about alternative waste management strategies to these groups to assist in the development of management plans and policies. The case studies also are enabling the research team refine the methods and data used in the MSW DST as well as the user interface to the MSW DST. Some examples of the issues being analyzed with the MSW DST for these different groups and studies are as follows:

- Lucas County, Ohio developed a 15 year plan for their solid waste management system. They felt their current waste operations were not cost effective and ignore pollution and life-cycle implications. The analyses and results of this case study helped them in the development of integrated, cost-effective, and environmentally preferable plans and targeting opportunities for improving recycling.

- Anderson County, South Carolina evaluated the cost and environmental implications of implementing a residential curbside recycling program for the more densely populated areas of the county as well as setting up a yard waste composting program. The results of the study assisted the County in determining the most cost effective strategies for implementing the programs.

- The U.S Navy in the Pacific Northwest used the MSW-DST to develop and implement an improved solid waste management plan to reduce cost, increase recycling rates, and ensure that environmental goals were being met. With the closing of smaller local landfills and with the transporting of waste by rail to a larger regional site, the Navy also evaluated subsequent changes in cost, energy consumption, and environmental releases. In order to identify more cost-effective and environmentally preferable solutions to a more regional approach for integrated waste management, the Navy evaluated options that would combine waste from nearby communities.

- The State of Wisconsin is investigating the environmental benefits of State-wide recycling programs. We are using the MSW DST to analyzing how changes in levels of State mandated recycling goals can potentially affect environmental burdens. We are also analyzing how landfill tip fee surcharges can affect the role of recycling. The results of this study will assist the State in deciding what solid waste strategies should be used in the future to meet environmental improvement goals.

- The Integrated Waste Services Association, in conjunction with the Municipal Waste Management Association, used the MSW DST to evaluate the effect of improvements in waste management technologies on greenhouse gas emissions in the United States during the past 25 years. Results indicate that although the amount of MSW has doubled, emissions have decreased due to adoption of integrated waste management programs and recycling, better control of landfill gas, and use of energy resulting from waste to energy and landfill gas to energy.

- **Life Cycle Inventory (LCI) Database:** includes environmental data for individual

MSW management operations, materials manufacturing operations, energy (fuels and electricity) production, and various types of vehicles and equipment. Environmental data include energy consumption and emissions (air, water, solid waste). The database allows users to search for data specific to a system unit process, structure, piece of equipment and or environmental parameter.

- **Community Case Studies:** Case study applications of the MSW DST with local communities to test the cost and LCI methodologies, supporting data, and the overall MSW DST. Studies were selected in a wide variety of rural and urban communities to investigate the flexibility of the MSW DST for different settings.

The information and tools developed through this effort were designed with local governments and solid waste planners in mind as the primary users. For example, at the local level, the decision support tool can be used to evaluate, for example, the affects of changes in the existing MSW management on cost and environmental burdens, identify least cost ways to manage recycling and waste diversion, evaluate options for reducing greenhouse gases or air toxics, or estimate the environmental benefit of recycling. The information and tools from this research will also be of value to other user groups such as Federal agencies, environmental and solid waste consultants, industry, LCA practitioners, and environmental advocacy organizations. These users can use the decision support tool, for example, to evaluate recycling policies and programs, policies and technologies for reducing environmental burdens, and strategies for optimizing energy recovery from MSW.

1.3 WHAT TYPE OF REVIEW HAS THE RESEARCH UNDERGONE?

To ensure the applicability and usefulness of the research products to local governments and other solid waste planners, we employed an inclusive review process for all research activities and documentation. The review process entailed various levels of review by different groups, including the following:

1) Internal project team and U.S. EPA and U.S. Department of Energy advisors.

2) Project stakeholders from U.S. government, industry, academia, and environmental organizations. A current listing of project stakeholders is included in Attachment 1 to this report.

3) External project peer reviews. Three separate peer reviewers were conducted and have included the following individuals:

    - David Allen, University of Texas at Austin
    - Robert Anex, University of Oklahoma
    - Kevin Brady, Demeter Environmental Inc.
    - Jürgen Giegrich, Ifeu- Institute
    - Allen Hershkowitz, Natural Resources Defense Council, Inc.

- Gregory Keoleian, University of Michigan
- Mitchell Kessler, TIA Solid Waste Management Consultants, Inc.
- Jay Lund, University of California-Davis
- Ruksana Mirza, Formerly with Proctor and Redfern, Ltd.
- Debra Reinhart, University of Central Florida
- Lynn Scarlett, Reason Foundation
- Aarne Vesilind, Duke University and Bucknell University
- Peter White, Proctor & Gamble
- Steven Young, Five Winds International

All research activities and outputs have been reviewed at each of these levels. Annual stakeholder meetings and stakeholder workgroup meetings were held to present the research activities and outputs and to solicit feedback and comments. Three external project peer reviews were conducted with experts in LCA and MSW management that were not already part of the project stakeholder group. Comments and suggestions from the stakeholder and peer review meetings have been documented and the research team has provided written responses. Attachments 1 through 3 to this document contain the comments from the three peer reviews and responses provided by the research team. Although considerable effort was made to address all comments received through these reviews, it is impossible to adequately address all comments due to technical, budget and schedule constraints. Issues that we were not able to address at the time were noted as issues for future research. The high level of involvement by project stakeholders and peer review committee members has contributed greatly to the success of this project.

1.4 WHAT ARE THE LIMITATIONS OF THE RESEARCH PRODUCTS?

Considerable effort was expended to make the products of the this research useful and easy-to-use so users could quickly obtain information that is accurate and as up-to-date as possible. However, as tools, they cannot address every situation and are limited in use for some applications. This section discusses some identified limitations of the data, process models, and MSW DST.

1.4.1 Limitations of the Data

The goal of the data collection effort was to rely on existing and available sources of data to the extent possible and to develop data for areas where gaps existed. The areas in which it was necessary to develop data included landfills and composting operations. Although we consider the data presented in the database to be the best possible data that can be developed from the available secondary data sources and from our primary data collection efforts, the data is not without limitations. Our hope is that ongoing and future data development efforts by the different industries and organizations will be made publicly available and can be used to update the data provided in the database over time.

To assess environmental aspects of recycling, we require information on the production of a materials from primary and secondary (recycled) resources. The LCI data for primary materials production includes all processes and activities from the extraction of raw materials to the manufacture of a product or material commodity. The data for secondary materials production includes all processes and activities associated with reprocessing the recycled resources to produce a “new” material commodity.

Data Represent Averages Across Industry

The data compiled and developed for this project, including data for waste management, materials production, fuels production, electrical energy generation, and transportation activities represent national averages. In this respect, the data included in the database and MSW DST assume a current level of technology where as in reality cost and emissions will be facility specific based on their location, level of technology, etc. The MSW DST was designed so that users could input their own data if they have more site-specific information, however the data in the database can only be changed by the developer.

The Materials Production LCI Data Sets Cannot Be Used To Directly Evaluate Recycling

Data for collecting and processing the recyclables at a materials recovery facility (MRF) and then transporting the materials to a remanufacturing site are not included in the upstream LCI data sets because this information is developed in other modules of the MSW DST. Therefore, these data sets cannot be used directly to compare the use of virgin and recycled materials. To conduct a more accurate evaluation of recycling, the materials collection, separation, and transportation processes also need to be considered.

Data Assumptions for Primary and Secondary Materials Production

The terms primary and secondary refer to the source of resources used to produce the materials and should be interpreted as being predominately primary or secondary. We have made assumptions, which are presented in a supporting materials production LCI data document (EPA, 2000) as to the types of resources that comprise these predominately primary and secondary materials production processes. In addition, for each material, a common manufacturing endpoint had to be defined and applied consistently for the primary and secondary system. For example, the endpoint for aluminum could be an aluminum can or an sheet/coil. In this case, we chose the endpoint to be at the sheet/coil stage and after that point.

Materials Production Data Can Only Be Reviewed to a Limited Extent

Due to the aggregated manner in which the materials production LCI data was made available for use in this research, data for specific processes is not available. This limits the level of review that can take place on the data sets. For example, reviewers can compare the LCI totals for the manufacture of primary steel compiled for this project to those developed for another project, but cannot compare the process-level (e.g., iron ore mining, coke production) data for the production of that steel. Although the materials data sets have been reviewed by industry representatives and peer reviewers, their ability to review and comment on the data according to ISO 14040 recommendations was not always possible.

1.4.2 Limitations Associated with the Process Models

Process models have been written to calculate the costs and LCI of each solid waste management unit operation in consideration of the quantity and composition of the waste processed. Separate process models are incorporated in the MSW DST for collection, transfer stations, transportation, separation, composting, combustion, RDF, landfills (traditional, bioreactor, ash) and remanufacturing. An overview of each process model is presented in Chapter 3 and full descriptions of each unit operation model are available separately. Some general comments on the structure of the process models and their importance are presented in this section.

The MSW DST and the Cost and LCI Estimates are Based on Linear Relationships.

The MSW DST is a linear model. This is the feature that allows for the evaluation of large numbers of alternate solid waste management strategies quickly on a personal computer. Thus, all process model coefficients must be linear, meaning that coefficients must be of the form of $ per ton MSW-component or mass NO_X per ton MSW-component. The resulting limitation of the model is that economies of scale cannot be considered mathematically. Thus, it is quite possible that a model solution will specify a unit operation to process an unreasonably small quantity of waste. For example, the model solution could include a combustion facility to process 20 TPD. This might occur if the user included combustion in the definition of diversion and was attempting to minimize cost while still meeting a diversion objective. It could also occur if the user wanted to maximize energy recovery while imposing a cost constraint. In these scenarios, the “optimal” solution might include combustion of enough waste to meet the diversion or energy objective, and a landfill for the remainder of the waste, assuming the cost of a landfill is below that of a combustion facility. The user should inspect a model solution for obvious problems such as an unreasonably small facility. Should this occur, the user should rerun the model after constraining it to generate a management strategy without using the facility (combustion in this example) that was originally proposed or require the use of combustion at some minimum tonnage.

The Process Models Were Not Designed for Optimization of Individual Unit Operations

The MSW DST can identify optimal solid waste management strategies given an objective to optimize one of 9 optimizable parameters. However, the model is not designed to identify the optimal designs of individual solid waste unit operations. For example, aluminum cans can be separated from a stream of commingled recyclables either manually or by use of an eddy current separator. The user must select the separation technology to be used. The process model will not identify one alternative as being favorable. Similarly in the collection process model, the model estimates average truck transportation costs, but it is not meant to identify the optimal routing strategy for waste collection.

Only one process is currently considered for each recyclable in the remanufacturing process model

As described in the system definition in Chapter 2, an offset analysis is used to account for the difference in the LCI associated with manufacturing processes for primary and secondary materials. The product manufactured from each recyclable is unique and was selected to facilitate use of an offset analysis. For example, old newsprint (ONP) is assumed to be converted to new newsprint but the actual printing process is not considered for either primary or secondary material production as it is the same for both. Similarly, recycled aluminum is converted back to sheet/coil from which many products can be made.

In many cases, a secondary material can be used in a number of ways. For example, ONP can be converted to new newsprint, animal bedding, or cellulose insulation among other products. For this project, ONP was assumed to be converted to new newsprint and the offset analysis was conducted on that basis. To the extent that ONP is converted to another product, the offset analysis would change. It should also be noted that many fiber recyclables are exported prior to the remanufacturing step. For this model, the location of the reprocessing step, even if it was in another country, was not considered.

The Offset Analysis Assumes Closed-Loop Recycling and Direct Product Substitution

The offset analysis used to analyze the reprocessing of recovered materials assumes that the production of a product from a secondary (recycled) material replaces the same product manufactured from the primary materials in a closed-loop recycling type system. This may not always be true. One project stakeholder presented an example where secondary HDPE was used in place of primary LDPE, which would have a slightly different LCI than primary HDPE. Similarly, discarded newspaper could be remanufactured into a variety of products other than newsprint.

Beneficial Reuse of Ash Is Not Included in the Combustion and RDF Process Models

Ash is produced from MSW during its combustion in either a combustion facility or RDF plant. The only management alternative available for such ash is burial in a landfill. The beneficial use of ash in construction materials is increasing, thus reducing the disposal of ash in a landfill. Thus, for a specific locality, the cost and environmental emissions associated with ash burial may not be relevant. Emissions from an ash landfill are reported in the MSW DST results output and can be subtracted from the total LCI if appropriate.

Landfill Life Assumes a Typical Design Life

While there exists a relationship between landfill diversion and landfill life, and hence, unit landfilling costs, this effect is minimal in the context of a high level screening tool. It is assumed that the landfill life is sufficiently long so that unit landfilling costs are minimized. That is, the discounted landfill replacement costs are insensitive to the assumed landfill life for a typical design life of a landfill.

The Cost and Price May Differ

The process models calculate the cost of each solid waste management unit operation in units of $/mass of a MSW component processed. These values are based on estimates of the cost for a particular unit operation and make no allowance for whether the unit operation is built and operated by the public or private sector. Where a part of the solid waste management system is built and/or operated by the private sector, the actual price (tipping fee) will likely be higher than the cost to account for a profit. Thus, the costs calculated in the model may not represent price.

Use of Engineering Economics for Cost Modeling

All economic modeling is performed using standard engineering economics. This means that the capital cost of a facility is amortized over the useful life of the facility at a user input interest rate. This annualized cost is combined with annual operating costs to estimate total costs. The economic model does not address issues of cash flow, taxes and the like.

Costs Borne by the Private Sector

The total solid waste management system cost includes the cost to manage all waste generated and managed within the 2 residential, 2 multifamily and 10 commercial sectors. Certain of these costs, specifically the cost to manage waste generated in the commercial sectors which are presumably privately owned, may be borne by the private sector. To obtain estimates of total public sector cost, the costs borne by the private sector, as identified by the model user, can be subtracted out. The model results are presented to allow the user to make this type of calculation. Alternately, wastes generated in sectors for which disposal is paid by the private sector can be excluded from the model to obtain public sector costs. However, private sector waste should not be included in the model at zero cost as the model will not properly evaluate cost-effective solutions for the private sector waste at zero disposal cost.

Decommissioning Costs Are Not Included

The economic analysis does not include the cost to return a site to its initial condition at the end of the useful life of the facility. In the case of a landfill, the economic analysis does include the cost for site closure and post-closure monitoring and maintenance.

1.4.3 Limitations of the MSW DST

The MSW DST is a mathematical representation of a highly complex solid waste management system. Given the complexities of the solid waste management system, it must be recognized that no model can completely describe an actual system. By necessity, some simplifications were required in its development. The first and most basic level of simplification is described in system description (see Chapter 2). The system description notes, for example, that MSW is divided into a finite number of components that includes the major components of MSW and the major recyclables. Nonetheless, there are hundreds if not thousands of components in MSW and they could not all be itemized in this model.

A second example of the basic system simplification inherent in the MSW DST is the use of sectors. The MSW DST can accommodate up to 2 residential, 2 multifamily and 10 commercial sectors. In reality, a MSW management district may include many residential and multifamily sectors and more than 10 commercial sectors. While there is no one strategy that will address this limitation for all users, an example of how this limitation was addressed in a recent case study for Lucas County, Ohio. In that study, it was determined that their MSW management system included about 28 separate residential sectors. These sectors included Toledo, which contained approximately 70% of the total population of the county-wide solid waste management district, and 27 smaller communities, each with its own collection contract. For the Lucas County case study, we devoted one residential sector in the MSW DST to represent Toledo and a second to represent average or typical data for the 27 smaller communities aggregated as one. This is just one example of the need for some creative use of the MSW DST in modeling existing solid waste management districts.

Additional limitations of the MSW DST are presented below.

The MSW DST Is a Planning and Screening Tool

The MSW DST is a screening tool and not a design tool. It is designed to be used to evaluate the entire solid waste management system, particularly when there is the potential to redesign a substantial part of the system. The model will identify a solid waste management solution that is optimal for a user defined objective and user defined constraints. A suggested use of the MSW DST is illustrated as follows. After specifying location-specific information and accepting or modifying process model inputs, the user may use the optimization capabilities of the model. For example, the user may run the model with the objective of identifying a solid waste management alternative that has the least cost (model objective) and meets a landfill diversion rate of 25% (a constraint). Based on this objective and constraint, the model will identify the least expensive solid waste management alternative in which 25% diversion can be accomplished. [Note that diversion can be defined by the user to include or exclude recycling, yard waste composting and combustion]. Similarly, the model could be given an objective to identify the solid waste management alternative that minimizes NO_X emissions (objective) while not exceeding a total annualized cost of 25 million dollars (constraint).

Once an “optimal” solution is identified, the user is encouraged to use the modeling to generate alternatives (MGA) feature of the MSW DST. Using this feature, the user can start with the optimal solution and then identify alternate solutions that are only marginally suboptimal and are different to the maximum extent possible. For example, the user may look at the least cost solution and have some concern about its political viability. Using the MGA feature, the user could then ask the MSW DST to search for solutions that are no more than an allowable increase in cost, for example 10% more expensive than the least cost solution. The MSW DST will then generate a solution that is different from the “optimal” solution but still attractive with respect to cost. Similarly, if the objective function is to minimize NO_X emissions, then the user can start with this "optimal" solution and, using the MGA feature, identify solutions that might lower the total waste management cost by allowing 15% (a user input value) higher NO_X emissions.

Note that the MSW DST cannot simultaneously optimize for minimum values of two LCI parameters. Rather, tradeoffs associated with multiple objectives such as cost and NO_X emissions should be obtained by multiple runs of the model with the appropriate objective functions and constraints.

The MSW DST should be used to identify multiple favorable solutions to a given problem. The user should then inspect the proposed solid waste management strategies to identify those that appear viable for a given community in consideration of factors that were not modeled. Such factors could include political and social considerations, or the divergence between the current solid waste management system and that proposed by the model.

Once a series of potentially viable MSW management alternatives is identified, designs and cost estimates for these alternatives should be developed in detailed engineering studies. Final decisions on the implementation of a solid waste management system should be based on the results of these more detailed studies and not on the model results alone. In this respect, the model is a screening tool that should be used to narrow down the focus of a detailed engineering study. The model is not a design tool that should be used as the basis for how many collection vehicles to order or the acres of land to purchase for a solid waste management facility.

There Is Uncertainty Associated with the MSW DST Results

Model results should be interpreted in consideration of the fact that they are not 100% precise. Two alternatives with slightly different costs or emissions may not be significantly different. It is not possible to state that cost or LCI are within some percentage as the results represent the combination of thousands of individual parameters, many of which will vary from scenario to scenario. With this in mind, the model is best used to identify several potentially favorable alternatives for detailed analysis that may include assessments of the uncertainty. Note also that to the extent that the data are imperfect, the model may still generate alternatives in the appropriate rank order as imprecision will affect all unit operations equally in the system.

While uncertainty estimates of the outputs are not provided by the MSW DST, the user is encouraged to perform sensitivity analysis on key variables. The MSW DST has been structured to make it easy for the user to change user-defined inputs and can perform a sensitivity analysis by repeated runs of the model. For example, if the user knows that labor wage rates may vary by 20% over the next year, then the model can be run with different wage rates in that range. While the user may have a reasonable idea of variability in the economics of solid waste management systems, many users will have little familiarity with variability in the life-cycle data. Some data quality information on the life-cycle parameters can be obtained from the stand alone database and users may apply this is in sensitivity analysis of the LCI parameters.

The MSW DST is a Steady-State Model

The MSW DST is strictly a steady-state model. This means that only one value for each model input parameter can be entered and the model solution assumes that this parameter remains constant with time over the planning horizon.

A community is likely to experience many changes over the useful life of a solid waste management system. Potential changes include increased population and community size, labor rate increases and volatility in the unit revenues for the sale of recyclables and recovered energy. The sensitivity of model results to these and other changes should be explored by the user by making multiple runs of the model with varying values for specific input parameters.

The revenue associated with recyclable sales is perhaps the most volatile input and warrants some further consideration. In the economic portion of the model, the net cost of a solid waste management program is the cost after the realization of income from the sale of recyclables. While accurate, in actuality, a contract for the collection and or separation of recyclables may be based on the costs for collection and separation, with some agreement to share the associated revenue. Thus, the cost calculated in the model, which is a net cost, may be lower than the cost of a contract that separates the collection and separation cost from the revenues from recyclables. From a business perspective, such separation may be essential given the volatility in recyclable prices.

The Calculated LCI Results Represent Global Emissions

The calculated value for each LCI parameter represents the total for the entire MSW management system. While the amount of a given emission that can be attributed to a specific unit operation, such as collection, landfill or remanufacturing is presented, the amount of a given emission that is attributable to sources within and outside of a community is not available. In actuality, only a fraction of each emission can be attributed to local activities. Some notable examples are discussed here.

In the case of collection, there are emissions associated with the collection vehicle that are clearly local. However, there are also emissions associated with the production of the diesel used to fuel the collection vehicle (precombustion emissions) and these emissions occur at the sites of petroleum extraction and refining followed by its transport to the local community. Emissions reported by the MSW DST will simply report the sum of emissions for a particular pollutant.

In addition, electricity is consumed due to activities associated with the administrative office and maintenance activities for refuse collection. The emissions associated with this power generation occur over a wide area. As described in the electrical energy process model, the electrical energy in the power grid is produced from a number of fuels at a number of distinct production facilities. These facilities are almost certainly not all within the local community.

With respect to recyclable manufacturing, note that the LCI is calculated as the difference between the value of the LCI parameter for primary and secondary materials production processes. In a case where the manufacturing location is different for the primary and secondary processes, changes in emissions at the facility handling secondary materials and at the facility handling primary materials will be different. For example, as the mass of a material that is recycled increases, emissions may increase at the facility handling these materials and decrease at the facility producing primary materials. Therefore, while the global emissions associated with a unit of material recycling may be negative, the local community emissions may be positive depending on the geographic location of the associated manufacturing facilities. Nonetheless, from a global perspective, all emissions are summed to present one emission value that may be negative if there is a savings attributable to the secondary materials production process.

The MSW DST Represents an LCI and Not an Impact Assessment

According to ISO 14040 (1997), an LCA includes a definition of goal and scope, an inventory analysis in which all emissions are quantified, an impact assessment in which the potential environmental impacts of the product system are calculated, and an interpretation of the results of the inventory or inventory and impact assessment to reach conclusions and recommendations. The MSW DST provides results for inventory analysis. Efforts have been made to present the data in a manner that will support environmental impact assessment as appropriate impact tools become available. In considering the impact assessment stage, the discussion of local versus global emissions must be considered.

The MSW DST Addresses Source Reduction in a Limited Manner

Source reduction includes a reduction in the mass, volume or toxicity of a waste. Examples of source reduction include a lighter aluminum can that holds the same amount of product, the development of substitutes for chlorofluorocarbons as refrigerants given their severe environmental impact, or the use of double sided copies for the distribution of reports. Although an important part of solid waste management, a specific source reduction process model was not included in the MSW DST. Rather a simple calculator tool was added to estimate the benefits of not producing a user-defined quantity of material that has been source reduced. However, this is only half of the source reduction equation. Users must also run the MSW DST a second time with a reduced waste generation rate (based on the source reduced materials). While this may be appropriate for some cases, it represents a highly simplistic approach and one that may not be accurate. For example, if the waste generation rate is decreased due to a substitution of cloth diapers for disposal diapers, then the extra activity associated with the washing of cloth diapers must also be considered. Similarly, if a manufacturing process is modified to reduce the mass of a product or to reduce the presence of a toxic metal in the product, then the modifications to the manufacturing process must also be considered. A full life cycle model of production processes is needed to analyze such tradeoffs. Users are cautioned to use the model to evaluate source reduction only when they can fully consider all of its environmental emission implications.

The MSW Management System That Was Modeled Begins at Curbside

The solid waste management system that was modeled is based on the management of waste set out at curbside or brought to drop off facilities for composting and yard waste. Activities associated with solid waste management that occur at the site of waste generation are not considered. Examples of such activities include the manufacture of collection bags and bins, backyard composting, rinsing of recyclables, and fuel used to transport materials to drop-off sites.

Construction Related LCI Effects Are Not Included.

A decision to exclude construction from the overall model was made during the system definition phase of this research. Estimates of the significance of construction have shown that for most waste management facilities, this assumption is appropriate. However, for landfills, the total energy consumption for construction were found to represent 25% and 2% of the total landfill LCI for scenarios without and with energy recovery, respectively. The parallel energy values for combustion without and with energy recovery were estimated to be 0.2 and 3.2%, respectively. To the extent that the model solution includes a traditional landfill, the overall LCI values will be low due to the exclusion of its construction.

The MSW DST Only Allows for One of Each Type of Facility

The overall model that is embedded in the MSW DST only allows for the presence of one of each type of solid waste management facility. For example, a large solid waste management district might have two landfills or two MRFs. However, the model would only allow for one of each facility. Of course, the model does allow for multiple types of the same type of facility. For example, the model allows for up to five different MRFs, three landfills (traditional, bioreactor, ash), yard waste and mixed waste composting, etc. This could lead to MSW management cost estimates that are somewhat higher than actual. For example, the optimal solution could include two MRFs, one receiving commingled recyclables and one receiving mixed refuse. If a solid waste district were to construct these two MRFs, then it is possible that they would be located at the same site and would share certain facilities such as a parking area, gatehouse, some rolling stock and personnel associated with marketing recyclables. The economies of scale associated with locating two facilities on one site are not accounted for in the model.

The MSW DST Does Not Consider How Cost Savings Associated with MSW Management Might Be Spent

Solid waste management may be provided as a public sector service financed through property taxes, through private subscription, or through some combination of the two. Funds not spent on solid waste management in the public sector may be returned to the taxpayers through a tax rate decrease, or used for other publicly funded programs. Similarly, cost savings associated with private subscription should result in individuals having more disposable income. This income, whether in the hands of the public sector or the private citizen, may result in spending money on something else. This alternative use of money will have its own LCI that is beyond the scope of the MSW DST.

The MSW DST Is Not A Dynamic Model

The MSW DST assumes that any facility can be replaced at the same cost, corrected for inflation, as the cost at which a facility can be built initially. Further, the model assumes that equipment and facilities are repeatedly replaced at the end of their useful life with equivalent units of equal value. The MSW DST does not address issues such as a transition from an existing MSW management system to a new management strategy. In particular, the model is not designed to optimize integrated waste management in the short term given an existing landfill with little remaining capacity.

To explore the importance of changes in variables such as the revenue from a recyclable, the generation rate, a collection parameter associated with a city growing - the user is encouraged to play “what if” games by deliberately changing various input parameters to explore the significance of the change on the model solution and the values of the cost and LCI parameters. The tool is designed to make this easy.

1.5 ORGANIZATION OF THIS DOCUMENT

This document is designed to provide readers with the essential information to gain a better understanding of the research and research products.

Any life cycle study must begin with a rigorous definition of the goals and system boundaries that are to be modeled. The system description for this study is summarized in Chapter 2. A stand-alone system description document was prepared and is available separately. An overview of the process models embedded in the MSW DST and describes the general facility designs, cost methodology, and LCI methodology for each model is presented in Chapter 3. Again, stand-alone and fully detailed documentation for each process model was prepared and is available separately. Chapter 4 contains a discussion of the main research products and Chapter 5 walks the reader through examples of how the MSW DST was used in recent applications.

The attachments to this document contain the individual reports from the three peer reviews conducted for this project. The reports include comments from the peer reviewers and responses provided by the research team.

A number of supporting documents are available from EPA if you would like to know more detail about the methodologies, data, database, and MSW DST. These supporting documents are made available as appendices to this report and include:

Appendix	A:	Collection Process Model
Appendix	B:	Transfer Station Process Model
Appendix	C:	Materials Recovery Facility Process Model
Appendix	D:	Combustion Process Model
Appendix	E:	Mixed and Yard Waste Composting Process Model
Appendix	F:	Landfill Process Model
Appendix	G:	Inter-unit Operation Transportation Model
Appendix	H:	Reprocessing Model
Appendix	I:	Electric Energy Model

Chapter 2
Goal and Scope Definition

The objective of this chapter is to describe the overall goal and scope for this research and to present the functional elements that comprise the system under study as well as system boundaries. This system description is a small but critical part of the overall project. Additional detail about the functional elements are provided in Chapter 3 of this document as well as in the supporting process model documentation available from EPA.

2.1 GOAL DEFINITION

The ***overall goal*** for this research was defined to develop information and tools to evaluate the relative cost and environmental performance of integrated MSW management strategies. For instance, how does the cost and environmental performance of a MSW management system change if a specific material (e.g., glass, metal, paper, plastic) is added to or removed from a community's recycling program? And, what are the tradeoffs in cost and environmental performance if paper is recycled versus combusted or landfilled with energy recovery?

The ***primary audience*** for this effort is local governments and solid waste planners. However, we anticipate that the information and tools developed through this study will also be of value to Federal agencies, environmental and solid waste consultants, industry, LCA practitioners, and environmental advocacy organizations.

The function of the system under study is to manage MSW of a given quantity and composition. Therefore, we have defined the ***functional unit*** as the management of a defined quantity and composition of MSW. We consider all activities required to manage this waste from the time it is sent out for collection to its ultimate disposition, whether that be disposal in a landfill, compost that is applied to the land, energy that is recovered from combustion and landfills, or materials that are recovered and remanufactured into new products.

2.2 SCOPE DEFINITION

The ***overall scope*** of the project includes all major processes and activities that are involved with, or are affected by, the management of MSW. The system is divided into a number of distinct solid waste management processes linked together as illustrated in Figure 1-1 in the previous Chapter. These processes include waste generation, collection and transfer, separation, treatment (which may include composting, combustion or RDF production) and burial. Remanufacturing is considered to the extent that a specific component of the waste stream is recycled. In this case, the LCI includes energy and resource consumption and the environmental releases involved in the remanufacturing process, as well as the energy, resources, or releases offset by virtue of using recycled versus virgin materials.

Although Figure 1-1 illustrates the functional elements which comprise the integrated MSW system, the key unit processes in the system and the manner in which waste can flow between these unit operations are illustrated in Figure 2-1. As presented in Figure 2-1, there is a lot of interrelatedness between the individual 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 2-2. This figure illustrates the possible paths for old newsprint (ONP) through the system.

In defining the solid waste management system, 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 would make the project unnecessarily complicated. Thus, there are likely to be situations where this system definition cannot be applied.

The remainder of this Chapter is structured to follow the order of the functional elements as presented in Figure 2-1. The discussion of system boundaries is summarized in the final section by which time the reader will have a more complete understanding of the proposed system.

2.3 WASTE COMPONENTS

The 42 MSW components include those defined by the U.S. EPA’s Office of Solid Waste (U.S. EPA, 1997a) and are listed in Table 2-1. This definition includes mixed MSW 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. We have also included ash that is generated from the combustion of MSW in our system, but combustion ash is not included as part of EPA’s definition of MSW. As shown in Table 2-1, we have divided the MSW stream into three different waste generation sectors: residential, multifamily dwelling, and commercial. The rationale for this separation is that different collection and separation alternatives may apply to each sector.

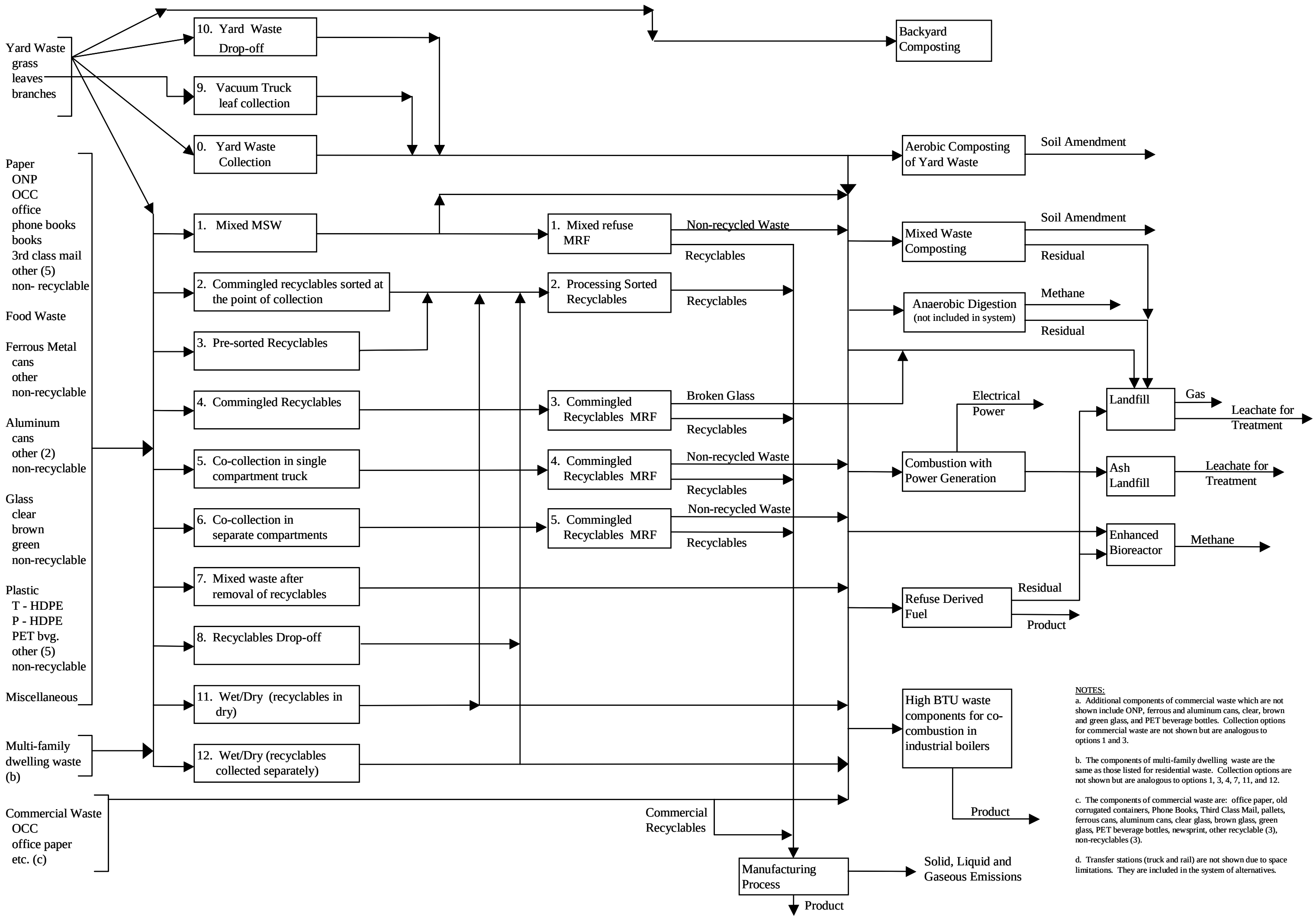


Figure 2-1. Illustration of Alternatives for MSW Management

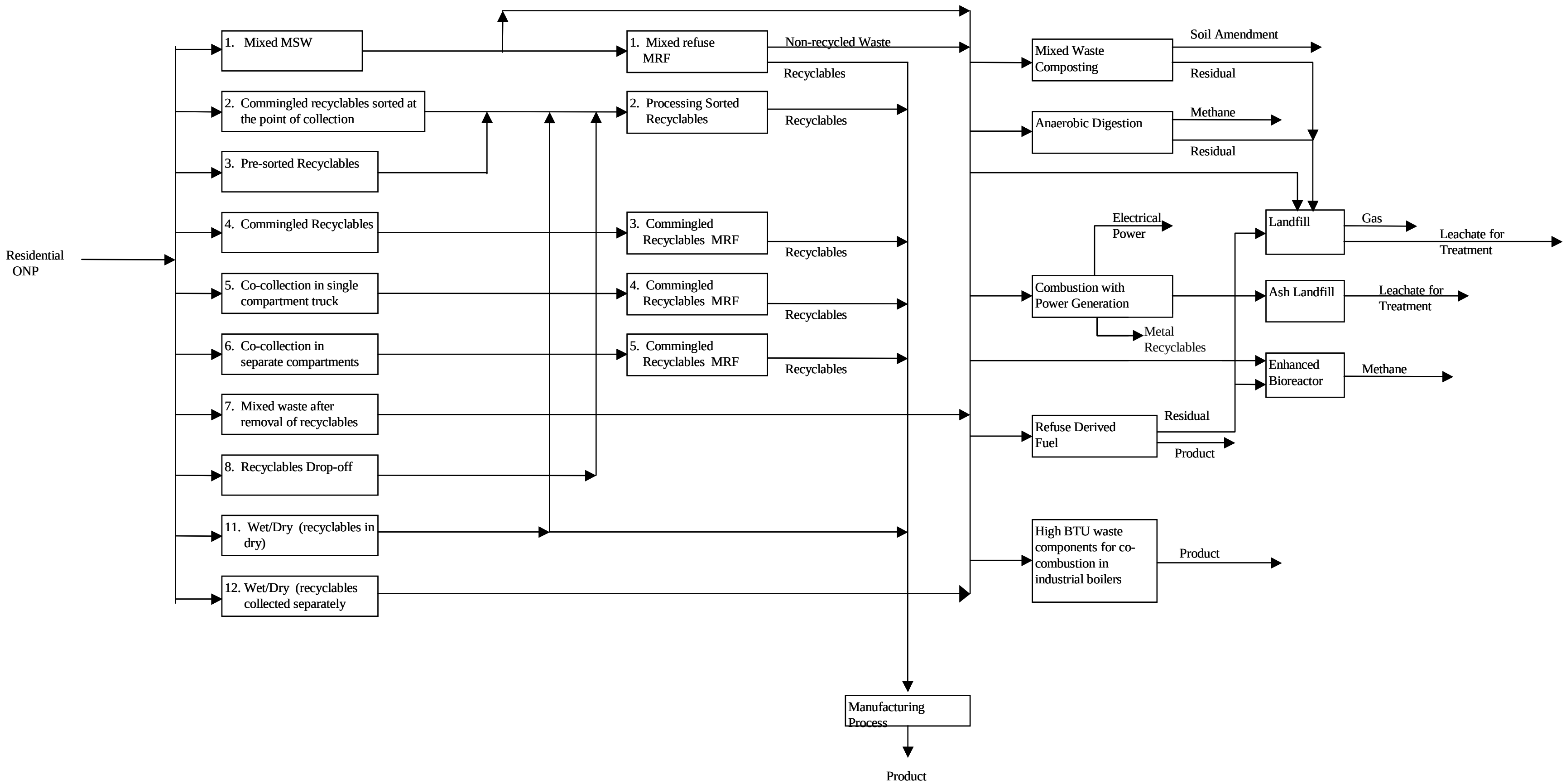


Figure 2-2. Illustration of Waste Flow Alternatives for Residential Newsprint.

[Note: Transfer Stations and MRFs for multi-family and commercial ONP not shown due to space limitations. They are included in the system.]

Table 2-1. Components of MSW Considered in this Study[a]

Residential Waste	Multifamily Dwelling Waste	Commercial Waste
Yard Waste	**Yard Waste**	1. office paper
1. grass	1. grass	2. old corrugated containers
2. leaves	2. leaves	3. phone books
3. branches	3. branches	4. third class mail
4. food waste	4. food waste	5. aluminum cans
Ferrous Metal	**Ferrous Metal**	6. clear glass
5. cans	5. cans	7. brown glass
6. other ferrous metal	6. other ferrous metal	8. green glass
7. non-recyclables	7. non-recyclables	9. PET beverage bottles[c]
Aluminum	**Aluminum**	10. newspaper
8. cans	8. cans	11-12. other recyclables
9-10. other - aluminum	9-10. other - aluminum	13-15. other non-recyclables
11. non-recyclables	11. non-recyclables	
Glass	**Glass**	
12. clear	12. clear	
13. brown	13. brown	
14. green	14. green	
15. non-recyclable glass	15. non-recyclable	
Plastic	**Plastic**	
16. translucent-HDPE[b]	16. translucent-HDPE[b]	
17. pigmented-HDPE[b]	17. pigmented-HDPE[b]	
18. PET beverage bottles[c]	18. PET beverage bottles[c]	
19-24. other plastic	19-24. other plastic	
25. non-recyclable plastic	25. non-recyclable plastic	
Paper	**Paper**	
26. newspaper	26. newspaper	
27. office paper	27. office paper	
28. corrugated containers	28. corrugated containers	
29. phone books	29. phone books	
30. books	30. books	
31. magazines	31. magazines	
32. third class mail	32. third class mail	
33-37. other paper	33-37. other paper	
38. non-recyclable paper	38. non-recyclable paper	
39. miscellaneous	39. miscellaneous	

[a]Numbers represent the number of individual MSW components that can be included in the decision support tool.
[b]HDPE = high density polyethylene
[c]PET = polyethylene terephthalate

2.4 UNIT PROCESSES

Unit processes are the building blocks of any LCA. The focus of this research was on the waste management end of the life and thus the majority of unit processes included are those dealing with waste management. Additional upstream processes are also included as needed. The major unit processes included in the overall system under study are:

Waste Management:
- Collection
- Transfer Station
- Materials Recovery Facility (MRF)
- Waste-to-Energy Combustion
- Refuse-Derived Fuel (traditional and process refuse fuel)
- Composting (yard waste and mixed MSW)
- Landfill (conventional, bioreactor, and ash)

Other Processes:
- Electrical Energy
- Inter-Unit Process Transportation
- Manufacturing of Materials from Virgin Resources and Remanufacturing of materials from Recycled Resources

For each of these unit processes, "process models" were developed that utilize generic design and operating parameters in conjunction with resource and energy consumption and emission factors to estimate cost and environmental (LCI) parameters. The cost and LCI results are highly dependent on the quantity and composition of incoming material to each unit process and thus the process models also contain methodologies for allocating cost and environmental parameters to each of the MSW components as listed in Table 2-1. The boundaries and methods used in the process models were made as consistent as possible across all unit operations. In cases where the boundaries and methods differ, the difference is noted and justified. Chapter 3 contains summaries for each process model and includes discussion of unique features to specific models. A brief description of each model is provided below.

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 affects the cost, resource utilization, releases and design of both the collection operation and potential down stream processing facilities such as a materials recovery facility (MRF). 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. We assume that commercial waste and recyclables are collected by private contractors. However, the energy and resource consumption, and environmental releases associated with commercial waste and recyclables collection will be accounted for in the proposed system. The construction of waste or recyclables collection bins is not included in the system boundaries.

Transfer Stations: Once refuse has been collected, there are a number of facilities to which it may be transported including a transfer station, MRF, a combustion facility, RDF plant, composting facility or a landfill.

Material Recovery Facilities: 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. This interrelatedness is captured in the system.

Composting: Composting is the aerobic biodegradation of organic matter and is considered as a treatment alternative. The compost process model can consider the composting of yard waste and 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 is not included in the system boundaries. We propose to consider two alternatives for yard waste composting; a low 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 design of the mixed waste composting facility can be based on mechanical or static aeration.

Combustion: Combustion represents a treatment alternative in which the volume of MSW requiring burial is significantly reduced. We consider a waste-to-energy (WTE) combustion 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 rationale for this selection is that the majority of combustion facilities constructed today include energy recovery as electricity. However, we can simulate a combustion facility without energy recovery by zeroing out material heating values.

Refuse Derived Fuel And Process Refuse Fuel: 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 solid waste management 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 which cost, energy, and emission factors are developed.

Landfills: Three types of landfills will be considered in the system; one designed as a conventional mixed waste landfill, one bioreactor landfill, and a second designed for the receipt of ash only. The mixed refuse landfill will be designed according to RCRA Subtitle

D and Clean Air Act standards. However, the user will have the opportunity to specify either a more lenient or stricter design with respect to the liner and cover systems. The landfill will be operated as a dry landfill. Consideration of the operation of a landfill with leachate recycle for enhanced decomposition and methane production was discussed in the previous section. The system will include both gaseous and liquid releases 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 offsite treatment facility. Energy and emissions associated with leachate treatment will be considered in the LCI.

Electrical Energy: The electric energy model provides an accounting of the total energy consumption and emissions resulting from the use of electric energy. Precombustion and combustion energy consumption and emissions on a per unit fuel basis are used in conjunction with unit efficiencies, transmission and distribution line losses, and electric generation fuel usage percentages to allocate energy consumption and emissions to the usage of an electric kilo-watt hour (kWh) based on the contribution to the generation of that kwh by each fuel type. Emissions and energy consumption per kwh are calculated for the national grid fuel mix as well as for the nine major electrical generating regions in the United States. Default values for parameters used in these calculations are provided with optional user override capability for the majority of these parameters.

Transportation: Transportation (separate from waste collection) modes included in the system are rail, heavy-duty diesel (tractor trailers), light-duty diesel vehicles and light-duty gasoline vehicles. Cost and LCI factors for transport of mixed refuse, fuel, and compost are calculated per ton of aggregate mass flow between nodes. In contrast, recyclable materials are often shipped separately and have item-specific densities. For example, loose glass has a density nine to ten times that of plastic. For this reason, item-specific cost and LCI factors are calculated for recyclables transport. Connections for which item-specific factors are determined for recyclables include transport from transfer stations to separation facilities and from separation facilities to remanufacturing.

Remanufacturing: As part of the LCI, we must account for all resources, energy, and environmental releases associated with the recycling and reprocessing of a waste component. This section presents the conceptual framework which we propose to use 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, at a MRF, or at another waste management facility. In addition to recycled materials, an offset will also be required in management strategies where energy is recovered from either the direct combustion of MSW, 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 assume that any "saved" electrical energy resulted from fossil fuel (coal, oil, or natural gas) and not from hydro or nuclear power.

2.5 DATA PARAMETERS TRACKED

The main categories for cost and environmental parameters tracked as part of the research included:

Cost Categories:
- Annual capital cost
- Annual operating cost

Environmental (LCI) Categories:
- Energy consumption
- Air emissions
- Waterborne releases
- Solid waste

To compare across alternative MSW management options, we can only use parameters for which comparable data exists across all unit processes. For example, although data for dioxin/furan emissions for MSW combustion facilities are readily available, comparable data do not exist for MRF, composting, and landfill operations. Thus, we cannot directly compare these unit processes based on dioxin/furan emissions.

A subset of the parameters in the MSW DST for which we currently have consistent data on can be optimized:

- Annual cost
- Carbon monoxide
- Carbon dioxide (fossil - resulting from the combustion of fossil fuels)
- Carbon dioxide (biomass - resulting from the biodegradation or combustion of organic material)
- Electricity consumption
- Greenhouse gas equivalents
- Nitrogen oxides
- Particulate matter
- Sulfur dioxide

These parameters can be optimized on as part of the MSW DST solution, as described in Section 5. Additional air and water parameters are tracked and reported in the MSW DST, but cannot be optimized on at this time. Based on the need of user to optimize on additional parameters, future versions of the MSW DST can be updated to include an expanded list of optimizable parameters.

2.6 SYSTEM BOUNDARIES

The system boundaries for this study have largely been defined through the description of the functional elements and unit processes and the manner in which each will be treated. These elements and processes are outlined in detail in a draft system description document and summarized in the following section. Unlike traditional LCAs, however, our study integrates cost and environmental data and the boundaries for each are slightly different as described below.

2.6.1 Boundaries for Environmental (LCI) Analysis

All activities which have a bearing on the management of MSW from collection through transportation, recovery and separation of materials, treatment, and disposal are included in the environmental analysis. It is assumed that MSW enters the system boundaries when it is set out or delivered to a collection site, whether it be a residential curbside, apartment collection site, or rural drop-off site. All "upstream" life cycle activities (raw materials extraction, manufacturing, and use) are assumed to be held constant. Thus, the production of garbage bags and cans and recycling bins are NOT included in the study. Similarly, the transport of waste by residents to a collection point have NOT been included.

The functional elements of MSW management include numerous pieces of capital equipment from refuse collection vehicles, to balers for recycled materials, to major equipment at combustion facilities. Resource and energy consumption and environmental releases associated with operation of equipment and facilities are included in the study. For example, energy (fuel) that will be consumed during the operation of refuse collection vehicles is included in the study. In addition, electricity consumed for operation of the office through which the vehicle routes are developed and the collection workers are supervised is also included in the study. However, activities associated with the fabrication of capital equipment are NOT included.

Where a material is recycled, the resource and energy consumption and environmental releases associated with the manufacture of a new product are calculated, assuming closed-loop recycling processes, and included in the study. These parameters are then compared against those from manufacturing the product using virgin resources to estimate net resource and energy consumption and environmental releases. This procedure also applies to energy recovery from other unit processes including combustion, RDF, and landfill gas recovery projects.

Another system boundary is set at the waste treatment and disposal. Where liquid wastes are generated and require treatment (usually in a publicly owned treatment works), the resource and energy consumption and environmental releases associated with the treatment process is considered. For example, if biological oxidation demand (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, during its burial (e.g., bulldozer) and after its burial (e.g., gas collection and leachate treatment systems) in the landfill. Also, if compost is applied to the land, volatile and leachate emissions are considered.

2.6.2 Boundaries for Cost Analysis

Costs have also included in this study because they play such a crucial role in making decisions about integrated MSW management strategies. Note that the system boundaries for cost analysis differ from that of the environmental analysis because they are designed to provide a relative comparison of annual cost among alternative MSW management strategies as incurred by the public sector. These costs are intended to provide a relative ranking of the different alternatives as part of a screening tool to narrow the range of options associated with integrated MSW management. No distinction is made between public and private sector costs. All MSW management activities are assumed to occur in the public sector and therefore costs are calculated as though they are accruing to the public sector. The cost analysis is intended to reflect the full costs associated with waste management alternatives based on U.S. EPA guidance from *Full Cost Accounting for Municipal Solid Waste Management: A Handbook* (U.S. EPA, 1997b).

In focusing the cost analysis on publicly accrued costs, the costs associated with electricity production, for instance, are not included in the study because the public sector only pays the price for electricity consumed. In cases where recyclables are shipped from a MRF, the cost analysis ends where the public sector receives revenue (or incurs a cost) in exchange for the recyclables. The cost analysis does not include the costs associated with the remanufacturing processes for different materials (e.g., recycled office paper). These costs occur in the manufacturing are borne by the manufacturing sector and not to municipal or county governments. The same procedure is applied to the generation and sale of electricity derived from combustion facilities or landfills. Where waste is produced as part of a waste management facility, the cost of waste disposal or treatment is included in the cost analysis of that facility. For example, we include the cost of leachate treatment in our cost analysis of landfills. We also include the cost of training, educational, or other materials associated with source reduction or other aspects of MSW management.

Similar to environmental parameters, cost parameters are also allocated to individual MSW components. Thus, the result of the cost analysis can illustrate, for example, the additional capital and operating costs to a MRF for processing and storing glass. Similarly, the cost associated with the separate collection of residential yard waste can be analyzed.

Chapter 3
Technical Approach for Unit Processes

The detailed methodologies for cost and environmental analysis for each unit process (see Figure 3-1) for a representation of a generic process model) are implemented in process models. Process models include sets of equations that utilize the default (or user input) facility design information to calculate all cost and environmental parameters based on the quantity and composition of waste entering each MSW management unit process. The process models included in the system boundaries are as follows:

Waste Management Processes

- Collection
- Transfer Station
- Materials Recovery Facility
- Compost (mixed MSW and yard waste)
- Waste-to-Energy Combustion
- Refuse Derived Fuel (traditional and process refuse fuel)
- Landfill (traditional, bioreactor, and ash)

Other System Processes

- Electrical Energy Production
- Inter-Unit Transportation (not including collection)
- Remanufacturing

The process models are linked in the MSW DST through a set of mass flow equations. The cost and environmental results from process models are used in the MSW DST to calculate the total system cost and environmental performance for alternative MSW management strategies. This Chapter includes summaries of the models developed for each unit process. These summaries are intended to provide the reader with a broad overview of the methodology employed for estimating cost and LCI coefficients. Key assumptions and issues for each process model are provided in Table 3-1. Full documentation for each process model drafted to date has been completed and is available as a series of Appendices to this report. Please contact EPA to obtain copies of the full process model documentation.

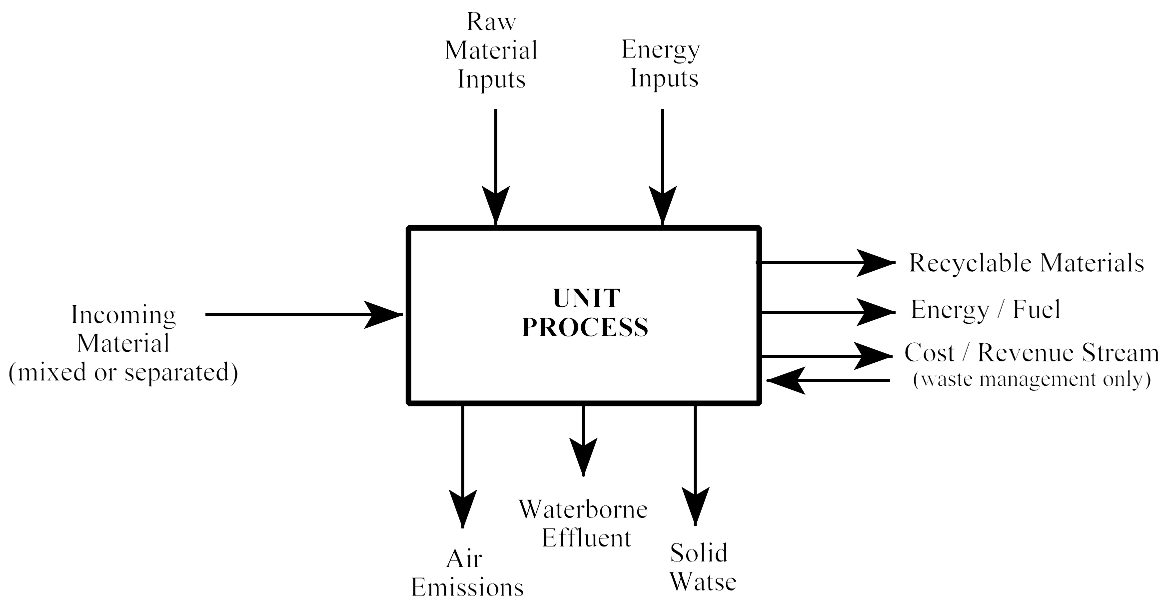


Figure 3-1. Illustration of a Unit Process

A given quantity and composition of material flows into each unit process. Default facility designs and operating conditions are used to estimate the energy and resource use, environmental releases, and cost (or revenue) for each unit process. These values are then partitioned to individual MSW components.

3.1 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, environmental releases, and design of both the collection operation and potential down stream processing facilities such as a MRF. The collection options included in the system are listed in Table 3-2. The design and generic cost and LCI methodologies for collection systems is presented in this section. There may be minor differences in the designs of the 20 collection systems included in Table 3-2. Please refer to full collection model documentation for addition details on the collection options.

The number of collection vehicles needed to collect the waste and recyclables generated in a community is calculated by determining the number of collection locations that a collection vehicle can

Table 3-1. Process Model Assumptions and Allocation Procedures

	Key Assumptions/Design Properties	Allocation Procedures[a]
Waste Management Unit Processes		
Collection	Location specific information (e.g., population, generation rate, capture rate) is provided by the user of the tool.	Environmental is based on mass. Cost is based on volume and mass.
Transfer Station	User selects between several default design options based on how the MSW is collected.	Environmental is based on mass. Cost is based on volume and mass.
Materials Recovery Facility	Design of the MRF depends on the collection type (mixed waste, commingled recyclables, etc.) and the recyclables mix. Eight different default designs are available.	Environmental is based on mass. Cost is based on volume and mass and includes revenue from the sale of recycables.
Combustion	The default design is a new facility assumed to meet the most recent U.S. regulations governing combustion of MSW. Designs to model older facilities are also available.	Environmental is based on mass and stoichiometry. Cost is based on mass and includes revenue from sale of metal scrap and electricity (based on Btu value of the waste and the heat rate of the facility).
RDF and PRF	Traditional RDF and Processed Refuse Fuel (PRF) design options are available. The facilities are assumed to meet the most recent U.S. regulations governing combustion of MSW.	Same as combustion.
Composting	A low and high quality mixed MSW and yard waste compost facilities are included. All use the aerated windrow composting process as the default design.	Environmental is based on mass. Cost is based on volume and mass and includes revenue from the sale of recyclables.
Landfill	The default design is a new facility that meets U.S. Subtitle D and Clean Air Act requirements. Enhanced bioreactor and ash designs are also available.	Cost and emissions for operations, closure, and post-closure are allocated equally over the mass of refuse buried. Landfill gas and leachate are allocated to MSW items
Additional Unit Processes		
Electrical Energy	Regional electrical energy grids are used for waste management processes; national grid for upstream processes.	Environmental is based on the fuel source used by regional or national electricity grids. Regional grids are used for waste management operations; National for manufacturing operations. Cost is not considered.
Inter-Unit Transportation	Distances between different unit operations are key input variables.	Environmental is based on mass. Cost is based on volume and mass, and is considered only for transportation necessary for waste management.
Manufacturing	Virgin and recycled (closed loop) processes are included.	Environmental is based on mass. Cost is not considered.

[A]Allocation of costs, resource and energy consumption, and environmental releases to individual MSW components

stop at along a collection route before it is filled to capacity. This number is multiplied by the amount of time that a vehicle spends at each location and traveling between locations, to yield the length of time that a collection vehicle takes to travel from the beginning to the end of its collection route. The length of time that a collection vehicle takes to make a complete collection trip includes the route travel time plus time spent traveling back and forth from the location where it unloads the material that it collects (landfill, MRF, composting facility, etc.) and the time spent unloading at that location.

Next, the number of daily collection vehicle trips is calculated. The number of fully loaded trips that a collection vehicle can make during one workday is calculated after time is deducted for travel to and from the vehicle garage at the beginning and end of each day, for the lunch break, and other break time.

The next step is to divide the total number of collection locations in the area served by a collection option by the number of collection locations that a vehicle stops at during one collection trip to determine the number of trips needed to collect all the MSW generated in that area during one collection cycle. A collection cycle may represent one or more visits to each collection site per week, with a default value of one visit per week.

Once the numbers of daily collection vehicle trips and total collection trips are known, the number of trucks is determined by dividing total trips by daily trips and by the number of days per week that collection vehicles operate. The number of trucks is used to calculate the annual cost and LCI of the collection system. Cost and LCI methodologies are discussed in the following sections.

3.1.1 Cost Methodology for Collection

Collection costs are divided into capital costs, operation & maintenance costs. Capital cost includes the cost of collection vehicles, backup vehicles, and an administrative rate that includes capital cost of the garage and maintenance facilities. Capital cost is expressed in annual terms using a capital recovery factor that is dependent upon the manufacturer estimated lifetime and discount rate.

The operation and maintenance (O&M) cost of the collection process includes the labor, overhead, taxes, administration, insurance, indirect costs, fuel cost, electricity cost, and maintenance cost.

The total annual collection cost is calculated by multiplying the number of trucks by economic factors including a vehicle's annualized capital cost based on the purchase price amortized over the service life, vehicle operating costs, labor costs, overhead costs, and costs for backup vehicles and collection crew personnel. Labor costs include the wages paid to drivers and collection workers. Overhead costs are calculated as a function of the labor costs and include administrative costs.

Table 3-2. Collection Options for Waste Generating Sectors

Residential	Multi-Family	Commercial
Mixed Refuse Collection • Collection of mixed waste in a single compartment truck. **Recyclables Collection** • Collection of commingled recyclables sorted by the collection crew into a multi-compartment vehicle. • Collection of presorted recyclables in a multi-compartment vehicle. • Collection of commingled recyclables in a vehicle with two compartments. **Co-Collection** • Collection of mixed refuse and recyclables in different colored bags in a single compartment vehicle. • Collection of waste, paper recyclables, and non-paper recyclables in a three compartment vehicle. **Residuals Collection** • 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** • Generator brings recyclables to a centralized drop-off facility. This could also be a buy-back center. **Yard Waste Collection** • Collection of yard waste in a single compartment vehicle. • Collection of leaves in a vacuum truck. • Dropoff at a compost facility. **Wet/Dry Collection** • Wet/Dry collection with recyclables included with the dry portion. • Wet/Dry collection with recyclables collected in a separate vehicle.	**Mixed Refuse Collection** • 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** • Collection of pre-sorted recyclables into multiple stationary or hauled containers. • Collection of commingled non-paper recyclables into a single compartment for containers and a second compartment for paper recyclables. **Residuals Collection** • If recyclables are collected in options 12 or 13, then residual MSW is collected in a single compartment vehicle as in option 11. **Wet/Dry Collection** • 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. • Wet/Dry collection with recyclables collected in a separate vehicle. The user will asked to specify whether various paper types are to be included in the wet or dry collection compartments.	**Recyclables Collection** • Collection of presorted recyclables. **Mixed Refuse Collection** • Collection of mixed refuse before or after recycling.

3.1.2 LCI Methodology for Collection

The number of collection vehicles and other parameters such as the miles traveled and fuel consumed by collection vehicles are used to calculate consumption rates and release rates for

LCI parameters. Default or user override values for the speed that a vehicle travels while performing different tasks and its fuel consumption rate are used to determine how many miles it travels and how many gallons of fuel it consumes per day. These in turn are multiplied by pollutant emission factors to arrive at values for the amounts of air pollutants, water pollutants, and solid wastes generated per ton of waste collected. The LCI parameter calculations also include the consumption of electrical energy at the garage where the collection vehicles are stored and maintained when not in service. LCI parameters are allocated by weight to individual components of the waste stream.

The quantity of fuel consumed in the collection process is calculated based on the fuel consumption rate of vehicles and the quantity of waste or recyclables collected. Electrical energy is used by the garage facility for heating and lighting. The amount of electricity used is provided by standard consumption rates and is based on the size (square feet) of the garage.

Air emissions in the collection process are from combustion of fuel in vehicles, and from the production of energy used in the collection process. Air emissions data from fuel production and fuel combustion in collection vehicles are included in the LCI.

Water releases associated with the collection process are releases from the production of energy used in the collection process. There are no process related water releases.

Solid wastes due to collection include wastes released due to energy production (collection vehicle fuel and electricity). No other process related solid wastes are considered in the LCI.

3.2 TRANSFER STATIONS

The transfer station process model includes five types of roadway vehicle transfer stations and three types of rail transfer stations. The following general description applies to all types of transfer stations modeled. Transfer stations require a covered structure that houses collection vehicle unloading areas, trailer loading bays, refuse tipping floor space, and office space. Collection vehicles enter through a scale-house, then proceed to unloading areas. Therefore, the site is partially paved to accommodate maneuvering of both collection and transport vehicles and container storage. Facility staff operate waste handling equipment to load and distribute refuse in hauling containers and to move refuse on the tipping floor. Office space includes an employee rest area and an administrative work area. The loading bay area includes a trailer footprint and trailer maneuvering space. The cost of refuse drop-off areas open to the general public is included in the construction cost for each design.

The types of transfer stations modeled are:

TR1: **Processing mixed MSW**. For mixed waste transfer stations, the user selects from five design options. The major differences between these design options are single or multi-level design, the presence or absence of a compactor, and the type of rolling stock required.

TR2: Processing commingled recyclables. At a commingled recyclables transfer station, recyclables are loaded from collection vehicles into tractor trailers. As for TR1, the user can select from the same five transfer station designs. However, in all TR2 designs paper recyclables are processed separately.

TR3: Processing separately bagged mixed waste, non-paper recyclables, and paper recyclables in a single compartment. Single compartment co-collection vehicles have paper recyclables in one bag, non-paper recyclables in a second bag, and mixed refuse in a third bag in one compartment of the collection vehicle. Mixed waste is collected in black bags and recyclables are collected in blue bags. The facility area for TR3 consists of a tipping floor for mixed black and blue bags, a storage area for separated blue bags, and separate loading areas for blue and black bags.

TR4: Processing separately bagged mixed waste, non-paper recyclables, and paper recyclables in separate compartments. Three compartment collection vehicles deliver source-separated mixed refuse (in black bags), non-paper commingled recyclables (in blue bags), and paper recyclables (in blue bags) to TR4. Non-paper recyclables are unloaded onto a tipping floor and then loaded into a trailer with front-end loaders. Mixed refuse is directly tipped into a compactor via a hopper.

TR5: Processing presorted recyclables. A presorted recyclable transfer station is expected to operate at low capacities relative to other transfer stations. The facility is of a simpler design and includes a roof but no walls. Recyclables are unloaded into separate roll-on/roll-off containers with adequate collection vehicle maneuvering. A small backhoe is used for material handling. Full containers are removed from loading areas and stored on site until transported.

RT1: Rail transfer of MSW from collection vehicles. Mixed refuse is transferred from collection vehicles to a rail car at RT1. The user selects from two design options for RT1 transfer stations - the first is a one-level design and the second is a two-level design. For the one-level design, a crane is used to load containers. For the two-level design, refuse is pushed from the tipping floor into a compactor. The cost of rail spurs connecting the transfer station to existing local rail lines is included in the RT1 construction cost.

RT2: Rail transfer of MSW from trains to landfill. At the landfill rail haul transfer station, a crane unloads incoming containers of MSW into a storage area. Stored containers are loaded onto tractors, then hauled to the landfill working face. Tippers unload containers by inclining them greater than 60 degrees from horizontal.

RT3: Rail transfer of MSW from trains to enhanced bioreactor landfill. The design of rail transfer stations receiving containers at an enhanced bioreactor is the same as the design for RT2.

The five roadway vehicle transfer stations (TR1 to TR5) are categorized by the type of material processed. Rail transfer station nodes (RT1 to RT3) consist of a transfer station for unloading mixed refuse from collection vehicles onto rail cars and receiving transfer stations located at a traditional landfill and an enhanced bioreactor landfill. There are some differences in the process flows transfer stations. Not all these differences are mentioned here. Refer to the complete transfer stations documentation for process flows and details.

3.2.1 Cost Methodology for Transfer Stations

The cost of a transfer station depends on the type of transfer station, the quantity and type of materials processed, and user input data. Costs are divided into capital costs and O&M costs.

Capital cost consists of construction, land acquisition, engineering, and equipment cost that can be expressed in annual terms using a given capital recovery factor that is dependent upon a book lifetime and discount rate.

- Construction cost includes the cost of the structure, paving, access roads, fencing, landscaping, etc. For rail transfer stations, the paving and site work includes the cost of rail spurs that connect the facility to local rail lines. The cost of the structure includes support facilities such as office space and weigh stations. Construction cost is obtained by multiplying the floor area of the transfer station by the construction cost rate.

- Total area for a transfer station includes area for the structure, access roads, fencing, weigh station, landscaping, etc. Total area multiplied by a cost rate gives the land acquisition cost.

- Engineering cost consists of fees paid for consulting and technical services for the transfer station planning and construction, and is estimated to be a fraction of the construction cost.

- Equipment cost consists of the capital and installation cost of equipment such as rolling stock and compactors.

O&M costs of the transfer station include wages, overhead, equipment and building maintenance, and utilities.

- Labor required for the transfer station consists of management, drivers and equipment operators. In estimating the labor wages, it is assumed that part-time services can be hired. Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to drivers and equipment operators.

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

- The cost of utilities (power, fuel, oil, etc.) is proportional to the weight of material processed in the transfer station.

- The cost of maintenance of equipment and structure is assumed proportional to the weight of materials processed in the transfer station.

3.2.2 LCI Methodology for Transfer Stations

The LCI methodology calculates energy consumption or production, and environmental releases from a transfer station and allocates these LCI parameters to individual components of the waste stream.

The transfer station process model uses default or user-supplied data on <u>fuel consumed</u> by rolling stock, for heating and lighting purposes, and for processing equipment to calculate the total quantity of energy consumed per ton of material processed.

The transfer station process model accounts for <u>airborne releases</u> from two sources: (1) the pollutants released when fuel is combusted in a vehicle (combustion releases), and (2) the pollutants emitted when the fuel or electricity was produced. Data for fuel and electricity generation production are included in the electrical energy process model documentation.

The transfer station process model accounts for <u>waterborne pollutants</u> from the production of energy (electricity and fuel) consumed at the transfer station. There are no process related water releases. Default values for water releases from energy production are provided in the Electrical Energy process model documentation.

The transfer station process model uses the fuel consumed and energy consumed by equipment and for heating and lighting the transfer station building to calculate the <u>solid waste</u> generated. Solid waste generation is expressed in terms of pounds of pollutant per ton of material processed. Note that the solid waste referred to in this section pertains to the waste generated when energy is produced. Default values for solid wastes generated due to energy production are provided in the Electrical Energy process model.

3.3 MATERIALS RECOVERY FACILITY (MRF)

MRFs are used to recover recyclables from the municipal waste stream. The process flow in a MRF depends on the recyclables processed and the manner in which they are collected. Thus a critical element of the MRF design is to enable the flexibility to process any composition of recyclables. This is necessary to allow the model solution to specify which recyclables should be recovered for a given model objective (e.g., minimize cost, energy consumption, greenhouse gases, etc.).

Eight different MRF designs are included in the MSW management system:

MRF 1: **Mixed waste MRF.** Processes mixed municipal solid waste.

MRF 2: **Presorted recyclables MRF.** Processes recyclables collected either presorted by the resident or sorted at the curbside by the operator of the collection vehicle.

MRF 3: **Commingled recyclables MRF.** Receives recyclables from a commingled recyclables collection program. All fiber recyclables are collected in one compartment and non-fiber recyclables are collected in a separate compartment on the collection vehicle.

MRF 4: **Co-collection MRF.** Processes commingled recyclables and mixed waste collected in a **single compartment truck**. Recyclables are collected in a color-coded bag (blue) with mixed waste collected in a bag of a different color (black). All fiber recyclables are placed in one bag and all non-paper recyclables are placed in another bag. The colors of bags used in a city can be different, but blue and black are the two colors chosen for the discussions in this document and in the model.

MRF 5: **Co-collection MRF.** Processes commingled recyclables and mixed waste collected in a **three compartment truck**. All fiber recyclables are collected in bags that are placed in one compartment. Bags containing non-fiber recyclables are placed in the second compartment and bags with residual mixed waste are placed in a third compartment. Recyclables are collected in blue bags and mixed waste is collected in black bags.

MRF 6: **Front end MRF to a composting facility.** 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 as specified by the user based on product quality requirements.

MRF 7: **Front end MRF to an anaerobic digestion facility.** Material recovery operations precede anaerobic digestion operations. The MRF is similar to a mixed waste MRF, but includes additional sorting to remove contaminants as specified by the user based on product quality requirements.

MRF 8: **Front-end MRF to an RDF facility.** Material recovery operations precede RDF operations.

In the general MRF design, mixed waste or recyclables are collected at curbside. Waste or recyclables are collected in bags and pass through a debagging point in the MRF. The opening of bags can be done manually or mechanically, as specified by the user. Loose material from the bag opening operation is then conveyed into an elevated and enclosed sorting room where the recyclables are recovered. The elevation of the sort room provides for space underneath for placement of bunkers into which separated recyclables are dropped. In a presorted MRF, non-glass incoming material is baled without sorting, and glass recyclables are loaded into trailers. For recycling collection options, paper recyclables, collected in separate bags, are conveyed to a paper sorting line, and newsprint is recovered through a negative sort. Other paper types can be removed by pickers.

Note that there are some minor differences in the process flows of MRFs depending on the type of MRF and the material being processed. Refer to the complete MRF documentation describing the details of the alternative MRF designs.

3.3.1 Cost Methodology for MRFs

The cost of a MRF depends on the type of MRF, the quantity and type of recyclables processed, and user input data. Costs are divided into capital costs, O&M costs, and revenue from recyclables.

<u>Capital cost</u> consists of construction, land acquisition, engineering, and equipment cost that can be expressed in annual terms using a given capital recovery factor that is dependent upon a book lifetime and discount rate.

- Construction cost includes the cost of the structure, access roads, fencing, landscaping, etc. The cost of the structure includes support facilities such as office space, a weigh station, and the loading conveyer. Construction cost is obtained by multiplying the floor area of the MRF by the construction cost rate. Total area for a MRF includes area for the structure, access roads, fencing, weigh station, landscaping, etc. Total area multiplied by a cost rate gives the land acquisition cost.

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

- Equipment cost consists of the capital and installation cost of equipment.

<u>O&M costs</u> of the MRF include wages, overhead, equipment and building maintenance, and utilities.

- Labor required for the MRF consists of management, drivers and equipment operators, pickers, and bag openers. In estimating the labor wages, it is assumed that part-time services can be hired. Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to pickers, drivers and equipment operators.

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

- The cost of utilities, assumed to be electricity, fuel, oil, etc., is assumed to be proportional to the weight of recyclables recovered in the MRF.

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

Residue in the MRF is a result of the sorting efficiency being less than 100% and recovery of less than 100% of a recyclable. The cost of disposal of residue depends on the disposal facility used and will be accounted for at the downstream processing alternative.

Recyclables recovered in the MRF provide revenue to help offset the costs of the MRF. The user can enter the item-specific value of recyclables.

3.3.2 LCI Methodology for MRFs

The LCI methodology calculates energy consumption or production, and environmental releases from a MRF and allocates these LCI parameters to individual components of the waste stream.

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

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

Depending on the source of energy, the feedstock could be coal, petroleum, natural gas, nuclear fuel, etc. For electricity, the source of energy also depends on the regional energy grid used. Default data on the energy required to produce a unit of electricity, including its precombustion energy, are included in the electrical energy process model documentation. The MRF process model uses default or user-supplied data on fuel consumed by rolling stock, for heating and lighting purposes, and for processing equipment to calculate the total quantity of energy consumed per ton of material processed.

The MRF process model accounts for airborne releases from two sources: (1) the pollutants released when fuel is combusted in a vehicle (combustion releases), and (2) the pollutants emitted when the fuel or electricity was produced. Data for fuel production and electricity production are included in the common process model.

The MRF process model accounts for waterborne pollutants associated production of energy (electricity and fuel) consumed at the MRF. There are no process related water releases. Default values for water releases from energy production are provided in the common process model.

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

3.4 COMBUSTION

The combustion process model calculates cost and LCI parameters on the basis of user input and default design information. The cost and LCI coefficients take into account the quantity and composition of the waste input to the combustion facility. The user can also model the following types of combustion facilities:

- newer combustion facility with state of the art air pollution control devices,
- older combustion facility with less advanced air pollution control devices,
- combustion with energy recovery, and
- combustion without energy recovery.

Default cost and emission factors for new and older combustion facilities are provided and are based on four basic designs of different capacities. The four designs include:

1. 100 ton per day (TPD) modular/starved air plant
2. 240 TPD modular/excess air plant
3. Mass burn/waterwall facilities handling 800 tons per day
4. Mass burn/waterwall facilities handling 2,250 tons per day

All designs assume that the facility will be operated to maintain compliance with all applicable regulations. The default heat rate assumes energy recovery. This can be changed for facilities that do not recover energy. Cost assumptions for the four designs are based on a U.S. EPA study (U.S. EPA, 1989) to estimate the cost implications for proposed emission standards. More recent cost data for NO_x pollution control devices and carbon injectors was used from the U.S. EPA (1994).

The air pollution control equipment assumed to be present in a modern combustion facility include a spray dryer for acid gas control, injection of activated carbon for mercury control, ammonia or urea injection for NO_x control (by conventional selective non-catalytic reduction) and a fabric filter for PM control. After the air pollution control equipment, the flue gas is released to the atmosphere through the plant stack. The fly ash is collected, mixed with the bottom ash, and sent to a landfill. In addition, air pollution monitoring equipment is installed in the facility.

3.4.1 Cost Methodology for Combustion

Default cost values for new combustion facilities are based on a regression of the four model plants described above. The regression was performed to arrive at linear cost functions. The cost of the combustion facility is assumed to be proportional to the facility capacity, though the revenue from energy recovery is a function of the BTU input to the plant. Costs are divided into capital costs, O&M costs, residue disposal costs, ferrous recovery revenue, and electricity generation revenue.

Capital cost includes the cost of combustors, ash handling system, turbine, and air pollution control and monitoring devices. The capital cost of a combustion facility is calculated from a unit capital cost with units of dollars per ton feed rate. It is adjusted with a capacity factor to account for the fact that the plant cannot operate at full capacity at all times. In addition, it can be expressed in annual terms using a given capital recovery factor that is dependent upon a book lifetime and discount rate.

O&M costs of the combustion facility includes the labor, overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, electricity cost and maintenance cost. The O&M cost function depends upon the unit O&M cost, the rate at which waste enters the plant (expressed in energy per unit time), the capacity factor, and the cost of ash disposal. Again, we developed default cost relationship by linear regression.

Combustion residue includes ash, unburned waste, and flue gas cleaning residue. Combustion residue includes fly and bottom ash attributed to combustion of the waste. The bottom ash includes combustible materials that do not combust due to inefficiencies of the combustors. The cleaning residue includes the solid salts formed in the neutralization of the acid gases. The cleaning residue is removed along with the fly ash by the fabric filter bags.

Electricity that is generated by recovery of heat from combustion of waste is sold to an end user. The recovery of the heat is not perfectly efficient. This inefficiency is represented by the heat rate of the plant in BTU per kWh. This heat rate takes into account the house load of the combustor.

Ferrous metal can be recovered from the bottom ash and can provide some revenue to help offset the costs of the combustion facility. Based on calculations presented in the full model documentation, the cost of a magnet to separate the iron from the bottom ash is sufficiently small in comparison to the imprecise estimate of the ferrous scrap price that it can be ignored.

3.4.2 LCI Methodology for Combustion

The LCI methodology calculates energy consumption or production, and environmental releases from the combustion process and allocates these LCI parameters to individual components of the waste stream.

<u>Energy recovered</u> by a WTE facility is credited as an energy gain in the LCI inventory, and it is assumed to displace a similar amount of electricity produced from conventional fuels (e.g., coal, natural gas). The exact mix of the energy that is based on the regional energy grid or fuel mix specified by the user in the electrical energy process model.

<u>Net emissions</u> from a WTE facility are the post treatment emissions from the combustion facility minus the emissions that would have otherwise been produced by the avoided electricity production.

Different sets of default <u>air emission</u> factors for combustion of MSW are provided in the process model. These defaults are based on existing combustors in compliance with standards for existing facilities. The user may override these emission factors with site-specific factors based on performance tests. For existing facilities, default emission factors corresponding to the regulatory limits for existing combustion facilities may be selected. For newer facilities, default emission factors are provided based on U.S. EPA (Radian Corporation, 1995) performance testing for new facilities and corresponding regulatory limits for new combustion facilities. For unregulated pollutants, defaults emission factors based on actual performance tests are provided.

Although air emissions may be based on performance or regulatory limits, the composition of the waste still impacts emission levels. For example, while a pollutant may be controlled to a particular emission concentration, the volume of flue gas produced from the combustion of the waste components will dictate the mass emission rates of the pollutants. Since flue gas production per ton varies considerably from component to component, the mass emission rates per ton of aggregate waste will vary with composition based on this methodology. Importantly, the flue gas production per ton of waste component is based on a stoichiometric combustion equation for the MSW components and relies on ultimate analysis studies that provide the carbon, nitrogen, hydrogen, oxygen, sulfur and chlorine contents of the waste constituents.

Default air emission factors for metals are handled somewhat differently for the case where regulatory limits are not assumed and for unregulated metals. Metals content by waste component and the partitioning of metals to the flue gas as observed in the Burnaby study (Chandler & Associates Ltd., et al., 1993) is used in conjunction with metals removal efficiencies based on multiple modern combustion facilities to form the basis for the calculations of mass metals emission rates. For lack of sufficient theory and empirical studies relating metals volatilization to waste composition, an underlying, albeit crude, assumption is made that metals emissions vary in proportion to metals input to the combustor. This approach was deemed to be preferable to the simpler approach that would have metals emissions vary with mass input alone with no sensitivity to the metals content of the waste.

Water releases associated with the combustion process are post-treatment releases from publicly operated treatment works of water used in the process and those offset by generation of electricity. Net releases from the combustion facility are the releases from water use in the combustion facility minus the releases that would otherwise have been produced by the type of utility generation displaced.

Solid wastes from the combustion process include the ash residue from combustion of waste and the solid wastes offset by generation of electricity. Ash residue is transported to a dedicated ash landfill for disposal and is not counted as solid waste in the overall model.

3.5 REFUSE-DERIVED FUEL (RDF) AND PROCESSED REFUSE FUEL (PRF)

The objective of the Processed Refuse Fuel (PRF) and Refuse Derived Fuel (RDF) process model is to calculate the cost and LCI parameters for converting MSW into fuel that is combusted in on-site combustors. The user can choose to use either the PRF design or the RDF design in the design of their integrated solid waste management system. Costs and LCI parameters are calculated on the basis of user input and default design information. Based on the cost and LCI design information, coefficients are calculated in the process model to represent the cost and environmental burdens associated with a PRF or RDF facility. The coefficients take into account both the quantity and composition of the waste input to a PRF and RDF facility and are used in the solid waste management model to calculate the total system cost and LCI parameters for solid waste management alternatives that involve the PRF and RDF processes.

The mathematical equations used for model development are presented in the combustion model documentation. Mass balance equations used to estimate the quantity and composition waste moving through the PRF or RDF process designs are presented in this document. The cost and LCI allocation methodologies are identical to the combustion process model, and are not presented in this document.

Two designs for fuel processed from mixed waste are presented in this document. The differences between the PRF and RDF lie in steps in the process flow design preceding combustion of fuel. The following sections present descriptions of the processes involved in a Processed Refuse Fuel facility and a Refuse Derived Fuel facility.

Processed Refuse Fuel Facility

For the PRF facility, MSW is conveyed directly into a shredder to provide a maximum particle size of 6 inches, with most of the materials being less than 2 inches in size. The shredded material is then passed under a magnet for removal of approximately 40% to 50% of the ferrous metal. The remaining shredded material now termed PRF, is blown into specifically designed boilers at a point approximately 2 meters above a traveling grate. Lighter materials burn in midair while heavier portions of the fuel including non-combustibles, drop to the rear of the grate. The grate moves from the back to the front of the furnace to allow for complete burnout of any combustible material at an ash bed depth of 12-20 centimeters. The heat liberated by the combustion of the PRF is recovered to produce superheated steam for the generation of electricity. By forcing most of the combustion air through the grate, grate temperatures are maintained below the melting point of glass and most metals, thereby eliminating slagging and producing a granular bottom ash from which marketable materials can be recovered. From the bottom ash, a substitute for natural aggregate can also be produced. Bottom ash and fly ash are collected separately in a dry state, allowing for recovery of ferrous and nonferrous metals and the production of aggregate from the bottom ash and isolation of the fly ash for conditioning and disposal by landfilling and for future beneficial reuse.

In the PRF process model design used in the MSW DST, it is assumed that there is no revenue associated with the sale of building aggregate material or coins and other metals that may be recovered from the bottom ash. The combustion stoichiometry and emissions allocation are exactly the same as in the combustion process model. Refer to the combustion model documentation for more information about emission estimation and allocation procedures.

Refuse Derived Fuel Facility

In the RDF facility, refuse that is received either unconfined or in bags, is loaded onto a conveyor system and enters a flail mill. The flail mill opens any unopened bags and reduces the sizes of some of the breakable materials in the refuse. From the flail mill, the refuse passes under a magnet that recovers ferrous materials which are a source of revenue. The remainder then continues into a trommel for removal of material less than 2 inches in diameter. The trommel removes materials like broken glass, grit, sand, etc. From the trommel, the refuse is shredded in a shredder to reduce the size of components of the waste. The shredded waste then passes through an air classifier that separates the "lights," considered to have the high BTU content, from the "heavies," which have a relatively low BTU content. The "lights" then flow to an eddy current separator for aluminum removal. The material remaining after aluminum removal is combusted and the heat energy liberated is converted to electricity.

The combustion stoichiometry and emissions allocation in the RDF process model are exactly the same as in the combustion process model.

3.5.1 Cost Methodology for RDF and PRF

Costs for the PRF and RDF facility designs are divided into six components: capital cost, operation and maintenance cost, revenue from electricity generation and revenue from ferrous recovery, and revenue from aluminum recovery. The cost equations for the PRF and RDF facilities are exactly the same as those in the combustion process model. Refer to the combustion documentation for details of the cost methodology.

3.5.2 LCI Methodology for RDF and PRF

The LCI equations for the PRF and RDF facility are exactly the same as for the combustion process model. Refer to the combustion documentation for details of the LCI methodology.

3.6 MIXED MUNICIPAL AND YARD WASTE COMPOSTING

The composting process model captures both MSW and yard waste composting operations. Composting using the windrow turner method is used for both types of facilities, instead of aerated static pile designs and in-vessel systems. The windrow turner design was selected because it is used by a majority of compost facilities in the United States.

The three composting facility designs included in the system are summarized as follows:

COMP 1: MSW compost facility, low quality compost. Processes mixed MSW is collected and preprocessed at a MRF to remove any recyclable or non-compostable materials. This facility produces low quality compost that is used for landfill cover or is landfilled.

COMP 2: MSW compost facility, high quality compost. Processes mixed MSW is collected and preprocessed at a MRF to remove any recyclable or non-compostable materials. This facility produces high quality that is used for soil amendment.

COMP 3: Yard waste compost facility. Processes yard wastes (e.g., branches, grass, leaves) is collected and delivered to the compost facility by residents or a yard waste transfer station. Only one type of yard waste facility is designed; it is the same general design as the high quality MSW compost facility design.

In the general compost facility design, waste is collected at curbside and transported to a MRF where recyclables and non-compostable materials are removed. The residual mixed waste is transported to a compost facility. At the compost facility, waste is deposited onto a tipping floor, where large items (if any) are removed manually. A front-end loading introduces the waste to a preprocessing trommel screen. The finer fraction is directed to the composting pad or hammermill for shredding and then to the composting pad. The oversized fraction is sent to a landfill for disposal. Moisture is added to the compost to achieve an optimal moisture content. Turning, mixing, and aeration of the windrows takes place once or twice a week (a user input value) using self-propelled windrow turner. Curing takes place without any turning of the curing piles in an uncovered area, while cured compost is distributed for use as cover or sold as soil amendment. The compost facility is designed to handle MSW tonnage rates from 10 to 10,000 tons per day.

Note that there are some minor differences in the process flows of the different compost facility designs depending on the type of material being processed and desired quality of the final product. Refer to the full compost process model document for descriptions of the alternative compost facility designs.

3.6.1 Cost Methodology for Composting

The cost of a compost facility depends on the type of facility, the quantity and type of material processed, and user input data. Costs are divided into capital costs, O&M costs, and revenue from the sale of compost.

<u>Capital cost</u> consists of construction, land acquisition, engineering, and equipment cost that can be expressed in annual terms using a given capital recovery factor that is dependent upon a book lifetime and discount rate.

- Construction cost includes the cost of the structure, access roads, fencing, landscaping, etc. The cost of the structure includes support facilities such as office space, a weigh station, and the loading conveyer. Construction cost is obtained by multiplying the floor area of the compost facility by the construction cost rate. Total area for the facility includes area for the structure, access roads, fencing, weigh station, landscaping, etc. Total area multiplied by a cost rate gives the land acquisition cost.

- Engineering cost consists of fees paid for consulting and technical services for the compost facility planning and construction, and is estimated to be a fraction of the construction cost.

- Equipment cost consists of the capital and installation cost of equipment.

<u>O&M costs</u> of the compost facility includes wages, overhead, equipment and building maintenance, and utilities.

- Labor required for the compost facility consists of management, drivers and equipment operators. In estimating the labor wages, it is assumed that part-time services can be hired. Management includes managers, supervisors, and secretaries. The wages paid for management are assumed to be a fraction of the wages paid to drivers and equipment operators.

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

- The cost of utilities, assumed to be electricity, fuel, oil, etc., is assumed to be proportional to the weight of incoming MSW or yard waste.

- The cost of maintenance of equipment and structure is assumed to be proportional to the weight of incoming MSW or yard waste.

High quality compost that is produced by the high quality MSW compost facility or yard waste compost facility may be sold as soil amendment and thus provide revenue to help offset the costs of the compost facility. The user can enter the value of compost.

3.6.2 LCI Methodology for Composting

The LCI methodology calculates energy consumption or production, and environmental releases from the compost facility and allocates these LCI parameters to individual components of the waste stream.

The composting process model accounts for two types of energy consumption: fuel and electricity. The energy calculations include:

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

For electricity, the source of energy depends on the regional energy grid used. Default data on the energy required to produce a unit of electricity, including its precombustion energy, are included in the electric energy process model documentation. The composting process model uses default or user-supplied data on fuel consumed by rolling stock, for heating and lighting purposes, and for processing equipment to calculate the total quantity of energy consumed per ton of material processed.

The composting process model accounts for airborne releases from two sources: (1) the pollutants released when fuel is combusted in a vehicle (combustion releases), and (2) the pollutants emitted from the biodegradation of organic material. Data for fuel production and electricity generation, and associated air emissions, are included in the common process model. Data for air emissions resulting from the biodegradation of organic material are being developed through a laboratory experiment being conduct at the University of Wisconsin-Madison. In this experiment, food, mixed paper, yard waste, and inorganics are biodegraded in lab-scale vessels. Emissions from the vessels are captured and analyzed and will ultimately be used to develop air emission factors for all waste components.

The compost process model accounts for waterborne pollutants associated production of energy (electricity and fuel) consumed at the compost facility. There are no process related water releases. Default values for water releases from energy production are provided in the common process model.

The compost process model uses the fuel consumed and energy consumed by equipment and for heating and lighting the compost facility to calculate the solid waste generated. Solid waste generation is expressed in terms of pounds of pollutant per ton of material processed. Note that the solid waste referred to in this section pertains to the waste generated when energy is produced. Default values for solid wastes generated due to energy production are provided in the common process model. Solid waste remaining after non-compostables are removed (residue) is routed to a treatment or disposal facility. The LCI of residue is accounted for in these treatment and disposal facilities.

3.7 LANDFILL

The objective of the landfill process model is to calculate the cost and life-cycle inventory (LCI) for the burial of one ton of municipal solid waste (MSW) or combustion ash in a landfill. The model is designed to calculate the cost and LCI for one ton of waste in consideration of user-input and default values for a conventional, bioreactor, and ash landfill and can also to specify whether the landfill includes liner, landfill gas collection, and leachate collection systems. The formats for the three types of landfills are similar and areas of divergence are addressed in the following section.

Three types of landfill designs are included in the MSW DST:

1) conventional landfills operated to minimize moisture infiltration,
2) bioreactor landfills operated to enhance decomposition, and
3) ash landfills.

These landfills are primarily defined by their physical characteristics and by the waste that they receive. All landfills are designed and operated in compliance with RCRA Subtitle D regulations. Bioreactor landfills use leachate recycling to enhance waste decomposition, leachate stabilization, and gas production. Ash landfills accept MSW incinerator ash.

All three landfill process models contain five different phases in the landfill lifecycle:

- Operations: considers fuel use and equipment emissions associated with landfill operation.
- Closure: considers fuel use and equipment emissions associated with landfill closure.
- Post-closure: This section details the post-closure phase of a modern MSW landfill including cover maintenance and monitoring.
- Landfill Gas: This section describes gas generation, treatment, and utilization.
- Landfill Leachate: This section describes leachate generation and treatment.

Contrary to other waste management options, which generally have instantaneous, landfill emissions occur over time. The emissions associated with disposal of a ton of waste in a landfill are reported for one of three user selected time horizons beginning from when the waste is placed in the site:

- A short-term time frame (20 years) corresponding roughly to the landfill's period of active decomposition.
- An intermediate-term time frame (100 years) corresponding roughly to the life span of a given generation.
- A long-term time frame (500 years) corresponding to an indefinite time reference, at which point the emission of any given environmental flow will have likely reached its theoretical yield.

Emissions are estimated for one time horizon which the user selects.

3.7.1 Cost Methodology for Landfills

The methodology used to estimate the costs associated with the three landfill options are described in the following sections. Landfill costs fall into four main categories: initial construction, cell construction, operations, and closure. To calculate the cost for each of these categories, the size of the landfill is needed. In order to size the landfill, the waste flowing to the landfill must be known. However, the waste flow to the landfill is specified by the decision support tool solution. Thus, to use the landfill process model, the size is based on user input values for the facility life and daily waste flow. As input by the user, these parameters are used to provide a rough estimate of landfill size which is used to calculate costs.

Landfills represent a unique problem relative to other MSW management unit operations in that all other operations have a useful life and assumed replacement cost equal to its original cost. The same assumption is made for replacing a landfill.

Initial Construction Cost

Included in the initial construction cost are land acquisition; site fencing; building and structures required to support operation of the landfill and for a flare required for landfill gas treatment; platform scales; site utilities installation; site access roads; monitoring wells; initial landscaping; leachate pump and storage (in accordance with 40CFR258.40); site suitability study, planning and licensing. A multiplier is applied to the overall initial construction cost to account for engineering costs. The total cost is then amortized over the operating period of the facility and normalized to the annual volume of waste received.

Cell Construction Cost

The section summarizes the costs applicable to the development and preparation of each individual cell of the landfill. Cell construction costs include site clearing and excavation; site berm construction; liner systems (if specified and in accordance with 40CFR258.40); leachate control materials for traditional and ash landfills; leachate collection and recirculation materials for bioreactor landfills; and any cell pre-operational costs (e.g., engineering design, hydrogeologic studies). The total cell construction cost is amortized over the operating period of the facility and normalized to the annual volume of waste received.

Operation and Maintenance Cost

The operation and maintenance (O&M) costs of a landfill include labor, equipment procurement, leachate treatment, daily cover overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, utilities, and maintenance. The O&M cost function depends upon the unit O&M cost, the rate at which waste enters the landfill. There is no amortization of the annual operation and maintenance because they are annual, recurring costs.

Closure and Postclosure Cost

Closure costs for the landfill model include costs associated with the installation of the final landfill gas extraction system (in accordance with 40CFR258.23); final cover (can include soil, geotextile, sand, HDPE, and clay as specified by the user); cost of replacing final cover; and perpetual care. The total closure cost is amortized over the operating period of the facility and normalized to the annual volume of waste received.

Revenue from Landfill Gas

If a turbine, boiler, or internal combustion engine is used to treat landfill gas, it may result in a revenue stream for the landfill. Three gas collection periods are defined in the model. Within each of the gas collection periods, the user has five options for landfill gas treatment: vent, flare, turbine, direct use, and internal combustion engine.. The electricity that is generated is assumed to be sold to an end user. The default value for revenue from electricity generation is set at the national average per kWh. The yearly revenue generated during each landfill gas treatment period is converted to the present value and then annualized over the operating life of the landfill. The amortized revenues are for each period are then summed to obtain the total revenue from landfill gas treatment. This total revenue offsets the cost of landfill construction, operation, and closure.

3.7.2 LCI Methodology for Landfills

The LCI methodology calculates the net energy consumption and environmental releases (air, water, and solid waste) from the landfill construction, operation, closure and post closure and allocates these LCI parameters to individual components of the waste stream.

Energy

Energy is consumed during the operation, closure and post-closure phases of the landfill. Energy that is recovered is credited as an energy gain in the LCI, and it is assumed to displace a similar amount of electricity produced from conventional fuels (e.g., coal and natural gas). However, the exact mix of the energy that is offset can be specified by the user if it is known. In addition, the user can specify whether or not energy is actually recovered.

Air Emissions

Air emissions are associated with equipment use during each phase of the landfill as well as with decomposition of the buried waste and emissions during leachate treatment. Where energy is recovered, some air emissions associated with electrical energy production from fossil fuel is avoided.

Water Releases

Water releases associated with the landfill are post-treatment releases from publicly operated treatment works (POTW) of leachate. Net releases from the landfill are the releases from the POTW plus uncontrolled leachate. If energy if recovered from the landfill, then water releases would net out the releases that would otherwise have been produced by the type of utility generation displaced.

Solid Waste Releases

Solid wastes from the landfill processes include the solid wastes associated with energy utilization, treatment of landfill leachate, and production of landfill materials. If energy is captured at the landfill, then total solid waste is calculated by netting out the solid waste that would have otherwise been produced by the type of utility generation being displaced.

3.8 ELECTRICAL ENERGY

The electric energy process model provides an accounting of the total energy consumption and emissions resulting from the generation and use of electric energy. Pre-combustion and combustion energy consumption and emissions on a per unit fuel basis are used in conjunction with unit efficiencies, transmission and distribution line losses, and electric generation fuel types to allocate energy consumption and emissions to the use of a kilo-watt hour (kWh). Emissions and energy consumption per kWh are calculated for the national grid fuel mix as well as for the nine major electrical generating regions in the United States (see Tables 3-3 and 3-4). The user may input a site-specific fuel mix.

The user may also change the default values for fuel mix by region, power generation efficiency, and other defaults.

The electrical energy process model results are used by spreadsheet models for other unit operations to obtain the total energy consumption and emissions related to electric energy usage in those unit operations. For example, energy is consumed and emissions result for each kWh of electricity used to operate a baler in a MRF. For each kWh consumed, the electrical energy process model provides the total energy consumed and the resulting emissions (pre-combustion and combustion).

3.8.1 Energy Conversion Processes

The vast majority of electrical energy in the United Sates is derived from seven major sources:

coal, natural gas, residual oil, distillate oil, uranium, hydroelectric and wood. Therefore, these seven major fuel types are addressed by the electric energy process model with provision for the model user to include one “other” fuel type. Key points associated with each of the major fuel types are as follows:

- **Coal:** Pre-combustion energy and emissions for coal are associated with surface and underground mining operations, size reduction, cleaning and transportation. Use of coal as a fuel consists of burning it in a boiler to produce steam that is then used to generate electricity or is used for other process operations.

- **Natural Gas**: Pre-combustion energy and emissions for natural gas are associated with oil well operations, pipeline pumping, transportation, and fugitive emissions from pumping and production facilities. Use of natural gas as a fuel consists of combusting it in several types of facilities including gas turbines and combined cycle units to produce steam that is then used to generate electricity or is used for other processes.

- **Residual and Distillate Oils:** Pre-combustion energy and emissions for residual and distillate oils are associated with oil well operations, refining (process and fugitive emissions), and transportation. Use of residual and distillate oils as fuels consists of combusting them in boilers to produce steam that is then used to generate electricity or is used for other process operations.

- **Nuclear:** Pre-combustion energy and emissions for nuclear fuel are associated with surface and underground mining operations, refining (process and fugitive emissions), and transportation. Use of nuclear fuel consists of reacting it in a nuclear reactor to produce steam that is then used to generate electricity.

- **Hydroelectric:** There are no pre-combustion energy and emissions associated with hydroelectric power generation, as a default. Use of hydraulic fuel usually consists of damming a river and using the potential energy of the entrained water to generate electricity by passing it through a water turbine-generator.

- **Wood:** Since wood fuel is usually a by-product of other wood processing operations and is usually burned on site for self-generated electricity, there are no pre-combustion emissions associated with wood fuel, as a default. Use of wood as a fuel consists of combusting it in a boiler to produce steam that is then used to generate electricity or is used for other process operations.

Insignificant contributions are made by sources such as solar, wind, geothermal, and other emerging technologies.

To provide the appropriate emissions and energy usage values to the various model components, it was necessary to define fuel usage by type for national and regional grids. Table 3-3 shows the regional grid definitions that have been adopted. The geographic locations of these grids are defined in Table 3-4. These grid definitions were adopted since they represent the vast majority of the United States, the area to which the model will most likely be applied. However, a "user-defined" region has been included to allow the model user to define a region with unique characteristics not available in the Table 3-3 default regions.

3.8.2 Cost Methodology for Electrical Energy

Cost for electrical energy generation is *not* included in the boundaries for cost analysis. The cost that waste management operations accrue for electricity consumption is accounted for in the individual waste management process models.

Table 3-3. Electric Region Definitions

Control Area Name	Control Area Description
ECAR	East Central Area Reliability Coordination Agreement
ERCOT	Electric Reliability Council of Texas
MAAC	Mid-Atlantic Area Council
MAIN	Mid-America Interconnected Network
MAAP	Mid-Continent Area Power Pool
NPCC	Northeast Power Coordinating Council
SERC	Southeasterm Electric reliability Council
SPP	Southwest Power Pool
WSCC	Western Systems Coordinating Council
User Defined	User Defined Electric Region

Table 3-4. Electric Region Locations

Control Area Name	Location
ECAR	Michigan, Indiana, Ohio, Kentucky, West Virginia
ERCOT	Texas
MAAC	Pennsylvania, New Jersey, Maryland, Delaware
MAIN	Illinois, Missouri (east) Wisconsin (excluding north west)
MAAP	North Dakota, South Dakota, Nebraska, Minnesota, Wisconsin (east)
NPCC	New York, Vermont, Connecticut, Maine, Rhode Island, New Hampshire
SERC	North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Mississippi
SPP	Kansas, Oklahoma, Arkansas, Louisiana, Mississippi (west) Missouri (west)
WSCC	Washington, Oregon, Colorado, California, Nevada, Montana, Idaho, Wyoming, Utah, Arizona, New Mexico

3.8.3 LCI Methodology for Electrical Energy

Wherever electricity is consumed in the waste management portion of the system, the cost for electricity accrues to the local government. However, environmental burdens association with the production and consumption of that electricity affects society as a whole. Therefore, the global environmental burdens associated with electrical energy production (termed precombustion emissions) are considered in this research. This section summarizes the approach used to determine precombustion emissions for different locales.

Electric Generation Fuel Usage

The national generation weighted usage for each fuel type was calculated from North American Electric Reliability Council (NERC) regional databases submitted to the Energy Information Administration (EIA) for 1994. These databases include several thousand generating units from the nine NERC regions in the continental United States and represent the vast majority of the U.S. generating capacity. The regional generation weighted usage for each generating region and fuel type were also calculated using EIA data.

Total Fuel Emissions

Pre-combustion and combustion emissions generated per 1000 fuel units combusted (pounds of coal, cubic feet of natural gas, etc.) on a national and regional basis are included in the appendices of the electric energy process model documentation. The default emissions data for all regions have been set to the values for national generation since data for fuel-related emissions for each of the nine generating regions were not available.

Energy and Emissions Offsets

To account for the energy and emissions savings associated with utility generation that is not required as a result of generating electricity from combusting MSW, RDF, or gases recovered from landfill or anaerobic digestion, it is necessary for the model user to specify the type of utility generation that is being displaced. This would typically be the type of generating unit being constructed in the region by the utility. The majority of units currently being constructed are coal and natural gas fueled. However, the type of fuel that would be displaced depends on the regional base-loaded fuel mix. For example, oil units are often base-loaded in Northeast states. If a base-loaded MSW combustor with energy recovery came on line in the northeast, the utility might back down an expensive oil-fired unit. Therefore, the definition of displaced fuel types is user definable with the default being coal and natural gas.

The default values and calculation methodology discussed in the preceding sections have been implemented in the electrical energy portion of the overall LCI model to ensure that the LCI implications of electrical energy consumption in various unit processes are accounted for. The intent of this implementation is to provide the best available default information. It is also to provide a model that is responsive to macro-level user input values such as electric generating region and generating efficiency by fuel type while allowing for user override of micro-level inputs such as emissions associated with coal combustion should region-specific data become available.

3.9 INTER-UNIT TRANSPORTATION

The inter-unit transportation process model includes transportation by rail, heavy-duty diesel (tractor trailers), light-duty diesel vehicles, and light-duty gasoline vehicles. The type of roadway transportation utilized between any two given nodes is site specific. However, typically tractor trailers are utilized for long distance hauling to economize on transportation costs, while light-duty vehicles are utilized for shorter distances and more frequent trips.

Cost and LCI factors for transport of mixed refuse, fuel, and compost are calculated per ton of aggregate mass flow between nodes. In contrast, recyclable materials are often shipped separately and have item-specific densities. For example, loose glass has a density nine to ten times that of plastic. For this reason, item-specific cost and LCI factors are calculated for recyclables transport. Connections for which item-specific factors are determined for recyclables include transport from transfer stations to separation facilities and from separation facilities to remanufacturing.

For each nodal connection, unique cost and LCI factors are calculated based on user input values pertaining to transportation modes and connections between facilities. The governing equations presented in this section fall into three categories:

1. Rail transport of mixed refuse.
2. Roadway transport of non-recyclables (mixed refuse, refuse recovered for fuel, and compost).
3. Roadway transportation of recyclables.

Refer to the full process model documentation for complete descriptions of the alternative inter-unit process transportation categories.

3.9.1 Cost Methodology for Inter-Unit Process Transportation

The cost methodology for mixed refuse rail transport, non-recyclables roadway transport, and recyclables roadway transport are discussed in this section. Unique factors for each nodal connection are calculated based on input values specific to each nodal connection. Cost factors are based on the rate charged for hauling MSW. Rail transportation costs also include fees for the use of existing local rail lines between a community and a landfill. The cost for spurs built to connect existing rail lines to a transfer station and rail lines within transfer station sites are included in transfer station cost factors. Costs and LCI factors associated with moving MSW from the landfill rail transfer stations to the working face of the landfill are accounted for in the transfer station cost.

Rail transportation costs are calculated on a per ton basis from the user input hauling rate in units of dollars per ton per mile and the distances between nodes.

Cost factors for roadway transportation of non-recyclable are calculated on a per ton basis from the user input hauling rate in units of dollars per mile, vehicle weight capacity and the distances between nodes. Item-specific factors are determined for recyclables because recyclable item densities vary. To calculate weight based factors, volume based costs for each transportation connection between nodes are first calculated. Volume based costs are divided by item-specific densities to give weight based factors. Costs per ton are then calculated for each recyclable item.

3.9.2 LCI Methodology for Inter-Unit Process Transportation

LCI factors account for production and combustion of fuel utilized by transportation vehicles. If the user selects a two-way trip as input for roadway transport connections, then calculated factors will account for empty vehicles returning to the origin. The transportation process model accounts for fuel energy used in vehicles to transport materials. The fuel energy calculations include:

1. Combustion energy: the energy used by rail engines and hauling vehicles, and
2. Precombustion energy: the energy required to manufacture the fuel from feed stock.

The process model uses default or user-supplied data on fuel consumed (e.g., diesel) for rail haul and roadway transport to calculate the total quantity of energy consumed per ton of material processed.

The transportation process model accounts for airborne releases from two sources: (1) the pollutants released when fuel is combusted in a vehicle (combustion releases), and (2) the pollutants emitted when the fuel was produced. Data for fuel production are included in a common process model, which contains data and conversion factors for common processes throughout the system.

The transportation process model accounts for waterborne pollutants associated production of energy (fuel) consumed during transportation of recyclables and waste. There are no process related water releases. Default values for water releases from fuel production are provided in the common process model.

Solid waste generation associated with the transportation process model are from production of fuel consumed by vehicles. Solid waste generation is expressed in terms of pounds of pollutant per ton of material transported. Default values for solid wastes generated due to energy production are provided in the common process model.

3.10 REMANUFACTURING

The remanufacturing process model was developed so that the net environmental benefit of recycling various materials could be captured. Whenever a material is recovered from the MSW stream it is assumed to be sold and recycled into a "new" product. The use of recycled materials means that there is an offset of the use of virgin materials, which presumably would result in some environmental benefit.

The remanufacturing process model provides estimates of net energy usage and emissions estimates on a per ton basis for products produced using virgin and/or recycled materials. The approach that has been taken in the remanufacturing process model is "cradle to product" in which the LCI parameters are compared up to some point in each manufacturing process where a common product can be identified. For aluminum, this is the point at which aluminum ingots are produced. For newsprint and corrugated containers, this is the point at which newsprint and corrugated liner and medium are produced.

Beyond these common points in the manufacturing process, the LCI parameters for each product are assumed to be identical regardless of what product is ultimately manufactured. Therefore, downstream items such as staples for corrugated containers and emissions from transporting the product to the user are not included in the LCI since these items are assumed to be unchanged regardless of whether the product is made from predominately virgin or recycled resources. This distinction is important in that it captures the difference between recycled and virgin manufacturing processes and not the absolute environmental burden.

3.10.1 Cost Methodology for Remanufacturing

The costs associated with remanufacturing any given material accrue to the private sector and not to the public sector waste management entity. Therefore, remanufacturing costs are not included in this research.

3.10.2 LCI Methodology for Remanufacturing

In MSW 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, at a MRF, or at another 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 is then be calculated as the difference between (E_r)and (E_v), where ($E_n = E_r - E_v$).

While energy has been used here as an example, a similar calculation is performed for all LCI 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. The calculation described above is illustrated conceptually for ONP in Figure 3-2. Figure 3-2 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 the Figure, newsprint is not produced from 100% recycled material; some virgin material is mixed with the recycled fiber.

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 (containerboard, cellulose insulation, animal bedding, etc.). For each recyclable, it will be necessary to collect data on remanufacturing processes to complete the LCI. Data collection efforts will focus initially on the major remanufacturing process for each recyclable. Additional remanufacturing processes will be included to the extent that resources are available to collect data on more than one remanufacturing process. The system is designed with the capacity to incorporate more that one remanufacturing process into the analysis.

The remanufacturing process model includes LCI parameters for the following categories:

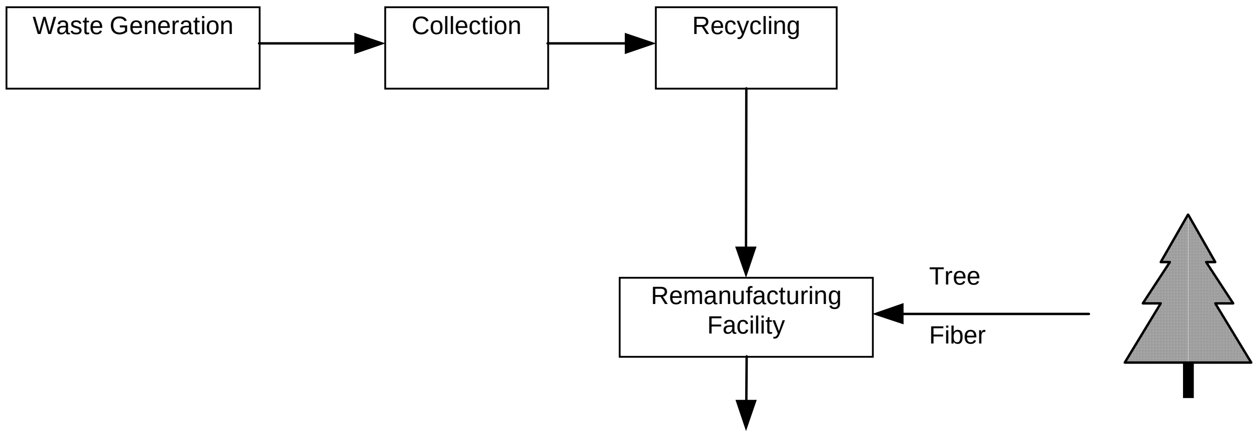
- **Material resource energy:** the fuel used in manufacturing that is physically integrated into the product rather that used to produce steam or electricity. Examples of this type of fuel usage are the use of coal to produce coke, which is then used to produce aluminum, or the use of petroleum to product plastics.

- **Combustion process energy:** the electricity consumed in producing the product and the energy associated with the amount of fuel combusted in the production process. An example of this type of fuel combustion is the use of coal in process boilers to produce process steam.

- **Pre-combustion process energy:** the energy consumed in mining and transportation steps required to produce fuels used in the manufacturing process. Examples of this type of energy are the use of energy to extract petroleum, transport it to a refinery, and produce natural gas that is combusted at a manufacturing facility for process steam.

- **Combustion transportation energy:** the energy consumed to transport the various intermediate products or materials to the next unit process in the system. This information is estimated by Franklin Associates, Ltd. using national average transportation distances and modes (truck, ocean freighter, etc.).

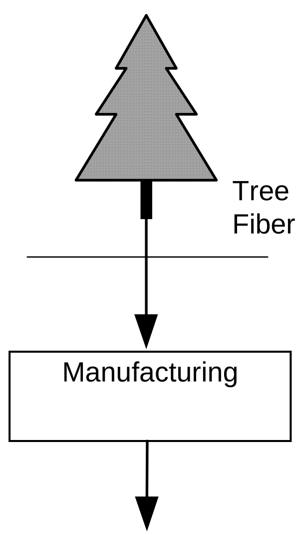
A. Calculation of E_r



1,000 Tons Secondary Newsprint

E_r = Total energy required to produce 1000 tons of newsprint using secondary material, from collection through new material production.

B. Calculation of E_v



E_v = Total energy required to produce 1,000 tons of newsprint from primary material. Includes energy from growth of trees through final production.

1,000 Tons of Primary Newsprint

Figure 3-2. Illustration of Framework For Calculating Remanufacturing Offsets for Newsprint.

- **Pre-combustion transportation energy:** the energy consumed in mining and transportation steps required to produce fuels for transportation. Examples of this type of energy are the use of energy to extract petroleum, transport it to a refinery, and produce diesel fuel for truck, ocean freighters, locomotives, etc.

- **Manufacturing emissions:** the total air, water, and solid waste emissions associated with both the production process and transportation energy consumption. This includes emissions from process, transportation, and pre-combustion activities.

- **Manufacturing energy consumption:** the total energy consumed in the manufacturing process, including combustion and precombustion, as well as process and transportation related energy consumption.

The LCI data for the virgin and recycled systems were compiled for this project by Franklin Associates, Ltd. and Roy F. Weston using a combination of their in-house LCI databases and publicly available LCI data.

Chapter 4
Research Products

The objective of this research effort has been to develop information and tool to assist solid waste planners in evaluating the relative cost and environmental performance of integrated MSW management strategies. The project is providing this information and tools through two main research products: a life cycle database and decision support tool. Each of these products is summarized in the following sections.

4.1 LCI DATABASE

The database is being developed to provide cost and life-cycle inventory type information for all unit processes included in the system (see Thorneloe et al., 1998 for a summary of data being collected). The approach used to build this database is as follows. First, data from publicly available and private MSW and LCA studies, and other relevant sources, were collected and reviewed against the data quality goals and data quality indicators established for this project. The data quality assessment is based on EPA guidance from *Guidelines for Assessing the Quality of Life Cycle Inventory Data* (Bakst et al., 1995). These existing data are being compiled into a database management system using commonly available software (Microsoft Access™). The format of the database is made as consistent as possible with other LCA data efforts and format guides such as SPOLD and SPINE in Europe and LCAD in the U.S.

The database management system was established to enable users to view environmental data for different aspects of waste management assessment. The main menu of the database is shown in Figure 4-1. Users can view LCI type data for energy production, equipment used in various waste management operations, general MSW properties (e.g., heating value), remanufacturing of recycled materials into new products, waste management data derived from the MSW DST and raw data collected from waste management operations. The menu for data relating to equipment that is used in various waste management operations is shown in Figure 4-2.

The database will be used to support the MSW DST, but it is not linked to the tool. Rather, the database will be made available as a stand-alone application that may be used as input data to other studies or models. If solid waste practitioners possess higher quality or more site-specific data than those provided in the database, users may add data to the database.

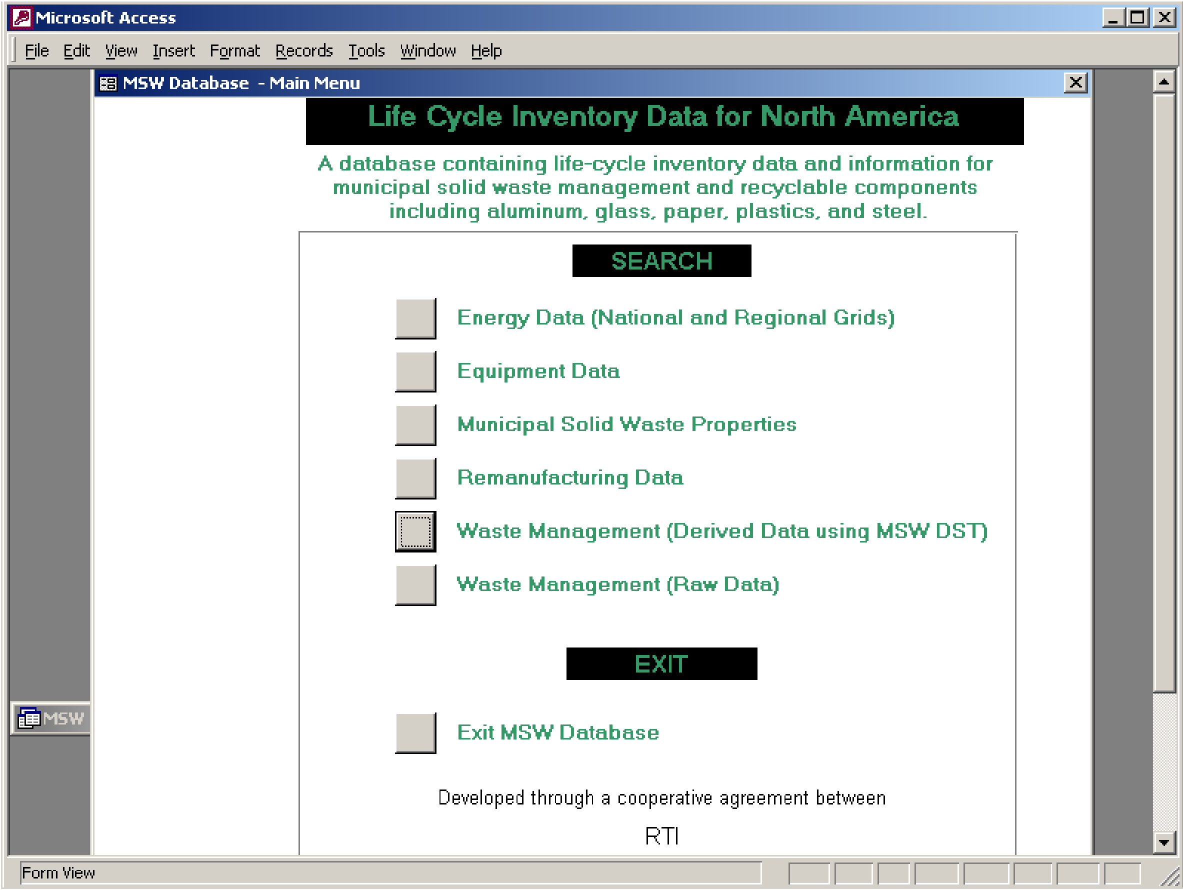


Figure 4-1. Main Menu from the Life Cycle Database

4.1.1 Appropriate Uses of the Database

The goal for the overall project is to develop information and tools to evaluate the relative cost and environmental burdens of integrated MSW management strategies. For instance, how does the cost and environmental burdens of a MSW management system change if a specific material (e.g., glass, metal, paper, plastic) is added to or removed from a community's recycling program? And, what are the tradeoffs in cost and environmental burden if paper is recycled versus combusted or landfilled with energy recovery?

The database was designed to enable users to perform such analyses, either through the use of the MSW DST developed in this project or through some other tool. The database can be used to perform such screening-level type analyses of MSW management options.

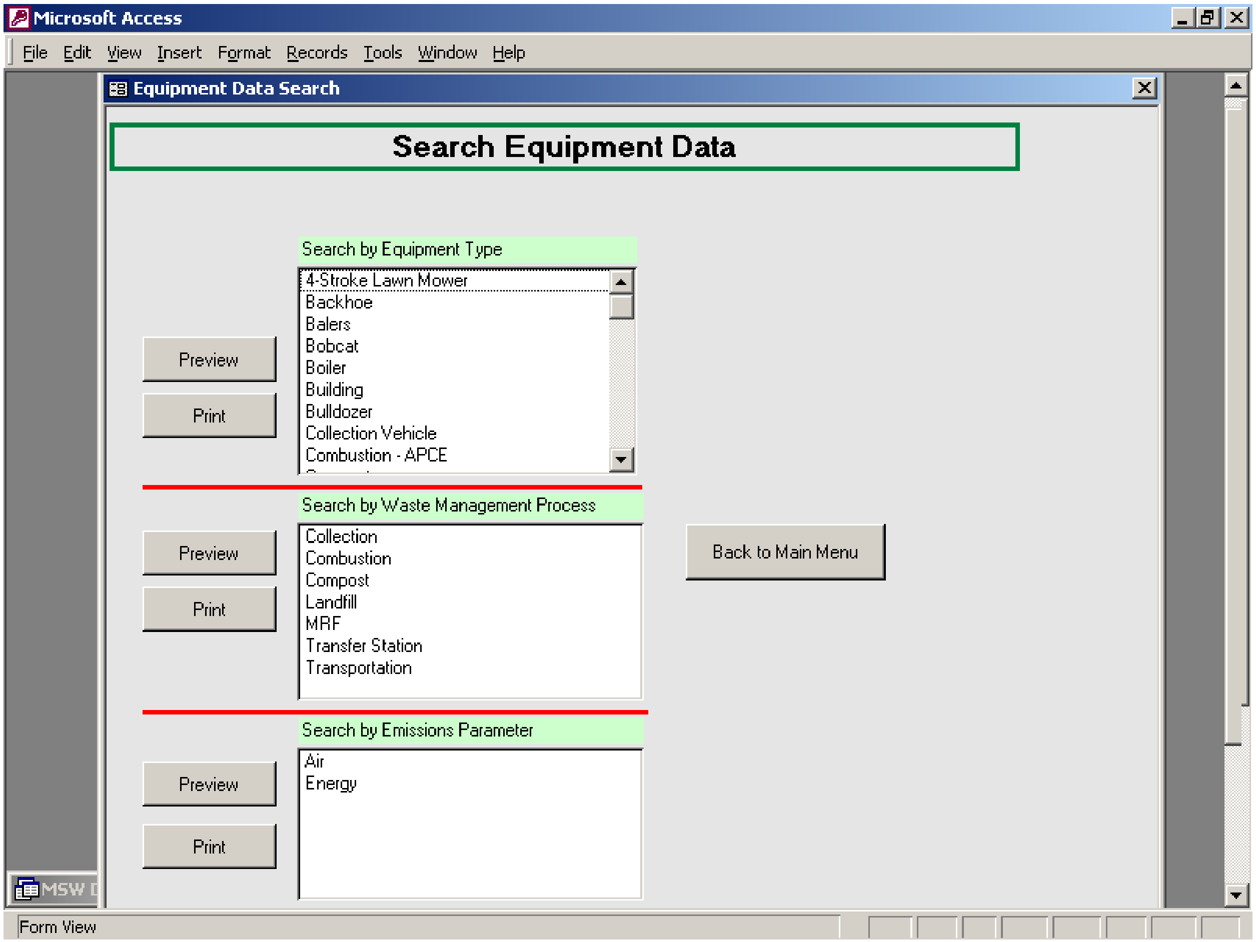


Figure 4-2. Menu for Waste Management Equipment

4.1.2 Limitations of the Database

See Chapter 1 of this document for a discussion of the limitations associated with the database. Appropriate uses and limitations of the database are also detailed in the database Users Manual, which is available as a stand-alone document.

4.2 MUNICIPAL SOLID WASTE DECISION SUPPORT TOOL (MSW DST)

The MSW DST provides a user-friendly interface that allows users to evaluate the cost and environmental burdens of existing solid waste management systems, entirely new systems, or some combination of both based on user-specified data on MSW generation, constraints, etc. The processes that can be modeled include waste generation, collection, transfer, separation (MRF and drop-off facilities), composting, combustion, RDF, and disposal in a landfill. Existing facilities and/or equipment can be incorporated as model constraints to ensure that previous capital expenditures are not negated by the model solution.

As illustrated in Figure 4-3, the MSW DST consists of several components including process models, waste flow equations, an optimization module, and a graphic user interface. The process models consist of a set of spreadsheets developed in Microsoft Excel. These spreadsheets use a combination of default and user supplied data to calculate the cost and environmental coefficients on a per unit mass (ton) basis for each of the MSW components being modeled (see Table 1) for each MSW management unit process (collection, transfer, etc.). For example, in the electric energy process model, the user may specify the fuel mix used to generate electricity in the geographic region of interest, or select a default grid. Based on this information, and the emissions associated with generating electricity from each fuel type, the model calculates coefficients for emissions related to the use of 1 kWh of electricity. These emissions are then assigned to MSW components for each unit process that uses electricity and through which the mass flows. MRFs, for instance, use electricity for running conveyor belts. The emissions associated with electricity generation would be assigned to the mass of materials that flowed through that facility. The user will also have the ability to override the default data if more site-specific data are available.

Optimization modeling is relatively new in life cycle studies and in this case allows MSW DST users to search for MSW management strategies that minimize an objective function. For example, the MSW DST currently enables users to optimize on annual cost, electricity consumption, greenhouse gas equivalents, or emissions of carbon monoxide, carbon dioxide (fossil or biomass), nitrogen oxides, particulate matter, and sulfur dioxide. The optimization module is implemented using a commercial linear programming solver called CPLEX and is governed by mass flow equations that are based on the quantity and composition of waste entering each unit process, and that intricately link the different unit processes in the MSW management system. Constraints in the mass flow equations preclude impossible or nonsensical model solutions. For example, the mass flow constraints will exclude the possibility of removing aluminum from the waste stream via a mixed waste MRF and then sending the aluminum to a landfill. Users may also specify constraints. Examples of user-specified constraints are the use of existing equipment/facilities and a minimum recycling percentage requirement.

The graphic user interface consists of a Microsoft Visual Basic routine that integrates the different components of the tool together to allow easy user manipulation of the spreadsheet models and the optimization module. It allows additional user constraints to be specified and provides a graphical representation of the solid waste management alternatives resulting from the optimization. Currently, results are presented on a dollar cost per ton or pounds of emission per ton basis and can be viewed at the system level, process model level, or MSW component level.

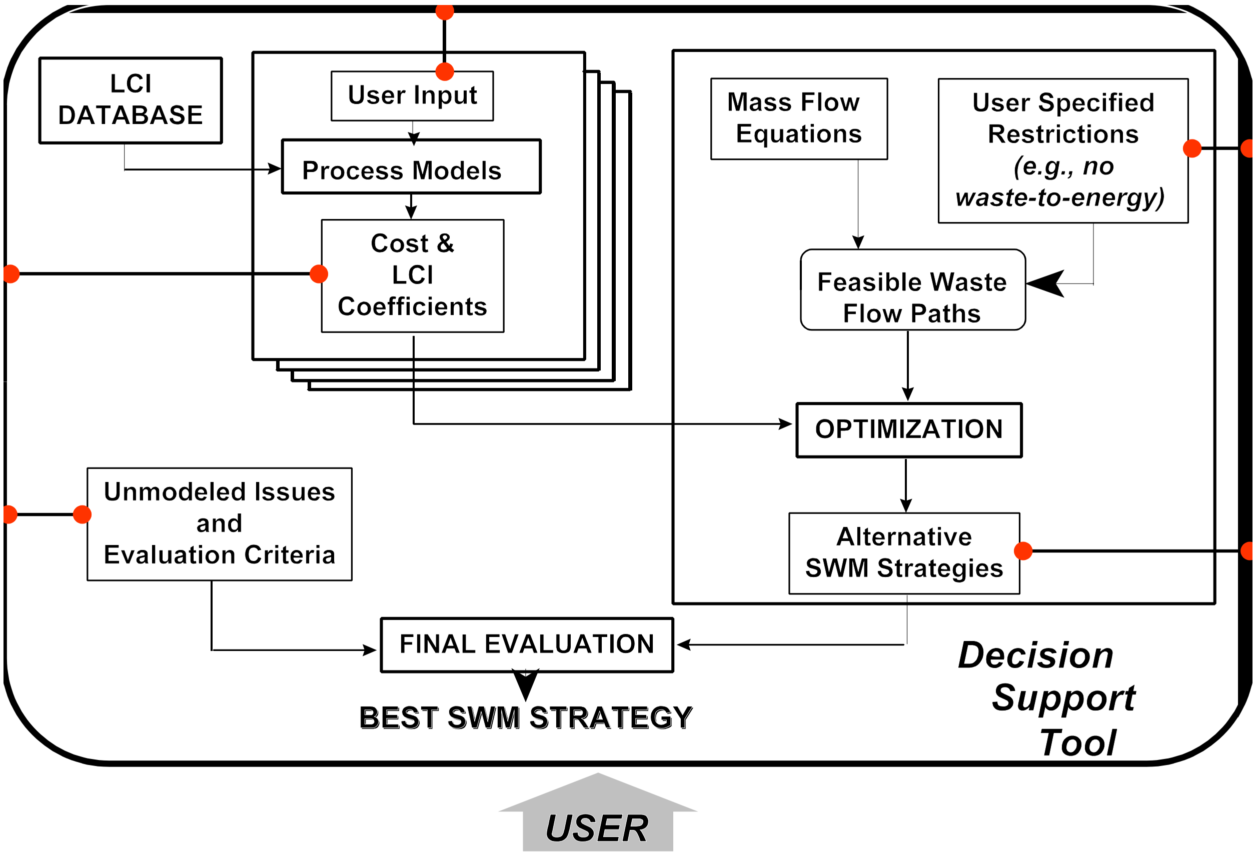


Figure 4-3. Framework for Decision Support Tool

4.2.1 Appropriate Uses of the MSW DST

The MSW DST is a screening level tool designed for use in evaluating community level MSW management strategies. It allows you to conduct scenario analyses of strategies with the objective of optimizing cost or environmental performance of the system. The MSW management system modeled may be an existing system, entirely new systems, or some combination of both based on user-specified data on MSW generation, requirements, etc. The processes that can be modeled include waste generation, collection, transfer, separation (material recovery and drop-off facilities), composting, combustion, refuse-derived fuel, and disposal in a landfill. Existing facilities and equipment can be incorporated as model constraints to ensure that previous capital expenditures are not negated by the model solution.

Local governments and solid waste planners can use the tool, for example, to evaluate the affects of changes in the existing MSW management on cost and environmental burdens, identify least cost ways to manage recycling and waste diversion, evaluate options for reducing greenhouse gases or air toxics, or estimate the environmental benefit of recycling. The tool will also be of value to other user groups such as Federal agencies, environmental and solid waste consultants, industry, LCA practitioners, and environmental advocacy organizations. These users can use the tool, for example, to evaluate recycling policies and programs, policies and technologies for reducing environmental burdens, and strategies for optimizing energy recovery from MSW.

The tool is not a cash flow model and therefore should not be used to set prices for any specific waste management service. The cost results provided by the tool represent screening level engineering costs. A more detailed cash flow analysis would be need to determine the appropriate prices for services and materials.

The tool also should not be used to conduct life cycle comparisons of specific products or materials. The LCI results for recycling are based on generic process designs for product manufacturing and remanufacturing operations. To properly compare the preferability of packaging materials, you would need to do a more in-depth analysis of the production, use, and pre-consumer recycling of the products or materials.

Screen captures from a prototype of the MSW DST are presented in Figures 4-4 to 4-9 to illustrate the functionality and the ease of use of the MSW DST. The ability to perform detailed economic and environmental analysis with ease, multiple scenario “runs,” and sensitivity analyses makes the MSW DST a unique and powerful software tool.

4.2.2 Limitations of the MSW DST

See Chapter 1 of this document for a discussion of the limitations associated with the MSW DST. Appropriate uses and limitations of the MSW DST are also detailed in the MSW DST Users Manual, which is available as a stand-alone document.

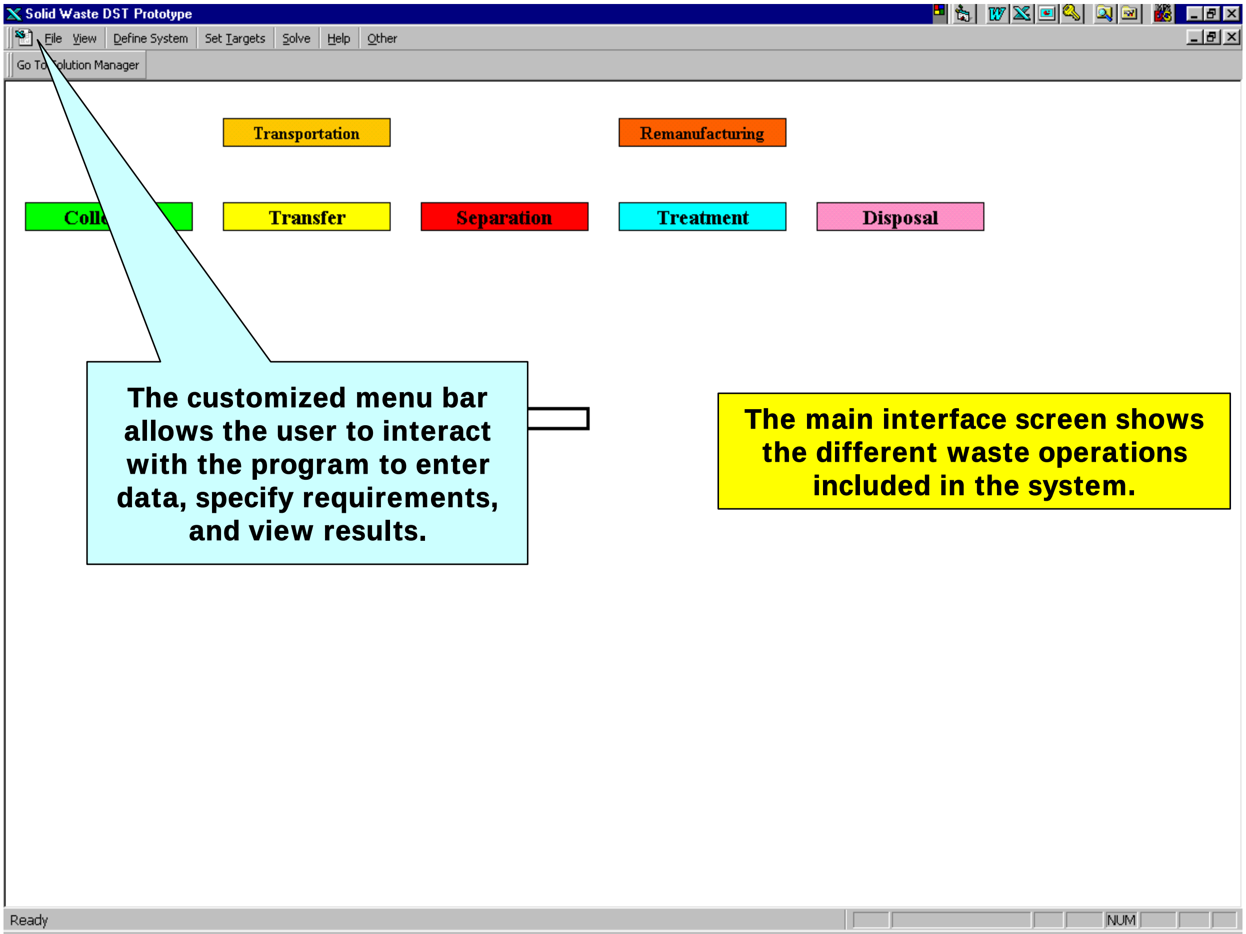
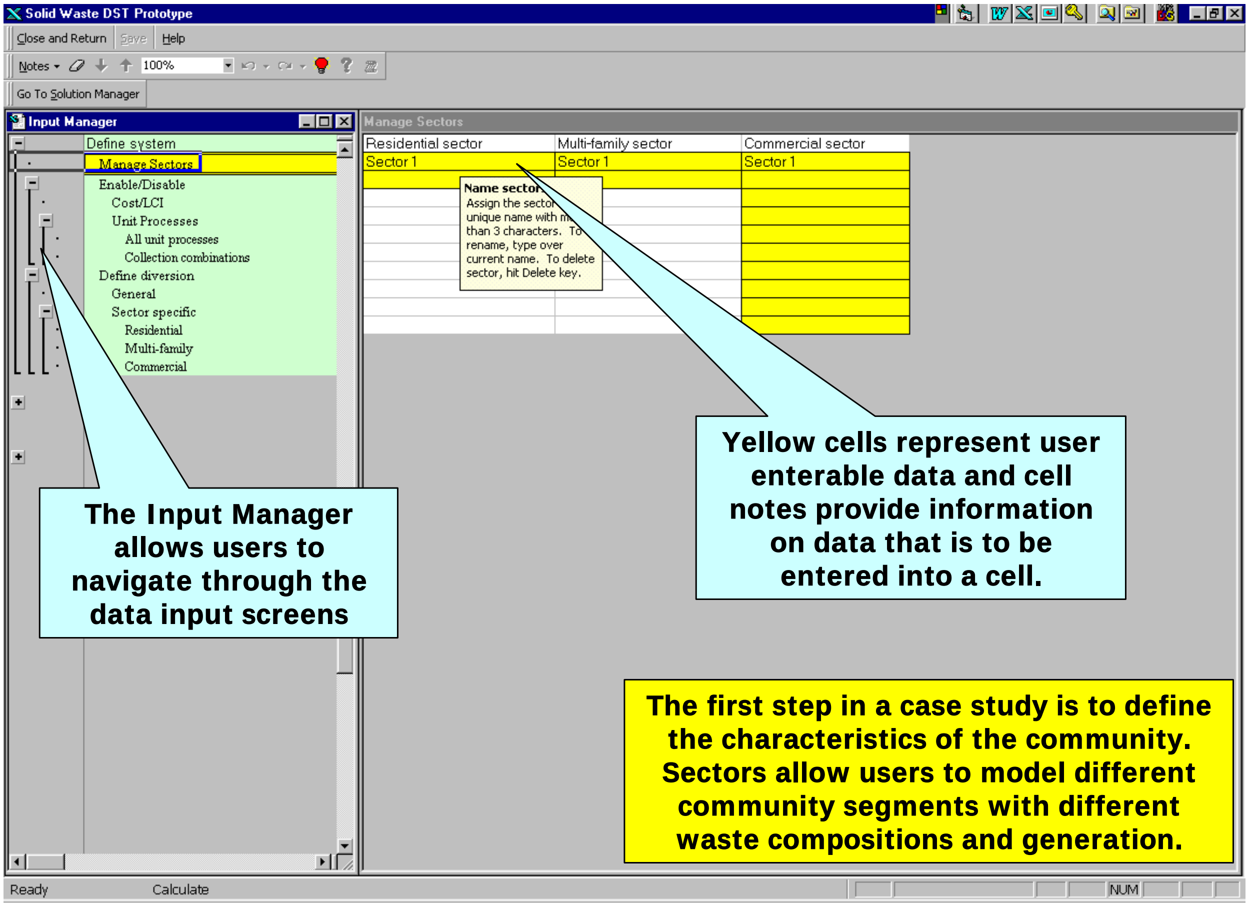


Figure 4-4. MSW DST Main User Interface

The MSW DST allows the user to enter dat to define the waste management system, set targets, solve scenarios, and view results.

Figure 4-5. Data Entry Through the Input Manager



A user can enter site-specific data (e.g., waste generation sectors) using the input manager.

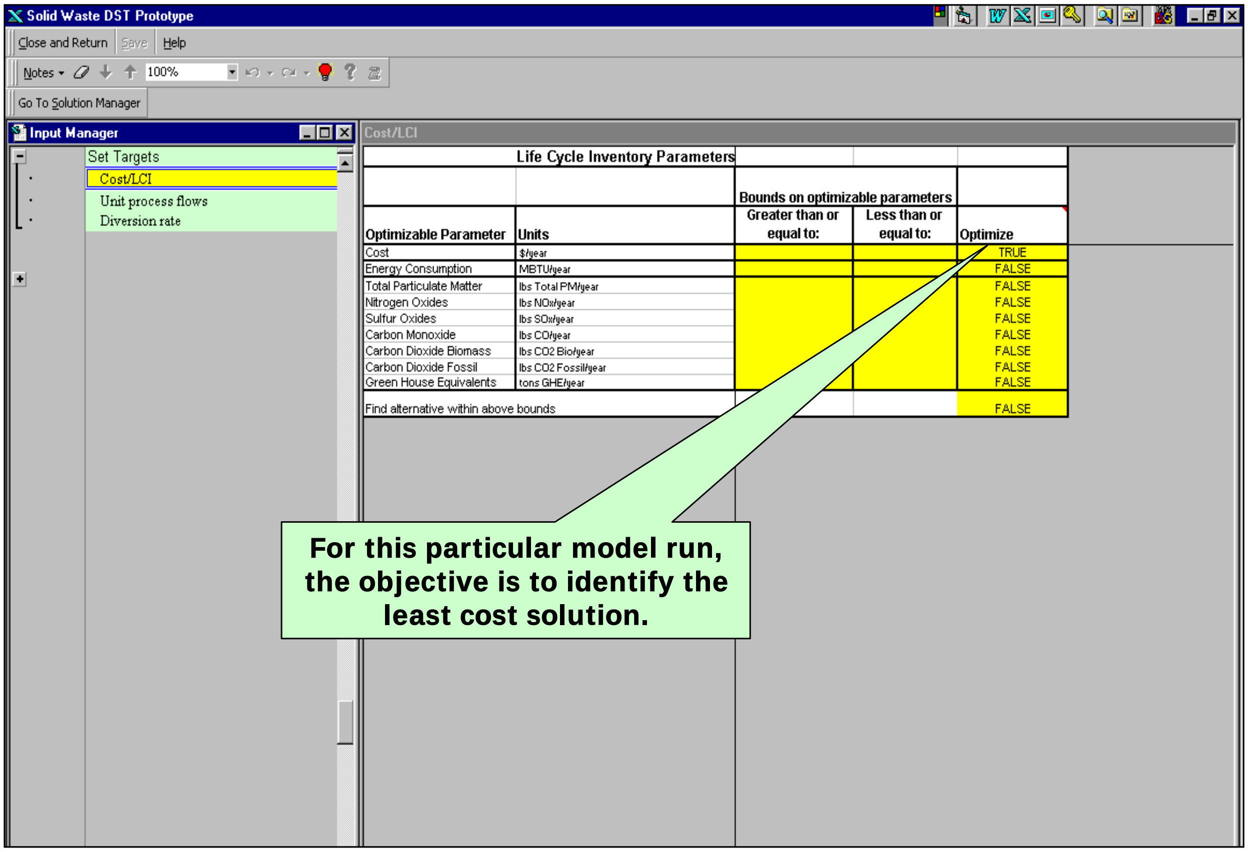


Figure 4-6. Setting Targets for Scenario Analyses

A user can specify economic and environmental goals for alternative waste management strategies.

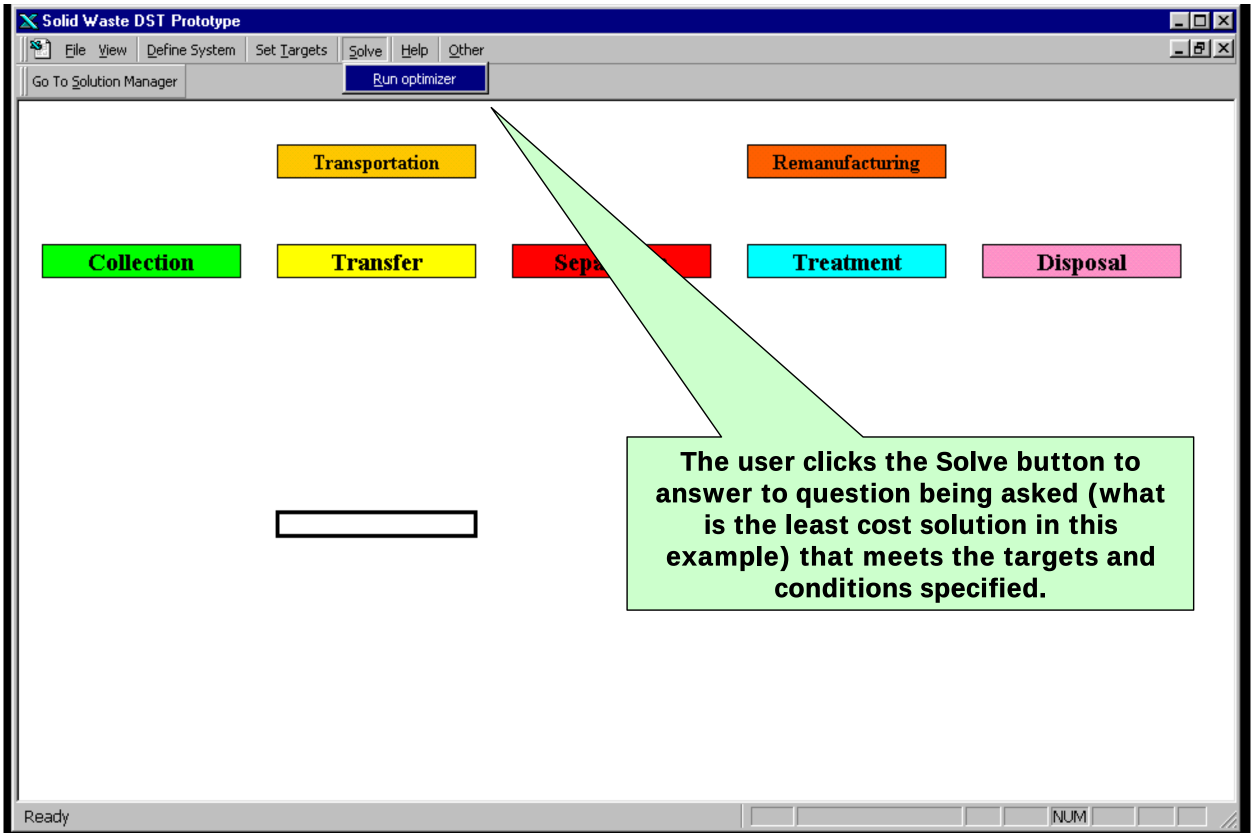


Figure 4-7. Running the Tool

A user can specify a descriptive name of the scenario being analyzed.

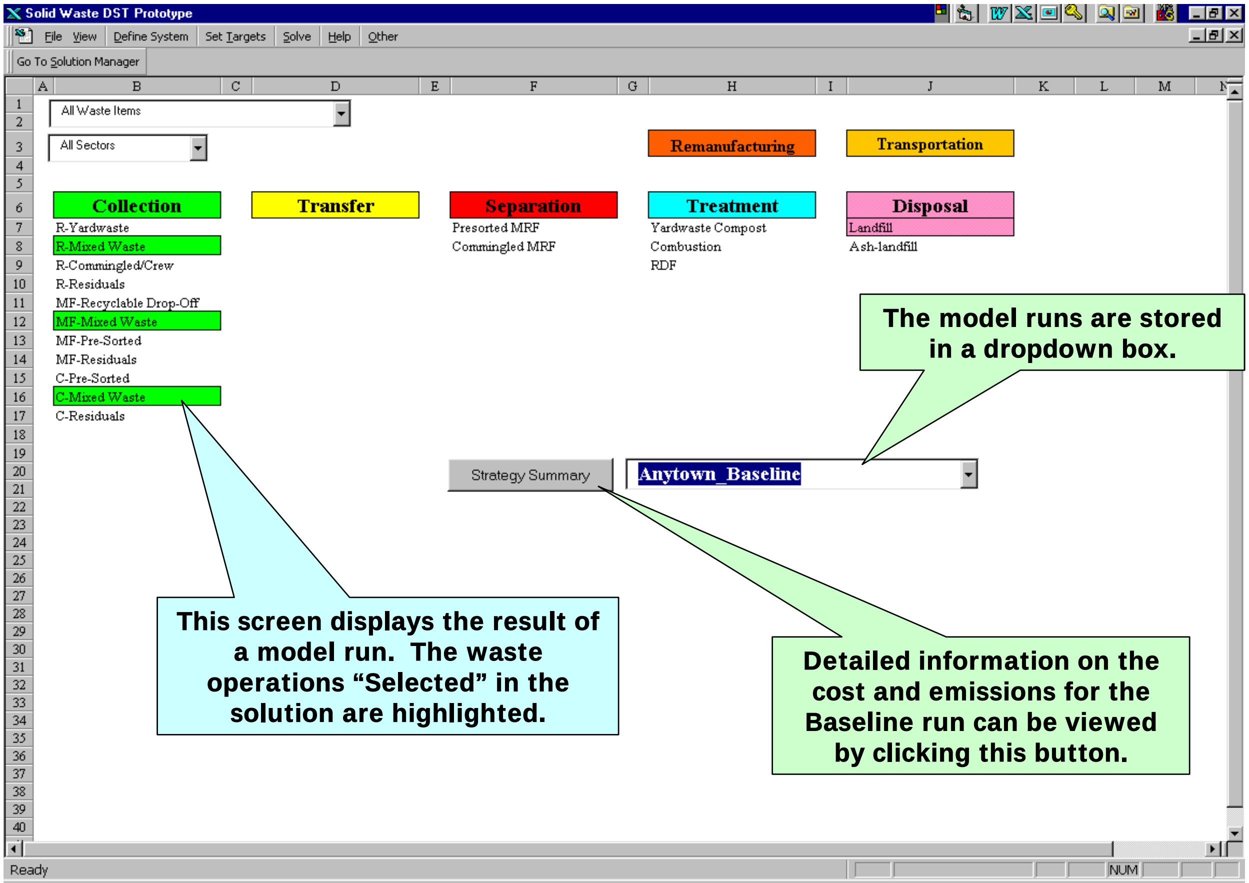


Figure 4-8. Sample Solution Display

A graphical display of the solution for the selected objective function (e.g., least cost) of the scenario being analyzed is presented.

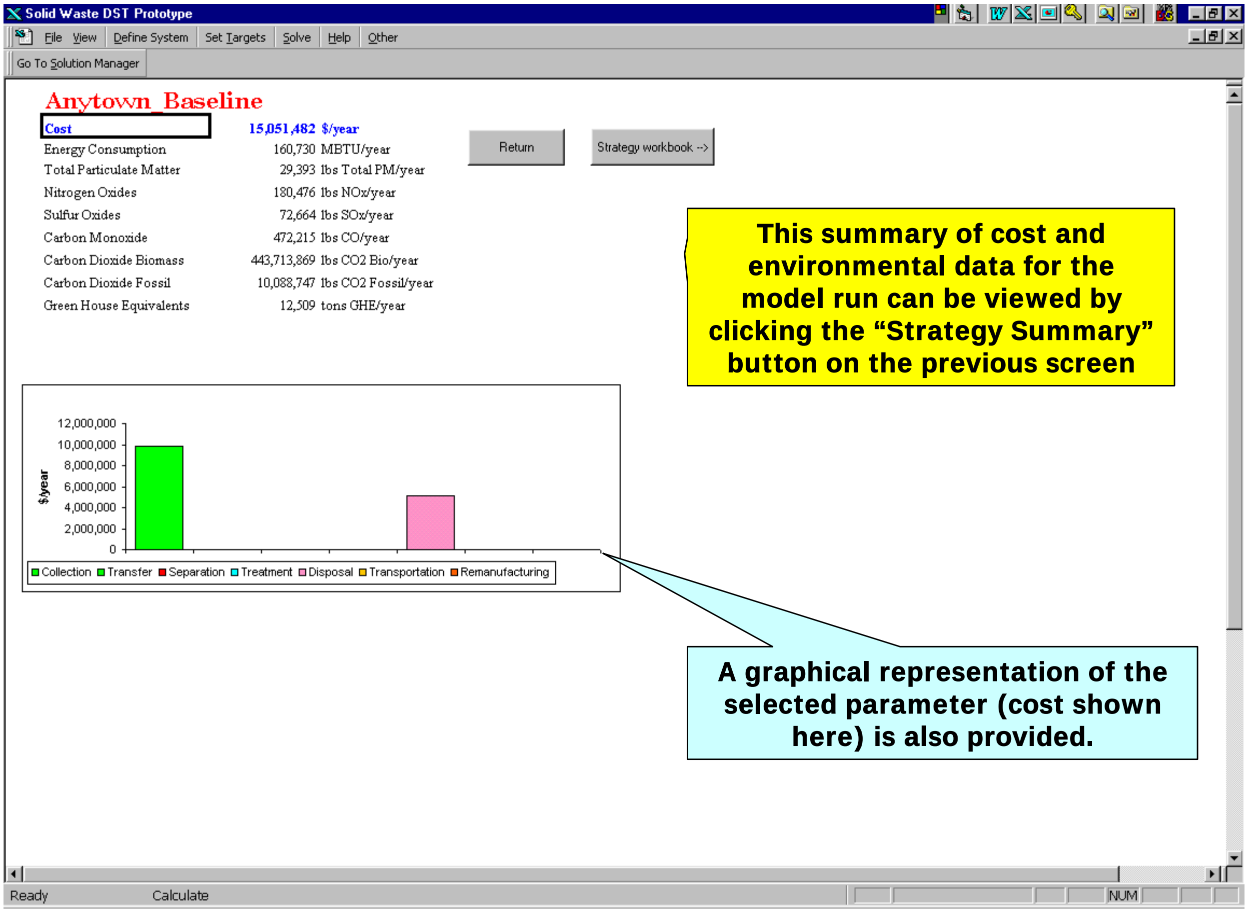


Figure 4-9. Sample Results Display

A graphical display of the results of the scenario being analyzed is presented.

Chapter 5
Sample Applications of the MSW DST

This chapter presents a sample of applications of the MSW DST. Although the MSW DST was designed with local governments and solid waste planners in mind as the primary users, the MSW DST has been used to support a wide variety of applications for different constituents and for different purposes.

At the local level, the MSW DST has been used to evaluate, the effects of changes in the existing MSW management on cost and environmental aspects. The Lucas and Anderson Counties studies show how the MSW DST can be used at the local level to evaluate the cost and environmental aspects of increased waste diversion through recycling or composting. For the cities of Seattle and Spokane Washington, tailored versions of the MSW DST were built to simulate each city's existing MSW management system. The MSW DST has been used at the to evaluate the effects of utilizing improved collection vehicles compared to the status quo of older, less-energy-efficient vehicles being used on Naval bases. The U.S. EPA in Research Triangle Park, NC used the MSW DST to assess its current composting strategy. As shown in the State of Wisconsin study in Section 5.7, the MSW DST can also be used on a larger scale. The study shows the full life cycle aspects of state-wide recycling programs. The MSW DST has also been used at the national level to assess how improvements in MSW management technology including WTE, improved landfill gas control, and increased recycling have lessened GHG emissions in the U.S. during the past 25 years.

Each study included in this chapter includes a description of the study purpose; a discussion of the waste composition, generation and recycling data; collection, recycling and disposal options used; assumptions; and results or remaining issues, if results were not generated. A results discussion was not generated for two case studies, Seattle and Spokane, because no specific management scenarios were analyzed. However, these applications provide insight into how simulation model are developed so they may be used to produce results specific to each City.

5.1 LUCAS COUNTY, OHIO

Lucas County was specifically interested in increasing commercial sector recycling. The study used the MSW DST to generate information about an increased recycling scenario to assist planners in evaluating appropriate recycling strategy. A baseline model of the current MSW management practices in Lucas County and an alternative scenario of increased commercial recycling were developed. The cost and environmental results of the alternative scenario were compared to the baseline model.

At the time of this study, the interface to the MSW DST was still under development. Thus, the analyses were completed by inputting data directly into the process models for collection, MRF, transport (of recyclables), remanufactuing, and landfills. This enabled each process to be examined carefully, ensuring that correct results were produced. This method also helped to identify the key input parameters for each process model.

5.1.1 Waste Composition, Generation, and Recycling data

A baseline material flow model of MSW within the Lucas County management system was developed using data supplied by Resource Recycling Systems, Inc. Scenario 1 models the effects of increasing the amount of commercial recycling from baseline levels by 30,000 tons.

For the purpose of this study, the County was divided into two waste generation sectors; the city of Toledo (Sector 1), and the remaining rural areas within the County (Sector 2). Additionally, the waste flow was divided into single-family dwellings (residential), multi-family dwellings, and commercial sector waste. The commercial sector waste was broken down into nine sectors, including a manufacturing sector. A total of thirteen waste generation sectors were defined in the study.

System boundaries were established to determine which unit operations within the solid waste management infrastructure should be modeled, and what data should be collected. The boundaries of this study were dictated by which waste management operations were currently used within the Lucas County system. For this study, the collection, MRF, transportation, remanufacturing, and landfill process models were used. The remanufacturing process model was also used to assess the environmental benefits of recycling.

5.1.2 Model Design

Baseline Model

Lucas County generates 917,023 tons per year (tpy) of waste: 305,271 tpy are recovered and recycled and the remaining 611,752 tpy are discarded in a landfill. Recovered waste included curbside recycling, drop-off center recycling, and composted yardwaste. All discarded waste was assumed to be landfilled.

The material flow was developed by separating the tons per year of waste generated, recovered, and discarded between the two residential, two multi-family, and nine commercial sectors. Within each of these sectors, the waste was broken down between collection, MRF, and landfill alternatives. These data, in addition to the selection of collection alternatives and MRF designs for each sector, were provided by the County, and are shown in Table 5-1.

Table 5-1. Lucas County Baseline Material Flow Data

Sector*	Population (people, employees)	Generation Rate (pppd)	Business Days in a Year	Waste Generated (tpy)	Waste Recovered (tpy)	Waste Discarded (tpy)
R1	267,995	3.42	365	167,038	27,069	139,969
R2	111,601	3.42	365	69,560	8,876	60,684
M1	49,608	3.42	365	30,920	5,085	25,835
M2	23,484	3.42	365	14,637	899	13,738
C1	788	5.75	260	589	0	589
C2	19,047	13.50	260	33,435	884	32,551
C3	12,770	10.00	338	21,581	2,540	19,041
C4	47,992	14.76	338	119,704	33,864	85,840
C5	23,447	21.08	365	90,189	6,889	83,300
C6	45,918	5.75	260	34,324	4,716	29,608
C7	1,160	10.00	364	2,111	0	2,111
C8	33,719	8.31	260	36,447	2,822	33,625
C9	38,003	42.75	365	296,488	211,627	84,861

*R=residential, M=multifamily, C=commercial
pppd = pounds per person per day
tpy = tons per year

Scenario 1 Model

Scenario 1 models the effects of increasing the amount of commercial recycling from baseline levels by 30,000 tons. The increase in recycling tonnage is anticipated by establishing collection programs for corrugated cardboard for commercial sectors C2, C3, C4 and C5 and office paper and newspaper from commercial sector C6.

The material flow of MSW throughout the management system changes from the baseline model because more waste is recovered than discarded in commercial sectors C2 through C6. This results in the material flow shown in Table 5-2.

Table 5-2. Lucas County Scenario Description

Sector	Description	Annual Waste Generation (tpy)	Baseline Recycling (tpy)	Additiona lScenario 1 Recycling (tpy)	Priority Materials
C2	Contractors/ Builders	33,435	884	6,500	Cardboard, Pallets
C3	Wholesale Goods	21,581	2,540	3,500	Cardboard, Pallets
C4	Retail Stores	119,704	33,864	10,000	Cardboard, Pallets
C5	Food Stores	90,189	6,889	6,000	Cardboard, Pallets
C6	Services	34,324	4,716	4,000	Office Paper, Newspaper
	Total:	**299,233**	**48,893**	**30,000**	

5.1.3 Major Assumptions

To develop the baseline model, site-specific data were input into the process models of the MSW DST to override default data. Where override values were not available, default values were assumed. The site-specific data include waste generation values, waste composition data, participation and capture rates, collection variables, and market values for recyclables.

Based on data supplied by Lucas County, it was assumed that in residential sector R1, 60% of recovered waste is collected by curbside recycling, while 40% is taken to drop-off centers. In residential sector R2 it was assumed that 40% of recovered waste is collected by curbside recycling, while 60% is taken to drop-off centers. In the two multi-family sectors, 100% of the recovered waste is collected by the drop-off alternative

Because pallets are not modeled by the MSW DST, collection and landfill disposal costs of pallets were not included in the study. All recycling costs and emissions within this scenario were due to the collection and processing of cardboard, office paper, and newspaper that were targeted for recycling by the County. The environmental savings of recycling these materials corresponds to the difference in materials production offset for the two scenarios (i.e., using recycled versus virgin resources).

Composting cost and emissions were not included in the total system analysis because the composting because only a small percentage of the waste stream is managed by this recovery method.

5.1.4 Cost and Environmental Results

The results from the Lucas County scenarios showed that the proposed scenario of increased commercial sector recycling resulted in a slight decrease in cost to the local government and a possible decrease in environmental burdens.

Cost Results

Table 5-3 shows the cost results of the baseline and scenario 1 models.

Table 5-3. Lucas County Cost Results

Cost Parameter	Baseline	Scenario 1	Difference
Total Annual Cost (not including Sale of Recyclables)	$101,200,000	$100,000,000	$1,200,000
Sale of Recyclables	$34,650,000	$36,010,000	$1,360,000
Total Annual Cost (including Sale of Recyclables)	$66,570,000	$64,020,000	$2,550,000
Cost per Ton (not including Sale of Recyclables)	$110.00	$109.00	$0.00
Cost per Ton (including Sale of Recyclables)	$73.00	$70.00	$3.00

In general, the total cost and cost per ton values are lower for the increased recycling scenario (scenario 1). However, because there is a less than 10% change in the difference in cost between the baseline and scenario 1, the results are considered insignificant. These results are useful for community solid waste managers and stakeholders to determine which waste management activities and waste generation sectors contribute most to the total annual cost. By targeting these streams of waste for future scenario development, the community may be able to decrease their overall solid waste management costs on a more significant level. Total annual cost can be broken down to determine which aspects of the waste management system are driving the costs. The cost can be broken down by waste management activity (e.g. collection, material recovery facility, landfill), by process alternative (e.g. collection method C2, C3 C4), or by waste generation sector.

The total annual cost broken down by waste management activity is shown in Table 5-4. Note that as the amount of waste recycled is increased from the baseline to the scenario 1 model, the cost of recyclables collection and MRF disposal increase, while the costs of residuals collection and landfill disposal decrease. As shown in Table 5-4, recyclables collection is the waste management activity driving the total annual cost.

Table 5-4. Lucas County Total Annual Cost by Waste Management Activity

Management Activity	Baseline	Scenario 1	Difference
Residuals Collection	$32,310,000	$31,090,000	$1,220,000
Recyclables Collection	$46,340,000	$46,890,000	-$550,000
MRF Disposal	$4,222,000	$4,601,000	-$379,000
MRF Revenue	-$34,650,000	-$36,010,000	$1,360,000
Landfill Disposal	$18,350,000	$17,450,000	$900,000
TOTAL*	**$66,570,000**	**$64,020,000**	**$2,550,000**

*Rounded to four significant figures.

Total annual cost broken down by sector is shown in Table 5-5. These costs are shown both with and without the revenue that is earned from the sale of recyclables. The manufacturing (C9) and retail (C4) commercial sectors, and the urban residential sector (R1) drive the total annual cost in the two scenarios. The retail sector (C4) has the largest decrease in total annual cost..

The results of the model indicate that there is a minimal decrease in total annual cost between the two scenarios. This difference is considered insignificant because there is a less than 10% decrease in cost between the baseline to the scenario 1 model.

Environmental Results

Although the increased recycling scenario generally had less environmental burden, the difference between the baseline and scenario 1 strategies was not considered to be significant, when considering emissions from residuals and recyclables collection, material recovery facilities, and landfill disposal. Although there is a slight decrease in emissions between the two scenarios, none of these decreases are more than a 10% difference. Table 5-6 shows these results for the eight emissions that can be optimized by the MSW DST.

Because the remanufacturing process model was not complete at the time of this case study, it was not possible to consider the emission savings from the remanufacture of all products using recycled material for each scenario. Preliminary data from the process model were available for some of the recyclable constituents, including newsprint, corrugated cardboard, and office paper. Because the recycling levels of these constituents increased between the baseline and scenario 1 models, these data were used to calculate the difference in emissions savings between the two scenarios.

Table 5-5. Lucas County Total Annual Cost by Sector

Sector	Baseline Cost	Baseline Revenue	Baseline Net Cost	Scenario 1 Cost	Scenario 1 Revenue	Scenario 1 Net Cost	Difference in Cost w/o Revenue	Difference in Net Cost
Residential (R1)	$14,300,000	$277,000	$14,023,000	$14,300,000	$277,000	$14,023,000	$0	$0
Residential (R2)	$6,293,000	$254,100	$6,039,000	$6,293,000	$254,100	$6,038,900	$0	$0
Multifamily (M1)	$2,664,000	$29,600	$2,634,400	$2,664,000	$29,600	$2,634,400	$0	$0
Multifamily (M2)	$1,321,000	$18,800	$1,302,200	$1,321,000	$18,800	$1,302,200	$0	$0
Agriculture (C1)	$261,400	$0	$261,400	$261,400	$0	$261,400	$0	$0
Contractors/Builders (C2)	$4,468,000	$624,900	$3,843,100	$4,951,000	$864,600	$4,086,400	-$483,000	-$243,300
Wholesale Goods (C3)	$3,154,000	$156,800	$2,997,200	$3,357,000	$292,700	$3,064,300	-$203,000	-$67,100
Retail (C4)	$21,690,000	$2,867,000	$18,823,000	$19,740,000	$3,286,000	$16,454,000	$1,950,000	$2,369,000
Food Stores (C5)	$7,487,000	$805,300	$6,681,700	$7,636,000	$1,063,000	$6,573,000	-$149,000	$108,700
Services (C6)	$7,184,000	$540,100	$6,643,900	$7,105,000	$850,200	$6,254,800	$79,000	$389,100
Hotels/Lodging (C7)	$166,700	$0	$166,700	$166,700	$0	$166,700	$0	$0
Health/Hospitals (C8)	$4,002,000	$218,500	$3,783,500	$4,002,000	$218,500	$3,783,500	$0	$0
Manufacturing (C9)	$28,240,000	$28,860,000	-$620,000	$28,240,000	$28,860,000	-$620,000	$0	$0
TOTAL*	**$101,200,000**	**$34,650,000**	**$66,570,000**	**$100,000,000**	**$36,010,000**	**$64,020,000**	**$1,200,000**	**$2,550,000**

* Rounded to four significant figures.

Table 5-6. Lucas County Environmental Results

Optimized Parameter	Baseline	Scenario 1
Energy (MBTU)	1.58 E+06	1.47 E+06
Carbon Monoxide	1.46 E+06	1.42 E+06
Nitrogen Oxides	4.31 E+06	4.15 E+06
Total Particulate Matter	9.77 E+05	9.54 E+05
Fossil Carbon Dioxide	7.49 E+08	7.25 E+08
Biomass Carbon Dioxide	1.33 E+08	1.30 E+08
Sulfur Oxides	4.89 E+06	4.78 E+06
MTCE	7.02 E+08	6.61 E+08

Table 5-7 shows the total emissions from residuals and recyclables collection, material recovery facilities, landfill disposal, and the remanufacturing of newsprint, corrugated cardboard, and office paper. When the remanufacturing data is included in the emissions total, there is a significant decrease in the emissions of energy, carbon monoxide, and biomass carbon dioxide. This difference is considered significant if it is more than 10%. At the time of this study, the remanufacturing data was not yet reviewed or finalized.

Table 5-7. Lucas County Environmental Results Including Remanufacturing Offset (from newsprint, corrugated cardboard, and office paper)

Optimized Parameter	Baseline	Scenario 1	Difference
Energy (MBTU)	1.32 E+06	1.06 E+06	-2.62 E+5
Carbon Monoxide	5.96 E+05	-6.14 E+04	-6.55 E+05
Nitrogen Oxides	4.01 E+06	3.66 E+06	Insignificant
Total Particulate Matter	1.08 E+06	1.08 E+06	Insignificant
Fossil Carbon Dioxide	7.86 E+08	7.86 E+08	Insignificant
Biomass Carbon Dioxide	-1.39 E+08	-2.75 E+08	-1.36 E+08
Sulfur Oxides	4.06 E+06	4.32 E+06	Insignificant
MTCE	7.02 E+08	6.61 E+08	Insignificant

5.1.5 Application of Results

The Lucas County study demonstrated the cooperation necessary between community solid waste managers and model operators, to develop site-specific data for the model. Additionally, the individual process models were verified by generating results that are comparable to Lucas County cost data. By looking at the trends in the results, the model results were validated by changes moving in the anticipated direction.

With these preliminary results, solid waste managers of Lucas County gained an understanding of potential applications of the MSW DST, individual process models, and the life-cycle methodology. Additionally, the results provided insight on the waste management activities and sectors that are driving the total annual cost of the system. With this information, they were able to increase recycling and improve the economic performance for their system.

5.2 ANDERSON COUNTY, SOUTH CAROLINA

The Anderson County study used the MSW DST to identify and evaluate the effects on cost and environmental aspects resulting from recycling and composting strategies being proposed by the County. A current baseline system model was develop as well as additional recycling and composting scenarios. The recycling scenario included adding a residential curbside recycling program. The composting scenario included the residential curbside recycling program as well as a yard waste composting program.

The study also analyzed varying three sensitive parameters to find the effects on cost, energy use, NOx emissions, and MTCE per ton of material processed. The three parameters varied were: loading time, travel distance and households per stop: These parameters were changed for the commingled recyclables collection option in the incorporated residential sector.

5.2.1 Waste Composition, Generation, and Recycling data

Waste generation and recycling data for this study were provided by Anderson County Solid Waste Management Staff. Information provided included the total tons of waste generated in one year, the county population, and the total tons of waste generated and recycled in each residential and commercial sector. From these data, a baseline analysis was established through the MSW DST, which calculated the cost and environmental parameters for the current Anderson County waste management system.

For the purpose of this study, the residential area was split into an incorporated residential sector, containing 7 municipalities, and an unincorporated residential sector, comprising the county area outside of the city limits. All of the businesses in Anderson were placed into one commercial sector because specific data on the waste breakdown and total tonnage collected from each of the businesses were not available.

In addition to the baseline model, two other scenarios were developed for Anderson County:

- **Scenario 1:** includes recycling of incorporated residential waste that was previously land filled.
- **Scenario 2:** includes the addition of both curbside recyclables collection and a yard waste composting facility.

5.2.2 Model Design

In the baseline scenario, MSW and yard waste is collected curbside in the incorporated sector. In the unincorporated residential sector, residents drop off their MSW and recyclables at different convenience centers located throughout the county. A portion of the unincorporated residential population has their waste picked up from their residence by private collectors. However, this is not modeled in the case study. MSW and recyclables in the commercial sector are collected directly from the businesses by county collection trucks. Scenario 1 includes the same management options as the baseline model with the exception of curbside recycling added to the incorporated residential sector. Scenario 2 includes the same management option as Scenario 1, however, yard waste composting is included. Table 1 outlines the management options included in each scenario. The new management options that are added in both scenario 1 and 2 are highlighted in this table.

Table 5-8. Anderson County: Management Options Used..

Sector	Baseline Scenario	Scenario 1	Scenario 2
R1	Yard waste Collection	Yard waste Collection	Yard waste Collection
R1	Mixed Waste Collection	Mixed Waste Collection	Mixed Waste Collection
R1		Recyclables Collection	Recyclables Collection
R2	Mixed Waste Drop-off	Mixed Waste Drop-off	Mixed Waste Drop-off
R2	Recyclables Drop-off	Recyclables Drop-off	Recyclables Drop-off
R2	Mixed Waste Collection	Mixed Waste Collection	Mixed Waste Collection
C1	Mixed Waste Collection	Mixed Waste Collection	Mixed Waste Collection
C1	Recyclables Collection	Recyclables Collection	Recyclables Collection
-	Pre-Sorted MRF	Pre-Sorted MRF	Pre-Sorted MRF
-	Landfill	Landfill	Landfill
-			Yard-Waste Composting

5.2.3 Major Assumptions

MSW DST default waste composition data in the model were used since waste composition data specific to Anderson County did not exist.

A 100% residential recycling participation rate was used in the model.

In this analysis, information on the separation between residential single-family homes and apartment houses was not available. Because of this, it was assumed that all residents in the county lived in single-family homes.

5.2.4 Cost and Environmental Results

Cost Results

The total cost of the scenarios includes costs associated with collection through the treatment of waste. The baseline cost equals $13,673,893. The total costs increase in scenario 1 to $13,920,714. In scenario 2, the total costs decrease to $13,862,946, but are still higher than the baseline costs.

The total cost increase in scenario 1 results from costs associated with the addition of the residential recyclables curbside collection system. The additional collection system requires more trucks than in the baseline scenario where only residuals are collected and sent to the landfill.

With the addition of a yard-waste composting system in scenario 2, the costs for yard waste collection decrease from scenario 1 to scenario 2. This is a result of the revenue generated through composted material sales, which offsets the total costs of the yard waste collection and composting systems.

Environmental Results

Energy use decreased from the baseline scenario through scenario 2. The energy use decreases from 176,256 MBTU/year in the baseline scenario to 166,178 MBTU/year in scenario 1. The energy use is decreased further in scenario 2, which uses 164,652 MBTU/year.

Particulate matter emissions, also decreased from the baseline scenario through either option. Particulate matter emissions equal 20,298 lbs/year in the baseline scenario and decrease to 19,810 lbs/year in scenario 1. The particulate matter emissions decrease further in scenario 2 to 18,752 lbs/year.

SOx emissions and NOx emissions both increase from the baseline scenario through either option. SOx emissions increase from the baseline output of 59,269 lbs/year to 59,388 lbs/year in scenario 1. A slight increase occurs in scenario 2 with a yearly emission rate of 59,556 lbs/year.

The NOx emissions increased from the baseline scenario in either option. There is a smaller increase in NOx emissions than in SOx, with an increase from 171,355 lbs/year in the baseline scenario to 172,266 lbs/year in scenario 1. The emissions are further increased to 174,423 lbs/year in scenario 2. This increase in scenario 2 results from a slight increase in emissions from residential yard waste collection and the introduction of yard waste composting.

The decreases in total energy use, total particulate matter, and total carbon dioxide emissions per year from the baseline scenario through scenarios 1 and 2, are primarily due to recycling and composting. In the case of recyclables, materials are diverted from the landfill and remanufactured into new products. The MSW DST takes into account, the energy required and emissions generated during the production of cans, bottles, etc., from virgin materials. Therefore, when this process is compared to the manufacturing of products using remanufactured material, there is a savings in energy use and the amount of emissions created.

Both the total SOx and total NOx emissions per year increase from the baseline scenario through scenario 2. Both of these compounds are emitted from gas-burning engines. This increase is related to the two additional collection systems created for recyclables collection and yard waste collection. Because NOx and SOx are both criteria pollutants under the Clean Air Act, an increase in these emissions may raise concerns for air quality compliance. Statistical analyses were not performed on the results from the scenario comparisons, and would have to be done to find the significance in change between scenarios.

5.2.5 Sensitivity Analysis Results

In this study, we also examined the effects of varying input parameters for the recycling collection option in the incorporated residential sector. The three parameters analyzed include:

loading-time at a collection stop, distance in miles from the garage to the collection site, and number of households collected at one stop. As loading time at a collection stop, and distance from garage to collection site, decreases; and the number of households collected at one stop increases, the cost, energy use and emission parameters also decreased. These factors decreased because the MSW DST calculates the number of trucks needed each day to collect waste by factoring in the time it takes the truck to get through a particular route.

The three parameters were analyzed as different varied collection options. Table 5-9 shows the compilation of varied collection parameters. As shown in number 7, the status quo or the baseline collection parameters were 9 minutes for loading time, 10 miles for the distance of the garage to the collection site, and 2 houses collected at once. These parameters were increased and decreased in increments. The loading time was decreased incrementally from 9 to 5 minutes, the garage to collection site distance was decreased from 10 to 7 minutes, and the number of houses collected at once was increased from 2 to 5 houses. For this analysis the peak, or best performing numbers are 5 minutes for loading time, 7 minutes for garage to collection distance, and 5 houses collected at once.

Table 5-9. Anderson County: Compilation of Varied Collection Parameters

No.	Loading Time (Minutes)	Distance (Miles): Garage to Collection Site	Number of Houses	Cost ($)	Energy (MBTU)	NOx (lb)	MTCE
1	**5**	**7**	**2**	116.89	0.876	1.804	0.0059
2	**5**	**7**	**5**	92.84	0.746	1.637	0.0052
3	**5**	**10**	**2**	117.92	0.892	1.844	0.0060
4	**5**	**10**	**5**	93.87	0.762	1.677	0.0053
5	**9**	**7**	**2**	126.91	0.915	1.849	0.0061
6	**9**	**7**	**5**	102.86	0.785	1.682	0.0054
7	**9**	**10**	**2**	127.94	0.931	1.889	0.0062
8	**9**	**10**	**5**	103.89	0.801	1.722	0.0055

All categories change - % reduction from status quo
Variable remains constant - % reduction from status quo for other two variables
Status quo
One variable changing from status quo

5.2.6 Application of Results

Comparing the baseline scenario results to the other scenarios allows the comparison of cost and environmental burdens between the three scenarios. This information can be used by Anderson County waste planners to target which waste management activities should be increased within their MSW management system. In addition, the collection scenarios can be used to determine which collection schedules will provide the optimal level of cost versus environmental impacts for Anderson County.

5.3 CITY OF SEATTLE, WASHINGTON

The purpose of this study was to develop a baseline model of the current Seattle MSW management; in effect, developing a tailored version of the MSW DST that simulates Seattle's current system. This involved changing default values in the MSW DST to match Seattle's system as the available data permitted. Models specific to Seattle were developed and the process by which they were developed is described in this section. Ultimately, the tailored versions of the MSW DST were transferred to Seattle so they may use the models and results to evaluate the economic and environmental aspects of the current system and to evaluate future MSW management alternatives.

5.3.1 Waste Composition, Generation, and Recycling Data

The development of the baseline model involved gaining an understanding of the system through information retrieval via the Internet and through phone conversations with Seattle Solid Waste Planning Staff. Data collection sheets were developed for Seattle staff to complete for transmittal into the Seattle-specific models developed by RTI staff. Data sheets created include general system information such as waste generation, tonnage quantities, population quantities, in addition to composting, landfill, transportation and collection, transfer station and recycling facilities data sheets.

5.3.2 Model Design

For the purpose of developing a manageable baseline model, Seattle was divided into modeling sectors based on data collection categories used by Seattle Solid Waste Planning Staff. The City evaluates MSW in terms of residential, commercial and self-haul categories.

Four MSW DST models were developed to depict the Seattle waste management system. Four models were necessary because of the complexity of the system, the large number of default changes, and unusual modeling scenarios that were constructed. The following section contains the four model descriptions in addition to the MSW DST unit processes enabled and the waste streams quantities.

Model 1 Description

Models single family and multifamily curbside yard waste, commingled recycling and mixed waste collection, treatment and/or disposal. The model also includes commercial curbside presorted recyclables and residual mixed waste collection, processing or disposal. The following MSW DST unit processes and associated waste streams are displayed below.

Single Family Sector 1 (total generation – 172,655 tons)

- Yard Waste Collection – 34,037 tons, Yard waste Composting
- Commingled recycling collection – 54,035 tons, Commingled MRF, Remanufacturing
- Residuals mixed waste collection – 84,583 tons, Rail transfer, Landfill

Multi family Sector 1 (total generation – 71,637)

- Commingled recycling collection – 10,085 tons, Commingled MRF, Remanufacturing
- Residuals mixed waste collection – 61,552 tons, Rail transfer, Landfill

Commercial Sector 1(total generation – 414,223)

- Presorted recycling collection – 185,807 tons, Presorted MRF, Remanufacturing
- Residuals mixed waste collection – 228,417 tons, Rail transfer, Landfill

Model 2 Description

Models single family mixed waste drop-off, recyclables drop off and yard waste drop off. Garbage drop-off is not a valid option in the MSW DST. However, garbage drop-off was modeled as though it was collected as single family residential curbside MSW residuals. The collection and emission coefficients for recycling drop-off were used as a proxy for MSW drop-off and were copied over to residential curbside residual collection in the Var.Coeff spreadsheet of the model. These coefficients automatically update so the user does not have to copy over the coefficients every time the default values are changed. In addition, The MSW DST does not permit yard waste drop-off to a transfer station prior to delivery to a yard waste composting facility as occurs in Seattle. The collection and emission coefficients for recycling drop-off were also used as a proxy for yard waste drop-off and were copied over to residential yard waste drop off collection in the Var.Coeff spreadsheet of the model. Although, these two model modifications are fairly simple, these type of changes are not something the novice modeler would do since it involves modifying the model itself instead of making changes in the user-input area of the model. The following MSW DST unit processes and associated waste streams are depicted below.

Single Family Sector 1 (total generation – 73,480 tons)

- Yard Waste Drop-Off Collection – 7,663 tons, Yard waste Composting
- Recycling Drop-Off Collection – 11,715 tons, Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste Collection – 54,103 tons, Rail transfer , Landfill

Model 3 Description

Models self-haul commercial waste. This includes recyclables drop-off, yard waste drop-off and residual drop-off. The commercial sector as defined in the MSW DST does not permit commercial recycling drop-off, nor is yard waste an option for modeling in the commercial sector. This model uses the residential sector as a proxy for the commercial sector to model recycling and yardwaste dropoff. Garbage drop-off collection is not a valid option in the MSW DST. However, garbage drop-off was modeled as though it was collected as single family residential curbside MSW residuals. The collection and emission coefficients for recycling drop-off were used as a proxy for MSW drop-off and were copied over to residential curbside residual collection in the Var.Coeff spreadsheet of the model. These coefficients automatically update so the user does not have to copy over the coefficients every time the default values are changed. In addition, The MSW DST does not permit yard waste drop-off to a transfer station prior to delivery to a yard waste composting facility as occurs in Seattle. The collection and emission coefficients for recycling drop-off were also used as a proxy for yard waste drop-off and were copied over to residential yard waste drop off collection in the Var.Coeff spreadsheet of the model. Although, these two model modifications are fairly simple, these types of changes are not something the novice modeler would do since it involves modifying the model itself instead of making changes in the user-input area of the model. The following MSW DST unit processes and associated waste stream are depicted below.

Single Family Sector 1 (Proxy for Commercial drop-off sector) (total generation-54,105 tons)

- Yard Waste Drop-Off Collection – 5,578 tons Yard waste Composting
- Recycling Drop-Off Collection – 747 tons Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste collection – 47,780 tons Rail transfer , Landfill

Model 4 Description

Models commercial yard waste and food waste collection and composting. The MSW DST does not permit commercial yard waste collection and treatment. However, the residential sector was used as a proxy since yard waste composting is a valid option in the residential sector. To model the food waste composting along with the yard waste composting, the mixed waste composting unit process was enabled since it permits food waste to be chosen as a waste stream item. The following MSW DST unit processes and associated waste streams are depicted below.

Single Family Sector 1 (Proxy for commercial yard waste collection sector) (total generation-10,704 tons)

- Mixed waste collection – 10,704 tons Mixed waste front-end separation, Mixed waste composting, Landfill

5.3.3 Major Assumptions

While the MSW DST is a powerful screening tool designed for use in evaluating community level MSW management strategies, it does not contain all possible MSW management options.

In addition, there are hundreds of default values within the model that can be changed based on community level data. In some cases, communities do not collect the types of data that can be entered into the MSW DST. Because of the unavailability of data and modeling constraints, the following assumptions were made in developing the Seattle-specific solid waste system models.

1. Residential and Commercial garbage is collected and taken to one of two city owned disposal stations where it is packed and then transferred to the rail yard for transport to the landfill. Since the MSW DST does not allow multiple transfer stations of the same type to be chosen, nor is it capable of modeling the transfer of waste from one transfer station, which occurs in the Seattle System, it was assumed that the rail transfer station is a proxy for the City owned transfer station.

2. There are approximately 16,000 tons of residential recyclables that are self-hauled to private sector recycling centers or collection boxes throughout the Seattle. For MSW DST modeling purposes, it was assumed that these private recycling tonnages are included with the city-owned transfer station drop-off recyclables.

3. Commingled recyclables from Seattle's residential and multifamily sectors are collected in a two compartment collection vehicle. One compartment holds glass containers and the other compartment holds the remaining commingled recyclables (fiber and commingled containers). The MSW DST contains a two-compartment truck option. However, it assumes that one compartment holds fiber and the other compartment holds commingled containers. While this collection option in the MSW DST does not model the Seattle collection system exactly, it was assumed that the commingled collection option of one compartment holding paper materials and the other compartment holding non-paper recyclables is a close approximation.

4. Seattle tracks the self-haul recycling and yard waste tonnage by the categories, cars and trucks. It was assumed that 100 percent of car tonnage is associated with the residential sector and 50 percent of truck tonnage is commercial and 50 percent is residential.

5. Commercial waste generation tonnage was available, however, the number of commercial collection locations was unknown during the data collection effort. To approximate the number of commercial locations, an assumption was made that each collection location generates of 400 pounds of waste per week. If data becomes available, the model can easily be updated. The formula for the number of commercial collection locations is as follows:

Total adjusted commercial generation (tons) * 2000 (lbs)/52 (weeks)*400 (lbs/week)

6. The city of Seattle also recycles some materials that could not be included in the modeling since the MSW DST does not have remanufacturing data for those items. To prevent these items from being treated as nonrecyclable and incorrectly increasing the quantity of waste landfilled, the tonnage of these recycled items was excluded from the generation data. These items amount to 4.3% of the waste generated.

7. The City of Seattle also tracks tonnages associated with residential backyard composting and grasscycling in their recycling tonnage estimates. Since the MSW DST does not does not model these components, these quantities were excluded from the baseline analysis. Therefore, the Seattle's recycling rate may be higher than the recycling rate determined in the MSW DST.

8. The default values for the market prices of recyclables were not changed. Although Seattle has historical data of the amount of money the city receives from the sale of recyclables, the city is not the end user of the products. The MSW DST notes that the market prices for recyclables must be based on the purchaser picking up the material at the MRF such that their transportation cost is reflected in this price since the transportation cost module assumes zero cost to the municipality for this transportation segment. Market prices of recyclables in the MSW DST were determined as of December 1999 from Recycling Manager Website http://grn.com/prices/rm-prices.htm.

9. Model contains a 90% participation rate for the residential recycling sector and a 60% participation rate for residential yard waste collection. Multifamily and commercial curbside participation was left at 100% participation rate. The model also contains the adjusted capture rates for recyclables and compostables. A few capture rates are above 100%. This may appear to be an error but is not due to the way the mass flow is determined by the MSW DST. The product of the capture rate and the participation rate cannot exceed 1, but individual capture rates and participation rates can exceed 1. The following mass flow equation is used in the MSW DST:

   *Total tons * waste composition * capture rate * participation rate.*

   Total tons and waste composition are fixed variables. The capture rate and the participation rate are the only changeable variables. The product of the capture rate and participation rate cannot exceed 1.

5.4 CITY OF SPOKANE, WASHINGTON

Similar to Seattle, the purpose of this application was to develop a baseline model of the current Spokane MSW management system using the MSW DST. The goal was to simulate Spokane's solid waste system. This involved changing default values and settings in the MSW DST to match Spokane's system as the available data permitted. Models specific to Spokane were developed and the process by which they were developed are described in this section. Spokane may use the models and results to evaluate the economic and environmental aspects of the current system and to evaluate future solid waste management alternatives.

5.4.1 Waste Composition, Generation, and Recycling data

The initial development of the study involved gaining an understanding of the system through information retrieval via the Internet and through phone conversations with Spokane Solid Waste

Planning Staff. Data collection sheets were developed for Spokane staff to complete for transmittal into the Spokane-specific models developed by RTI staff. Data sheets created include general system information such as waste generation, tonnage quantities, population quantities, in addition to composting, landfill, combustion, transportation and collection, transfer station and recycling facilities data sheets.

5.4.2 Model Design

For the purpose of building the baseline model, the City and regional area were divided into modeling sectors based on data collection categories used by Spokane Regional Solid Waste System Staff. The City evaluates MSW in terms of residential, commercial and self-haul categories.

Three models were developed to emulate the Spokane Solid waste system. The models contain some Spokane-specific data, but do not contain crucial waste generation data. As this and other data becomes available, it can be added to the models. The first model depicts residential and commercial curbside waste management for the City of Spokane. The second models residential and commercial curbside waste management for the greater Spokane (unincorporated) areas. The third models all self-haul garbage, recycling and yard waste for the residential, multifamily and commercial sectors.

Model 1 Description

Models City of Spokane residential and commercial curbside waste collection. Single family residential and multifamily data are combined. Residential garbage management includes single family and multifamily residual mixed waste collection transported to a WTE facility. Ash residue from combustion is transported to an ash landfill. Residential recycling includes single family and multifamily crew-sorted recycling collection transported to a presorted MRF, which is then transported to remanufacturing facilities. Residential yard waste management includes single family and multifamily collection of yard waste transported to a yard waste composting facility. Commercial garbage collection includes residual mixed waste collection transported to a WTE facility. Ash residue from combustion is transported to an ash landfill. Commercial recycling includes presorted recycling collection transported to a presorted MRF, which is then transported to remanufacturing facilities. The following MSW DST unit processes are depicted below.

Residential Sector 1 — City

- Yard Waste Collection, Yard waste Composting
- Crew-sorted recycling collection, Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste collection, WTE, Landfill

Commercial Sector 1 — City

- Presorted recycling collection, Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste collection, WTE, Landfill

Model 2 Description

Models residential and commercial curbside waste collection for the greater Spokane unincorporated areas. Model assumes that single family residential and multifamily data are combined. Residential garbage management includes single family and multifamily residual mixed waste collection transported to transfer station, which is then transported to a WTE facility. Ash residue from combustion is transported to an ash landfill. Residential recycling includes single family and multifamily crew-sorted recycling collection transported to a presorted materials recovery facility MRF, which is then transported to remanufacturing facilities. Residential yard waste management includes single family and multifamily collection of yard waste transported to a yard waste composting facility. Commercial garbage collection includes residual mixed waste collection transported to a transfer station, which is then transported to a WTE facility. Ash residue from combustion is transported to an ash landfill. Commercial recycling includes presorted recycling collection transported to a presorted MRF, which is then transported to remanufacturing facilities. Note: Unless the private sector provides commercial recycling data, Spokane does not have access to this information. The commercial recycling unit process was enabled for model flexibility purposes only and is not intended to show results. The model can be set such that no unincorporated recycling tonnages are analyzed. However, if data becomes available, the model can show commercial recycling results. The following MSW DST unit processes are depicted below.

Residential Sector 1 — Greater Spokane Unincorporated Areas

- Yard Waste Collection ,Yard waste Composting
- Crew-sorted recycling collection, Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste collection4 Transfer Station, WTE, Landfill

Commercial Sector 1 — Greater Spokane Unincorporated Areas

- Presorted recycling collection, Presorted Recycling MRF, Remanufacturing
- Residuals mixed waste collection, WTE, Landfill

Model 3 Description

Models all self-haul garbage, recycling and yard waste for the residential, multifamily and commercial sectors. Recycling drop-off includes self-haul to a presorted MRF, which is then transported to re-manufacturing facilities. Yard waste drop-off includes self-haul to a transfer station, which is then transported to a high-end yard waste composting facility. Self-haul garbage is not a valid option in the MSW DST. However, garbage drop-off was modeled as though it was collected as single-family curbside MSW residuals transported to a transfer station, which is then transported to a WTE facility with final ash residue transported to an ash landfill. The collection and emission coefficients for recycling drop-off were used as a proxy for MSW drop-off and were copied over to residential curbside residual collection (C7) in the Variable Coefficients spreadsheet of the model. These coefficients automatically update so the user does not have to copy over the coefficients every time the default values are changed. In addition, The MSW DST does not permit yard waste drop-off at a transfer station prior to delivery to a yard waste composting facility as occurs in Spokane. The collection and emission coefficients for recycling drop-off were also used as a proxy for yard waste drop-off and were copied over to residential yard waste drop off collection (C10) in the Variable Coefficients spreadsheet of the model. Although, these two model modifications are fairly simple, these types of changes are not something the novice modeler would do since it involves modifying the model itself instead of making changes in the user-input area of the model. The following MSW DST unit processes are depicted below:

Single Family Sector 1 — all residential, multifamily, and commercial self-haul yardwaste recycling and garbage

- Yard Waste Drop-Off Collection, Yard waste Composting
- Recycling Drop-Off Collection , Presorted Recycling MRF , Remanufacturing
- Residuals mixed waste collection, Transfer Station, WTE, Landfill

5.2.3 Spokane Modeling Assumptions

Although the MSW DST is a powerful screening tool designed for use in evaluating community level municipal solid waste management strategies, it does not contain all possible solid waste management scenarios. In addition, there are hundreds of default values within the model that can be changed based on community level data. In some cases, communities do not collect the types of data that can be entered into the tool. Because of the unavailability of data and modeling constraints, the following assumptions were made in developing the Spokane-specific solid waste system models.

1. The models were constructed based on the assumption that multifamily and single family data are combined. Intuitively, it seems that the multifamily sector could be disabled in the model. However, that is not the case. To circumvent this problem, the multifamily population, generation rate, and the number if locations were changed to values of zero.

2. Unincorporated area commercial recycling data is not tracked by Spokane Regional Solid Waste Management. These recyclables by-pass the City's system, making tracking of tonnages very difficult. For model flexibility reasons, the commercial recycling unit process was enabled. However, the model can be set such that no recycling tonnage is analyzed for unincorporated area commercial recycling.

3. Commingled recyclables from Spokane's (within Spokane's city limits) residential, multifamily and commercial sectors are collected and presorted in a three compartments collection vehicle. One compartment holds glass containers. The second compartment holds commingled recyclables (aluminum, tin and plastic containers). The third compartment holds fiber (paper and cardboard). The private haulers providing service in the greater Spokane unincorporated areas may divide recyclables in a different manner. For simplicity purposes, the models assume that private recycling mimics the City of Spokane's collection system.

4. The City of Spokane collects some glass from the commercial sector within the city limits. however, the tonnage is collected and included in the residential recycling collection program.

5. Spokane's yardwaste composting system consists of the Ag-Bag in-vessel composting technology. The system uses very low density polyethylene bags (3-ply, 9 ½ mil) approximately 10 feet in diameter and 200 feet long. The compostable materials are grinded and forced into the bag by a hydraulic arm. After the bag is full, air is blown into the bag by small, electric motors. After 60 days the compost is ready for curing. Unfortunately, the MSW DST does not include this type of composting technology. However, the aerated static pile yard waste composting treatment was assumed to be a close approximation to the Ag-Bag in-vessel composting technology.

5.5 NAVY REGION NORTHWEST (NRNW)

A study of MSW management on Naval Bases in the Navy Regional Northwest (NRNW) was performed by Concurrent Technologies Corporation (CTC) using the MSW DST under the guidance of RTI. The MSW DST was used to evaluate the Navy's proposed strategy of replacing old collection vehicles with new collection vehicles as an area of potential savings. This involved creating a baseline scenario and comparing it to a future scenario with new collection vehicles. This case study documents CTC's approach and study results.

5.5.1 Waste Composition, Generation, and Recycling data

CTC used information provided by NRNW and information gathered in an earlier "as is" study to create models for the NRNW. Two models were developed dividing NRNW geographically. The West Puget Sound model consists of Submarine Base, Bangor and Puget Sound Naval Shipyard. The East Puget Sound model consists of Naval Station, Everett and Naval Air Station, Whidbey Island.

Information from the "as is" study was provided to RTI who calculated East and West Sound capture rates, which were included in the baseline models. Capture rates are the fraction of a particular recyclable that a participating recycler would be expected to be able to segregate from MSW.

5.5.2 Model Design

Information entered into the system involved defining sectors for both the baseline and future models. The West Sound was modeled as one residential sector, one multi-family sector, and one commercial sector. The East Sound was modeled as one residential sector and one commercial sector. Population, average persons per house, and generation rates were entered for both models. Detailed information that was not specifically provided or available from the previous baseline study was left as default values in the MSW DST.

Baseline Model

In building the baseline model as much information as possible was entered to override default data regarding the existing trucks. Data were entered with respect to cost of the trucks, gas mileage, capacity, and collection labor associated with the operation of the vehicles. Data left as default for the current trucks and future trucks included maintenance cycles, various fluid capacities, and specific usage information that was not available.

Future Scenario (New Trucks)

Information relating to the new trucks was changed in the future scenario model. The new trucks cost more than the current trucks, but get better gas mileage. The new trucks require only one driver/collector, whereas the baseline trucks use a driver plus two additional collectors.

5.5.3 Cost and Environmental Results

A total of 12 optimization runs were made. The MSW DST allows two strategies for comparing different process models, by mass flow and by life cycle inventory. Within each comparison strategy, nine life-cycle inventory parameters can be optimized. As shown in Table 5-10, CTC made runs of the MSW DST on each model (East and West, both baseline, and with new trucks) on three optimization parameters; cost, energy consumption (EC), and total particulate matter (TPM).

Table 5-10. NRNW Model Strategies and Objective Functions

Strategies	Objective Functions
Compared by cost/life cycle inventory (LCI)	Cost
	Energy consumption
	Total particulate matter
Compared by mass	Cost
	Energy consumption
	Total particulate matter

Model run results are provided in Tables 5-11(a-d). It can be seen from the data that in the future model (i.e., with the new trucks) cost went down, energy consumption went down, and total particulate matter went down (a larger negative number represents a decrease). For example, reviewing the West Sound model compared by cost/life cycle inventory and optimized cost (see Table 5-10), indicates that implementing the new trucks would reduce operating costs by approximately 46 percent. (Optimizing on cost - baseline cost $5,696,666 and future cost $3,062,407.)

5.5.4 Application of Results

The NRNW used the results from this application of the MSW-DST to develop and implement an improved MSW management plan that reduced cost, increased recycling rates, and ensured that environmental goals are being met. In addition, with the closing of smaller local landfills and with the transporting of waste by rail to a larger regional site, the Navy is evaluating subsequent changes in cost, energy consumption, and environmental releases. In order to identify more cost-effective and environmentally preferable solutions to a more regional approach for integrated waste management, the Navy is also evaluating options that would combine waste from nearby communities.

Table 5-11a. NRNW West Sound Model Results for Cost/LCI Strategy and Optimization Parameters

Strategies compared by Cost/LCI		Cost		Energy Consumption		Total PM	
Parameter	Units	Base	Future	Base	Future	Base	Future
Cost	$	5,696,666	3,062,407	8,036,747	4,402,559	8,036,747	4,402,559
Energy Consumption	MBTU	-38,417	-62,020	-106,166	-114,787	-106,166	-114,787
Total Particulate Matter	lb	-11,894	-12,889	-24,146	-24,337	-24,146	-24,337
Nitrogen Oxides	lb	3,119	-10,894	-6,765	-20,678	-6,765	-20,678
Sulfur Oxides	lb	-47,933	-50,299	-79,857	-81,268	-79,857	-81,268
Carbon Monoxide	lb	-10,005	-14,533	-53,329	-55,664	-53,329	-55,664
Carbon Dioxide Biomass	lb	122,983,532	122,983,189	120,789,682	120,789,350	120,789,682	120,789,350
Carbon Dioxide Fossil	lb	2,190,307	1,642,386	-225,137	-583,863	-225,137	-583,863
Green House Equivalents	MTCE	3,154	3,079	2,673	2,623	2,673	2,623
Hydrocarbons	lb	19,979	16,532	9,692	8,407	9,692	8,407
Lead	lb	-528	-528	-644	-644	-644	-644
Ammonia	lb	-7	-7	-8	-8	-8	-8
Methane	lb	997,162	996,868	944,131	943,908	944,131	943,908
Hydrochloric Acid	lb	1,364	1,363	1,029	1,028	1,029	1,028
Total Solid Waste	lb	-430,717	-466,249	-1,106,181	-1,113,639	-1,106,181	-1,113,639
Dissolved Solids	lb	4,581	2,697	-9,400	-11,294	-9,400	-11,294
Suspended Solids	lb	6,064	5,982	8,095	8,051	8,095	8,051
BOD	lb	41,523	41,483	44,118	44,111	44,118	44,111
COD	lb	51,698	51,548	43,513	43,466	43,513	43,466
Oil	lb	10,687	10,627	10,288	10,244	10,288	10,244
Sulfuric Acid	lb	338	333	312	311	312	311
Iron	lb	1,447	1,446	1,674	1,673	1,674	1,673
Ammonia	lb	845	837	745	744	745	744
Copper	lb	0	0	0	0	0	0
Cadmium	lb	0	0	-1	-1	-1	-1
Arsenic	lb	0	0	0	0	0	0
Mercury	lb	0	0	0	0	0	0
Phosphate	lb	15	15	11	11	11	11
Selenium	lb	0	0	0	0	0	0
Chromium	lb	0	0	-1	-1	-1	-1
Lead	lb	0	0	0	0	0	0
Zinc	lb	19	19	22	22	22	22

Table 5-11b: NRNW West Sound Model Results for Mass Strategy and Optimization Parameters

Strategies compared by Mass		Cost		EC		TPM	
Parameter	Units	Base	Future	Base	Future	Base	Future
Cost	$	8,036,747	3,062,407	5,945,685	4,402,559	11,596,427	4,402,559
Energy Consumption	MBTU	-106,166	-62,020	30,465	-114,787	-106,040	-114,787
Total Particulate Matter	lb	-24,146	-12,889	4,734	-24,337	-24,143	-24,337
Nitrogen Oxides	lb	-6,765	-10,894	49,863	-20,678	-6,480	-20,678
Sulfur Oxides	lb	-79,857	-50,299	12,721	-81,268	-79,836	-81,268
Carbon Monoxide	lb	-53,329	-14,533	135,725	-55,664	-53,283	-55,664
Carbon Dioxide Biomass	lb	120,789,682	122,983,189	133,882,287	120,789,350	120,789,687	120,789,350
Carbon Dioxide Fossil	lb	-225,137	1,642,386	1,977,368	-583,863	-218,584	-583,863
Green House Equivalents	MTCE	2,673	3,079	3,606	2,623	2,674	2,623
Hydrocarbons	lb	9,692	16,532	26,905	8,407	9,692	8,407
Lead	lb	-644	-528	12	-644	-644	-644
Ammonia	lb	-8	-7	0	-8	-8	-8
Methane	lb	944,131	996,868	1,165,102	943,908	944,134	943,908
Hydrochloric Acid	lb	1,029	1,363	1,682	1,028	1,029	1,028
Total Solid Waste	lb	-1,106,181	-466,249	95,672	-1,113,639	-1,106,070	-1,113,639
Dissolved Solids	lb	-9,400	2,697	17,069	-11,294	-9,372	-11,294
Suspended Solids	lb	8,095	5,982	1,135	8,051	8,095	8,051
BOD	lb	44,118	41,483	38,006	44,111	44,118	44,111
COD	lb	43,513	51,548	104,309	43,466	43,514	43,466
Oil	lb	10,288	10,627	10,453	10,244	10,289	10,244
Sulfuric Acid	lb	312	333	323	311	312	311
Iron	lb	1,674	1,446	23	1,673	1,674	1,673
Ammonia	lb	745	837	1,182	744	745	744
Copper	lb	0	0	0	0	0	0
Cadmium	lb	-1	0	1	-1	-1	-1
Arsenic	lb	0	0	0	0	0	0
Mercury	lb	0	0	0	0	0	0
Phosphate	lb	11	15	9	11	11	11
Selenium	lb	0	0	0	0	0	0
Chromium	lb	-1	0	1	-1	-1	-1
Lead	lb	0	0	0	0	0	0
Zinc	lb	22	19	0	22	22	22

Table 5-11c. NRNW East Sound Model Results for Cost/LCI Strategy and Optimization Parameters

Strategies compared by Cost/LCI		Cost		EC		TPM	
Parameter	Units	Base	Future	Base	Future	Base	Future
Cost	$	3,691,334	2,013,356	5,439,932	3,061,210	5,439,932	3,061,210
Energy Consumption	MBTU	-33,533	-45,703	-57,820	-63,051	-57,820	-63,051
Total Particulate Matter	lb	-10,834	-11,320	-13,278	-13,391	-13,278	-13,391
Nitrogen Oxides	lb	4,731	-3,030	4,325	-3,770	4,325	-3,770
Sulfur Oxides	lb	-35,290	-36,582	-40,901	-41,758	-40,901	-41,758
Carbon Monoxide	lb	-1,385	-3,718	-15,871	-17,236	-15,871	-17,236
Carbon Dioxide Biomass	lb	61,398,763	61,398,559	61,504,257	61,504,055	61,504,257	61,504,055
Carbon Dioxide Fossil	lb	-324,140	-617,547	-951,940	-1,164,045	-951,940	-1,164,045
Green House Equivalents	MTCE	1,342	1,301	1,247	1,218	1,247	1,218
Hydrocarbons	lb	9,430	7,297	5,504	4,365	5,504	4,365
Lead	lb	-266	-266	-268	-268	-268	-268
Ammonia	lb	-4	-4	-4	-4	-4	-4
Methane	lb	483,916	483,749	480,796	480,661	480,796	480,661
Hydrochloric Acid	lb	475	475	427	426	427	426
Total Solid Waste	lb	-640,401	-657,984	-730,702	-735,222	-730,702	-735,222
Dissolved Solids	lb	-3,767	-4,897	-7,249	-8,399	-7,249	-8,399
Suspended Solids	lb	3,888	3,844	4,058	4,031	4,058	4,031
BOD	lb	22,260	22,241	22,608	22,604	22,608	22,604
COD	lb	28,170	28,093	28,434	28,405	28,434	28,405
Oil	lb	5,686	5,652	5,566	5,540	5,566	5,540
Sulfuric Acid	lb	212	210	197	197	197	197
Iron	lb	674	674	665	664	665	664
Ammonia	lb	407	403	399	398	399	398
Copper	lb	0	0	0	0	0	0
Cadmium	lb	0	0	-1	-1	-1	-1
Arsenic	lb	0	0	0	0	0	0
Mercury	lb	0	0	0	0	0	0
Phosphate	lb	4	4	3	2	3	2
Selenium	lb	0	0	0	0	0	0
Chromium	lb	0	0	0	-1	0	-1
Lead	lb	0	0	0	0	0	0
Zinc	lb	9	9	9	9	9	9

Table 5-11d. NRNW East Sound Model Results for Mass Strategy and Optimization Parameters

Strategies compared by Mass		Cost		EC		TPM	
Parameter	Units	Base	Future	Base	Future	Base	Future
Cost	$	3,692,195	2,013,356	5,439,932	3,061,210	5,439,932	3,061,210
Energy Consumption	MBTU	-33,533	-45,703	-57,820	-63,051	-57,820	-63,051
Total Particulate Matter	lb	-10,834	-11,320	-13,278	-13,391	-13,278	-13,391
Nitrogen Oxides	lb	4,731	-3,030	4,325	-3,770	4,325	-3,770
Sulfur Oxides	lb	-35,290	-36,582	-40,901	-41,758	-40,901	-41,758
Carbon Monoxide	lb	-1,385	-3,718	-15,871	-17,236	-15,871	-17,236
Carbon Dioxide Biomass	lb	61,398,763	61,398,559	61,504,257	61,504,055	61,504,257	61,504,055
Carbon Dioxide Fossil	lb	-324,140	-617,547	-951,940	-1,164,045	-951,940	-1,164,045
Green House Equivalents	MTCE	1,342	1,301	1,247	1,218	1,247	1,218
Hydrocarbons	lb	9,430	7,297	5,504	4,365	5,504	4,365
Lead	lb	-266	-266	-268	-268	-268	-268
Ammonia	lb	-4	-4	-4	-4	-4	-4
Methane	lb	483,916	483,749	480,796	480,661	480,796	480,661
Hydrochloric Acid	lb	475	475	427	426	427	426
Total Solid Waste	lb	-640,401	-657,984	-730,702	-735,222	-730,702	-735,222
Dissolved Solids	lb	-3,767	-4,897	-7,249	-8,399	-7,249	-8,399
Suspended Solids	lb	3,888	3,844	4,058	4,031	4,058	4,031
BOD	lb	22,260	22,241	22,608	22,604	22,608	22,604
COD	lb	28,170	28,093	28,434	28,405	28,434	28,405
Oil	lb	5,686	5,652	5,566	5,540	5,566	5,540
Sulfuric Acid	lb	212	210	197	197	197	197
Iron	lb	674	674	665	664	665	664
Ammonia	lb	407	403	399	398	399	398
Copper	lb	0	0	0	0	0	0
Cadmium	lb	0	0	-1	-1	-1	-1
Arsenic	lb	0	0	0	0	0	0
Mercury	lb	0	0	0	0	0	0
Phosphate	lb	4	4	3	2	3	2
Selenium	lb	0	0	0	0	0	0
Chromium	lb	0	0	0	-1	0	-1
Lead	lb	0	0	0	0	0	0
Zinc	lb	9	9	9	9	9	9

5.6 COMPOSTING AT EPA'S NEW RESEARCH TRIANGLE PARK FACILITY

The construction of a new EPA facility in Research Triangle Park, NC was completed in 2002 and is the largest complex ever built and owned by the EPA and houses 2,200 people, 400 individual laboratories, a conference center, a cafeteria, a national computer center, and a childcare center. The campus consolidates the EPA's functions on a site neighboring the National Institute of Environmental Health Sciences (NIEHS). EPA and NIEHS share a centralized utility plant and common services including the conference facilities, child care, landscaping, security, and waste management. This closeness in proximity creates efficiencies and enhances opportunities for collaboration between these two environmental organizations.

A great deal of effort went into balancing function and environmental impact during the design and construction of this facility. As part of this process, it was decided to compost non-recycled organic waste rather than have it landfilled. Unfortunately the MSW DST was not yet available at the time that decisions were being made. We were contacted to help quantify the environmental benefit of composting versus landfilling this waste. This study is a good example of how the MSW DST can be used in decision making.

5.6.1 Waste Composition, Generation, and Recycling Data

The EPA facility produces approximately 158 tonnes per year of organic materials, including:

- 90 tonnes of food waste;
- 56 tonnes of yard trimmings (grass, leaves, and branches);
- 8 tonnes of mixed paper; and
- 4 tonnes of animal bedding (wood shavings).

Currently, this material is collected by a private collection company and taken to a landfill where it is composted with other organic material.

5.6.2 Model Design

The following waste management scenarios were analyzed as part of this study:

- **Scenario 1:** Food waste and mixed paper are collected, sent to a transfer station, and then hauled to a regional landfill (145 km from EPA) (Figure 3). The 60 tonnes of yard waste and animal bedding are collected and sent to the transfer station for mulching using a tub grinder. Waste is collected 3 times a week, and the transfer station is 24 km away. The remaining waste is collected 3 times a week, hauled to the transfer station (24 km away), packed in a semi-tractor, and hauled 145 km. The landfill has been operating for 5 years and is in compliance with all state and national regulations. Landfill gas is collected and flared.

- **Scenario 2:** Waste is composted at an off-site facility that is 96 km from EPA (Figure 4). The animal bedding and mixed paper are collected three times per week, sent to the transfer station, and then long hauled to the landfill. The yard waste is also collected three times per week, sent to the transfer station, and mulched using a tub grinder. Food waste is collected three times per week and transported to off-site composting facility using windrows which are turned ten times during a 9-week composting and curing process. There is no pre-grinding or shredding of the food waste prior to composting. The final compost product is screened using a front-end loader and trammel screen.

- **Scenario 3:** Organics are composted at an on-site facility. Organic wastes are collected three times per week and transported ~2 km to the compost site in a light duty diesel truck. Once at the compost site, the 158 tonnes are composted as described in Scenario 2. The yard waste (56 tonnes) is chipped in a shredder chipper prior to composting. The energy use and emissions associated with the shredder have been included in the calculations.

5.6.3 Major Assumptions

The total number of employees from all 11 facilities is assumed to be 37,600. The ratio of the Facility's employees to this total is 1 to 18.8, which is the multiplier used for several of the rough assumptions on which analysis of this option is based.

The estimated site area required for this windrow operation is 4.5 acres.

Other key assumptions include the following:

- The following additional equipment is required for this option compared to the option in which the Facility composts alone at its site: a shredder/chipper, a scales, a compost screen, a collection truck, a computer, and small equipment such as shovels and temperature probes.
- The amount of feedstock from all the companies is 18.8 times the amount assumed for the Facility alone.
- The ratio of feedstock types remains the same as that from the Facility alone.
- All partner companies share use of the finished product in proportion to their contribution of feedstock to the composting operation.
- Management is 30 hours per week and two full-time employees handle operations and collection.
- Utilities and gasoline expenses are increased.
- Personnel training is four times the amount assumed for the option in which the Facility site is used to capacity.
- Organizational training is 11 times the amount assumed for the Facility alone.
- The average distance between companies is 1.5 miles, and the distance from the route to the first company is 1 mile.
- Each company uses the resulting product in proportion to its contribution of feedstock.

5.6.4 Environmental Results

A comparison of energy consumption by process (collection, transportation, and landfilling or composting) indicates that the least energy efficient is Scenario 2, composting off-site (Figure 5-1).
The landfill option is the highest emitter of GHGs due to fugitive landfill methane not captured by the collection system (Figure 5-2). Landfill gas is flared so there are no offsets for landfill methane utilization. An energy recovery project is being considered, and once it is implemented, we can rerun the results to reflect the type of technology in use and the off-sets associated with the project. Scenario 2, the offsite compost facility option, had the highest emissions of nitrogen oxides (Figure 5-3).

Those requesting this analysis were quite surprised by the results. They had assumed that composting must be more environmentally beneficial than landfilling the waste. The significant difference between the first two scenarios was how the waste was being transported. Although the landfill was ~50 km further in distance than the off-site compost facility, this option was more energy efficient and resulted in lower NOx emissions. This is because a transfer station was used where the waste is combined with that from other facilities, compacted, and then long-hauled in a semi-tractor trailer to the landfill. The type of truck used for hauling waste to the landfill is more energy efficient than what is used for hauling waste to the compost facility.

Scenario 3, a compost facility on-site or within a closer proximity, was definitely the option that has the least environmental impact.

5.6.5 Application of Results

The results of this study were presented and discussed with the EPA, NIEHS, and facilities in the Research Triangle Park of North Carolina. A centrally located compost facility at EPA's new location, or at another site within the Research Triangle Park area is being explored by a consortium of companies in the Research Triangle Park to minimize collection and transportation burdens and maximize the benefits of composting. The results also helped to identify where the existing operation is inefficient. If off-site composting is to be continued at a site that is 96 km from EPA, maybe there are other options for collection and transportation such as rail haul. The application of the MSW DST for this study has provided a baseline and helped identify inefficiencies in current operations and opportunities for environmental improvement.

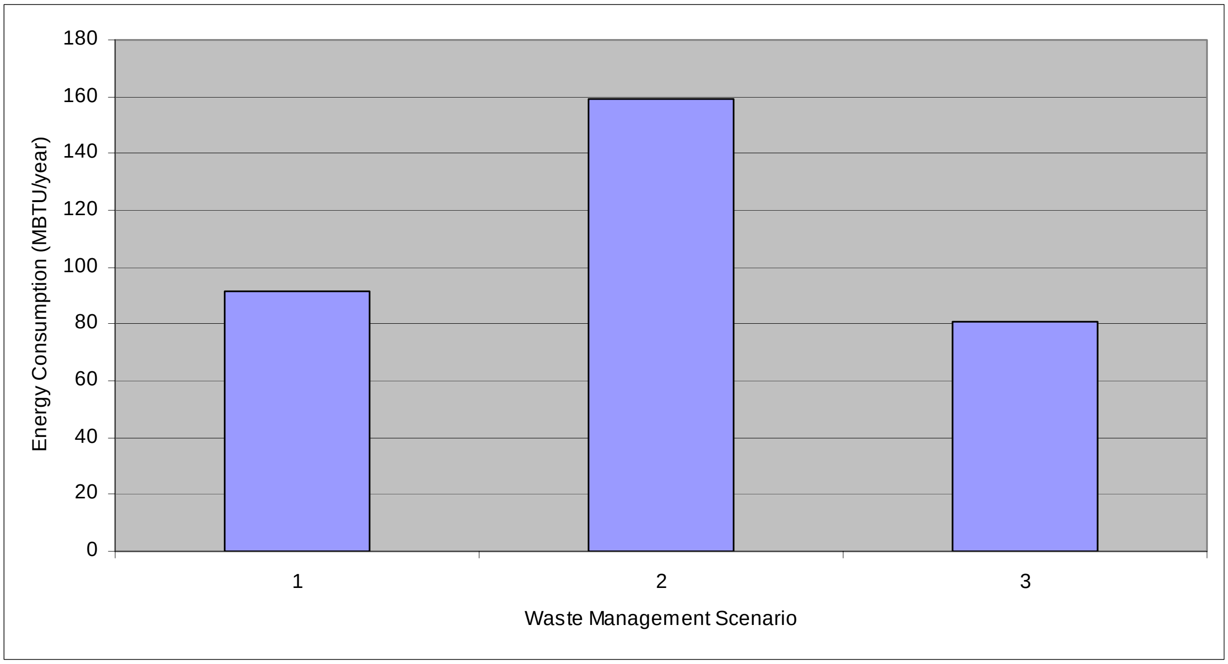
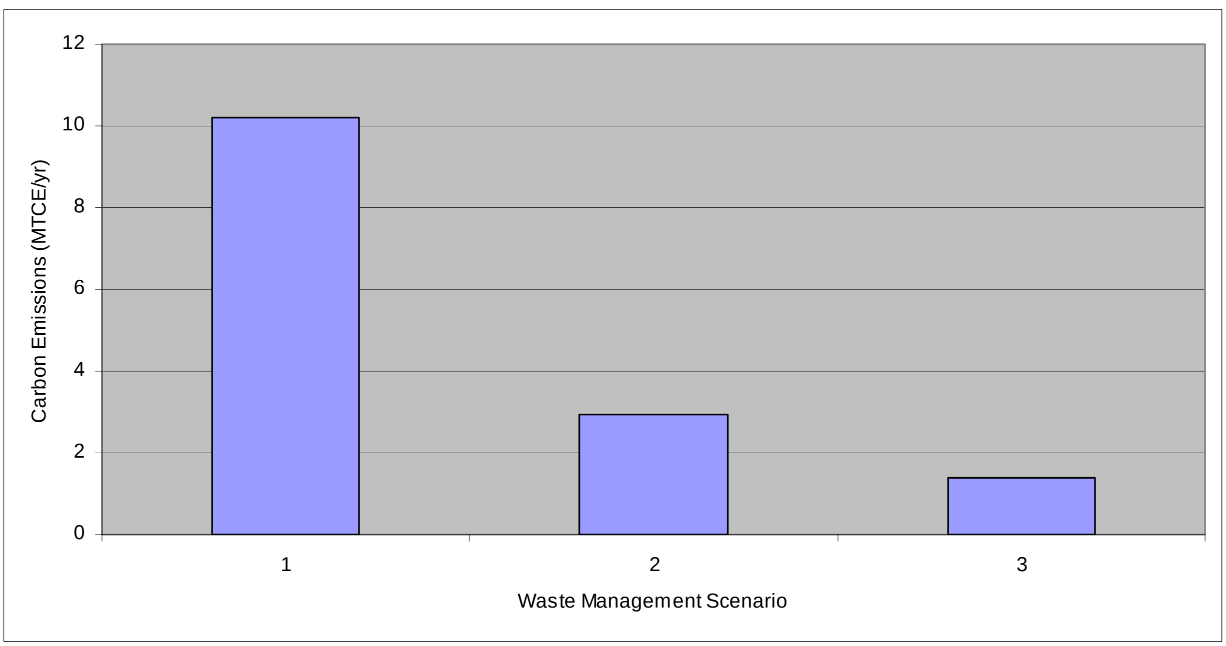


Figure 5-1. Energy Consumed by EPA Waste Management Scenario

Figure 5-2. Greenhouse Gases Emitted by EPA Waste Management Scenario



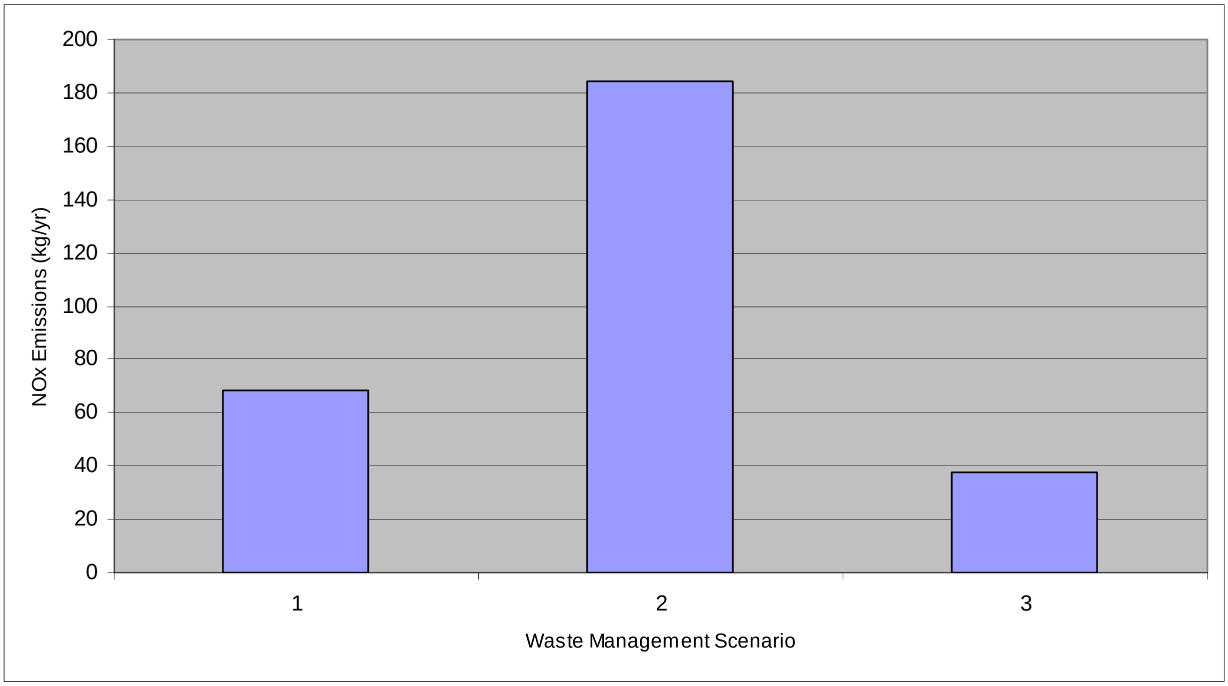


Figure 5-3. Nitrogen Oxides Emitted by EPA Waste Management Scenario

5.7 STATE OF WISCONSIN

The purpose of this study was to apply the MSW DST to estimate the environmental aspects of recycling and MSW management in Wisconsin. Specifically, the State was interested in quantifying the full life-cycle environmental aspects of recycling in Wisconsin in 2000 as compared to 1995 levels. Additionally, the environmental aspects of recycling at 2000 levels were also compared to the hypothetical scenario where no recycling was implemented in Wisconsin in 2000.

5.7.1 Waste Composition, Generation, and Recycling data

Waste generation data and recycling rates estimated for year 2000 were used for model year 2000, and waste generation and recycling rates for 1995 were used for model year 1995. Complete life-cycle energy use and emissions for waste management are compared in the years 1995 and 2000.

Two separate models were developed to represent 1995 and 2000 waste management scenarios for the State of Wisconsin. The data collected to develop these models include, population, waste generation rates, and the percent composition of generated and recycled materials.

5.7.2 Model Design

To model the waste management in Wisconsin in 1995 and 2000, the waste flows developed from the available data sources were entered into the MSW DST. The following waste management processes were used in modeling waste flows for Wisconsin.

- Collection of presorted recyclables and collection of remaining (residual) waste
- Processing of recyclables in a presorted Materials Recovery Facility
- Yardwaste is composted in a composting facility. In addition to yardwaste collected and composted, yardwaste is also composted in residential backyards.
- Disposal of residuals (waste remaining after recyclables are removed) in a Subtitle D landfill.

5.7.3 Major Assumptions

When applying the MSW DST to the real-world waste management practices of Wisconsin, some assumptions are required to “fit” the real-world practices into the modeling environment of the MSW DST. Wisconsin study included the following assumptions in the analysis:

- Some materials that were actually recycled in Wisconsin could not be entered as recyclables because the Decision Support Tool does not have remanufacturing data for those items, e.g., food waste, batteries, tires, etc. To prevent these items from all being treated as non-recyclable and thus incorrectly increasing the waste landfilled, the quantity of these items recycled were left out of the generation data. These items that were excluded are approximately 5% of the waste generated. This approach ignores the downstream life-cycle inventory (LCI) benefits (or costs) of recycling the materials.
- The emissions and energy use in processing of a ton of yardwaste composted in backyards was assumed to be the same as that from composting a ton of yardwaste composted in a compost facility run by the community.

5.7.4 Environmental Results

The recycling levels for model year 2000 were higher than those for model year 1995 for all components. The net emissions include emissions from the collection, processing, treatment, disposal, and remanufacturing of waste and recyclables in Wisconsin.

Comparison of environmental aspects of recycling in 1995 and 2000

- Emissions and energy use in remanufacturing of recyclables drive the total emissions and energy use from integrated waste management.

- Tables 5-12 and 5-13 show net emissions and energy use from projected waste management in 2000 compared to the net emissions and energy use in 1995. The different recyclables quantities managed in 2000 resulted in different LCI numbers from 1995. The results show that for some LCI parameters, recycling at year 2000 levels results in lower overall air, water, and solid waste releases, and energy usage. For other LCI parameters, the releases were higher in 2000 compared to 1995 levels. The largest decrease in emissions in 2000 from 1995 was for air NOx (428%), and the largest increase in emissions from 1995 was for water Zinc releases (50%).

- For several environmental releases and energy, the net numbers in the results are negative. A negative number indicates that there was a net savings or offset in emissions for those LCI parameters due to the environmental benefits of recycling. The negative numbers in the results are from the remanufacturing stage of waste management and represent the savings in emissions due to recycling.

Comparison of environmental aspects of recycling in 2000 to a "no recycling" scenario

- Tables 5-14 and 5-15 show the environmental benefits and costs of recycling in 2000 compared to no recycling in 2000. Thus, the two model runs being compared are recycling at 31% (excluding yardwaste composting) of the waste, and recycling 0% of the waste generated.

Table 5-12. Summary of Emissions and Energy Consumption that Decreased for managing all of Wisconsin's waste in 2000 from 1995

Parameter	Units	1995 LCI	2000 LCI	Percent Decrease in 2000
Energy Consumption	Million BTU/year	-14,782,000	-16,149,000	9%
Air Emissions				
Total Particulate Matter	lbs/year	-3,973,000	-4,338,000	9%
Nitrogen Oxides	lbs/year	188,000	-616,000	428%
Sulfur Oxides	lbs/year	-12,646,000	-13,991,000	11%
Carbon Monoxide	lbs/year	-16,744,000	-19,471,000	16%
Carbon Dioxide (Fossil fuel sources)	lbs/year	-503,792,000	-517,980,000	3%
Hydrochloric Acid	lbs/year	-83,000	-91,000	10%
Lead	lbs/year	-64,000	-75,000	17%
Ammonia	lbs/year	-900	-1,000	11%
Solid Waste from Remanufacturing	lbs/year	-246,723,000	-276,696,000	12%
Water Releases				
COD	lbs/year	-1,642,000	-2,321,000	41%
Dissolved Solids	lbs/year	-3,233,000	-3,625,000	12%
Ammonia	lbs/year	15,000	11,000	27%

Table 5-13. Summary of Emissions that Increased for managing all of Wisconsin's

waste in 2000 from 1995

Parameter	Units	1995 LCI	2000 LCI	Percent Increase in 2000
Air Emissions				
Carbon Dioxide(Biomass fuel sources)	lbs/year	4,157,689,000	4,482,558,000	8%
Carbon Equivalents of Greenhouse Gases	tons /year	-6,000	-4,000	33%
Methane (CH4)	lbs/year	21,907,000	23,353,000	7%
Hydrocarbons (non-CH4)	lbs/year	-1,609,000	-1,306,000	19%
Water Releases				
Suspended Solids	lbs/year	1,230,000	1,353,000	10%
BOD	lbs/year	2,196,000	2,415,000	10%
Sulfuric Acid	lbs/year	-7,000	-5,000	29%
Oil	lbs/year	115,000	136,000	18%
Iron	lbs/year	160,000	189,000	18%
Zinc	lbs/year	2,000	3,000	50%

Note: Data are totals for all stages of the waste management system: collection, recycling, treatment, disposal, and remanufacturing.

Table 5-14. Decreases in Energy and Emissions due to Recycling in Wisconsin in 2000 v/s a hypothetical "no recycling" scenario in 2000

Parameter	Units	2000 LCI	2000 LCI without Recycling	Percent Decrease due to Recycling in 2000 *
Energy Consumption	Million BTU/year	-16,149,000	6,452,000	350%
Air Emissions				
Total Particulate Matter	lbs/year	-4,338,000	171,000	2637%
Nitrogen Oxides	lbs/year	-616,000	6,227,000	110%
Sulfur Oxides	lbs/year	-13,991,000	1,345,000	1140%
Carbon Monoxide	lbs/year	-19,471,000	2,840,000	786%
Carbon Dioxide (Fossil fuel sources)	lbs/year	-517,980,000	228,488,000	327%
Carbon Equivalents of Greenhouse Gases	tons /year	-4,000	116,000	103%
Hydrocarbons (non-CH4)	lbs/year	-1,306,000	1,481,000	188%
Hydrochloric Acid	lbs/year	-91,000	23,000	496%
Lead	lbs/year	-75,000	3,000	2600%
Methane (CH4)	lbs/year	23,353,000	29,488,000	21%
Ammonia	lbs/year	-1,000	0	10100%
Total Solid Waste	lbs/year	-276,696,000	8,282,000	3441%
Water Releases				
COD	lbs/year	-2,321,000	1,290,000	280%
Dissolved Solids	lbs/year	-3,625,000	1,871,000	294%
Sulfuric Acid	lbs/year	-5,000	0	1350%
Ammonia	lbs/year	11,000	18,000	39%

* Where necessary, unrounded numbers were used to calculate percent decrease

Table 5-15. Increases in Energy and Emissions due to Recycling in Wisconsin in 2000 v/s a hypothetical "no recycling" scenario in 2000

Parameter	Units	2000 LCI	2000 LCI without Recycling	Percent Increase due to Recycling in 2000 *
Air Emissions				
Carbon Dioxide(Biomass fuel sources)	lbs/year	4,482,558,000	2,936,273,000	53%
Water Releases				
Suspended Solids	lbs/year	1,353,000	107,000	1164%
BOD	lbs/year	2,415,000	347,000	596%
Oil	lbs/year	136,000	55,000	147%
Phosphate	lbs/year	11,000	5,000	120%
Iron	lbs/year	189,000	3,000	6200%
Zinc	lbs/year	3,000	0	2900%

* Where necessary, unrounded numbers were used to calculate percent increase

- The tables show that except for Carbon dioxide from biomass fuel sources, there are net savings in all other air emissions from recycling at the 2000 levels. Some water releases from the recycling scenario in 2000 are higher than the no recycling scenario in 2000. The 2000 recycling scenario results in a net saving in energy use from waste management.

5.7.5 Application of Results

The State of Wisconsin is using the results from this study to evaluate the environmental benefits of statewide recycling programs. In particular, the State is looking at specific materials that are currently targeted for recycling and whether or not it makes environmental sense to continue to promote the recycling of those materials.

5.8 U.S. GREENHOUSE GAS ANALYSIS

MSW management decisions made at the local level can impact the release of greenhouse gas (GHG) emissions that contribute to global climate change. This study was conducted using MSW DST to track changes in GHG emissions during the past 25 years from the management of MSW in the U.S.

The scope of the study included all activities that play a role in MSW management from the point at which the waste is collected to its ultimate disposition. These activities include MSW collection, transport, recycling, composting, combustion (with and without energy recovery), and landfilling (with and without gas collection and energy recovery). The life-cycle environmental aspects of fuel and electricity consumption were also included, as well as the displacement of virgin raw materials through recycling and the displacement of fossil-fuel-based electrical energy through energy recovery from. The GHG emissions studied in this analysis were carbon dioxide (CO_2) and CH_4. Carbon sinks associated with MSW management were evaluated and results presented with and without carbon sinks.

5.8.1 Waste Composition, Generation, and Recycling data

For the baseline year of 1974, MSW management consisted of limited recycling, combustion without energy recovery, and landfilling without gas collection or control. This was compared to data for 1980, 1990, and 1997, accounting for changes in MSW quantity, composition, management practices and technology. The percentage of MSW being recycled (which includes composting), landfilled and combusted along with total MSW generated are provided in Table 5-16 for each of the years included in this study.

In 1974, waste management primarily involved the collection and landfilling of MSW. About 8% of waste was recycled as commingled material and 21% of the waste was combusted (without energy recovery and little or no pollution control). The remaining 71% of the waste was landfilled without landfill gas control. During the next 25 years, recycling steadily increased from 8% in 1974 to 10% in

Table 5-16. Total MSW generated (tons/year) in the U.S. for each study year and the percentage of MSW recycled, landfilled and combusted.

Year	Waste Generated	Recycling	Combustion	Landfill
1974	116,000,000	8%	21%	71%
1980	137,000,000	10%	9%	81%
1990	186,000,000	16%	16%	68%
1997	197,000,000	27%	17%	56%

1980, 16% in 1990, and 27% by 1997. By 1980, waste combustion without energy recovery declined and was replaced by waste-to-energy plants. Data indicated that by 1997, 17% of the MSW generated in the U.S. was used to produce electricity at 102 waste-to-energy facilities nationwide. These facilities also have heat recovery, electricity production, and the highest levels of pollution control. Also in 1997, 56% of the waste that is landfilled is going to about 1,200 sites with liners, leachate collection and control. Some of these sites, primarily the larger ones, also have landfill gas control. All of these considerations were taken into account in the calculations.

5.8.2 Model Design

The boundaries for this study include unit processes associated with waste management including production and consumption of energy, extraction of raw materials, and transport, collection, recycling/composting, combustion and landfilling. The following waste management processes were used in modeling waste flows in the study.

- Collection of presorted recyclables and collection of remaining (residual) waste
- Processing of recyclables in a presorted Materials Recovery Facility
- Yardwaste is composted in a composting facility.
- Disposal of residuals (waste remaining after recyclables are removed) in a landfill or a combustion facility with landfilling of ash residue.

5.8.3 Major Assumptions

For some of the lower quantity materials in MSW, data from the MSW DST were not available. This represented 1.5 % of the total waste generated in 1974 and 4% in 1997. For these waste streams, data were obtained from the EPA Office of Solid Waste. These items include durable goods, wood waste, rubber tires, textiles, and lead-acid batteries.

Although waste management strategies and technologies changed from 1974 to 1997, other aspects, such as transportation distances, were kept constant since their overall contribution to the results were minimal.

The energy consumed and environmental releases associated with production of new products as well as those saved by using recycled instead of virgin materials were included in the analysis.

GHG emission savings were also calculated for MSW management strategies (namely MSW combustion and landfill) where energy was recovered. In calculating the GHG emission savings associated with energy recovery, the "saved" energy was assumed to result from offsetting the national electric grid. For every kilowatt-hour of electricity produced from MSW, the analysis assumed that a kilowatt-hour of electricity produced from fossil fuels was not generated. Wherever energy is consumed (or produced), the analysis includes environmental releases (or savings) associated with both the use and production (e.g., the production of a gallon of diesel fuel) of that energy**.**

When CO_2 is removed from the atmosphere by photosynthesis or other processes and stored in sinks (like forests or soil), it is sequestered. One of the more controversial issues with accounting for GHG emissions from MSW management is associated with whether carbon sinks should be considered. There is no current consensus on a methodology for estimating carbon storage in forests, soils, and landfills. During the series of peer reviews conducted on the methodology developed for the MSW DST, the recommendation from the reviewers was that carbon sequestration should not be considered unless a full product life cycle was being analyzed. However, the MSW DST was developed to include an offline calculator for estimating carbon storage potentials resulting from forests, soils, and landfills. For this study, results with and without carbon storage are included.

For combustion, emissions are released immediately. For landfills, the GHG emissions are released over a long time period, and not all potential carbon is re-released. For this study, GHG emissions during a100 year time period was used.

For the baseline year of 1974, there was no gas control or energy recovery. For 1997, using recent data, GHG emissions were calculated based on 50% of MSW being landfilled at sites with landfill gas collection and control. Of this 50%, half of the gas was flared and half was used for energy recovery using recent statistics of the distribution of energy recovery projects (internal combustion engines, direct gas use, gas turbines, etc.). Specific assumptions for landfill gas parameters in each study year are included in Table 5-17.

Table 5-17. Key Landfill Design and Operation Assumptions.

	Study Year			
Parameter	**1974**	**1980**	**1990**	**1997**
Percent of waste managed in landfills with gas control	0%	10%	30%	50%
Landfill gas collection efficiency	0%	75%	75%	75%
CH_4 Oxidation rate	20%	20%	20%	20%
Percent of controlled landfill gas utilized for energy recovery projects using boilers, reciprocating engines and turbines	0%	0%	31%	50%

5.8.4 GHG Results

Figure 5-4 illustrates the overall trend in GHG emissions from a 1974 to 1997. Two technology pathways are shown. One pathway represents GHG emissions from the actual integrated MSW management technologies employed in each study year. The other pathway represents GHG emissions if the same 1974 technologies and MSW management practices were used in all study years (i.e., 1980, 1990, and 1997). As illustrated in this figure, by adopting new technologies and MSW management practices, GHG emissions have decreased from 1974 to 1997, despite an almost two-fold increase in the quantity of waste generated. Net GHG emissions in 1997 were about 8 MMTCE versus 36 MMTCE in 1974. If the same technology and MSW management practices were used today as in 1974, then net GHG emissions would be approximately 60 MMTCE. Thus, it could be concluded that the employment of new MSW management technologies are currently saving in the order of 52 MMTCE per year.

Carbon Sequestration and Storage

The magnitude of carbon storage relative to the magnitude of emissions is shown in Table 5-18. When considering carbon storage is included in the calculations, it dramatically offsets all of the energy and landfill emissions. If carbon sequestration is considered in this analysis, then net GHG emissions avoided are still about a factor of 6. Overall, the basic findings remain the same: improvements in management have resulted in dramatically reduced net GHG emissions from the waste sector.

Figure 5-4. Comparison of Net GHG Emissions for MSW Management Reflecting Technological Changes, Landfill Diversion, and Source Reduction.

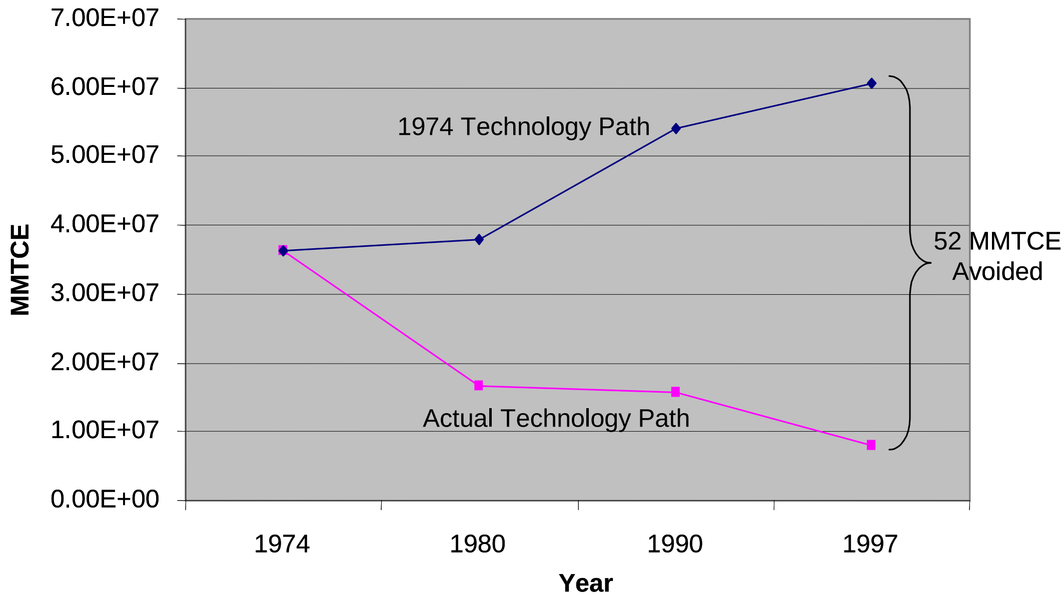


Table 5-18. Net GHG Emissions Including the Effects of Carbon Sequestration for Waste Management Strategies (MMTCE/year).

Scenario	Estimated Amount of Carbon Sequestered	Estimated GHG Emissions	Total Net GHG Emissions
1974	-18.3	36.2	17.9
1980	-25.6	16.7	-8.9
1980 with 1974 Technology	-22.1	38.0	15.9
1990	-34.2	15.6	-18.6
1990 with 1974 Technology	-29.6	54.2	24.6
1997	-41.2	8.0	-33.2
1997 Using 1974 Technology	-30.6	60.5	29.9

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Attachment 3:
September 1997 Peer Review Report

APPLICATION OF LIFE CYCLE MANAGEMENT TO EVALUATE INTEGRATED WASTE MANAGEMENT STRATEGIES

Peer Review Panel Report, September 1997

Peer Review Panel: Dr Peter R. White, Procter & Gamble Ltd., UK (Chairperson);
Kevin Brady, Demeter Group, Canada;
Dr Jay R. Lund, University of California, Davis, USA
Dr Steven B. Young, SB Young Consulting, Canada.

Scope of the Review:

This is a multi-disciplinary project. It combines collection and analysis of solid waste, manufacturing and energy production data, modelling of solid waste management processes, state of the art developments in Life Cycle Assessment (LCA), the application of LCA to waste management, economic modelling and the development of decision support software. A single review is not able to fully evaluate all of these areas. In line with the charge to the Review Panel and the expertise of Panel members, this review addressed the overall objectives of the project, concentrating on the proposed use and limitations of the software tools under development, the relevance of a Life Cycle approach and way in which LCA has been used. It has also addressed the technical issues connected with certain specific waste treatment options. The review has not attempted to validate any of the data presented in the project reports, nor has it assessed the accuracy, reliability or user-friendliness of any of the software that has been developed so far. The limited economic expertise of the Peer Review Panel also restricted any in-depth scrutiny of the cost model.

Further specific reviews of these additional elements will be required in the future, and these are the subject of some of the recommendations in this report.

The review is based on the project report documents provided to Panel members and presentations and discussions with the project team and stakeholder "observers" at the Workshop held at the EPA, Research Triangle Park on Sept 9th-11th, 1997.

Summary of Review Panel's Comments.

1. This is an ambitious, state-of-the-art project. It represents the most comprehensive attempt to date to take an overall systems approach to solid waste management, allowing assessment of both economic and environmental aspects.

2. The project has assembled a talented and diverse team, which has been well led and co-ordinated.

3. The project has taken a highly inclusive approach by including stakeholders from state and local government, industry, academia, environmental organisations and local communities via the case studies.

4. The project is taking the right approach to the planning of municipal solid waste management. The project's objective is to provide a decision support tool (DST) that will help municipalities and regions select the best combination of treatment options for their particular waste stream, existing infrastructure, availability of markets, etc. The aim is not to simply rank individual options as currently attempted in the "solid waste hierarchy." Instead, this project will support Integrated Solid Waste Management.

5. Life Cycle Assessment (LCA) is the correct approach to take in this project. By taking a systems approach, LCA has the ability to help prevent "problem shifting" from one part of the waste management system to another, or from one environmental medium to another.

6. This study does look at the full Life Cycle for municipal solid waste. Suggestions that studies of this sort are not "complete LCAs," as they do not include the manufacturing of the products before they become waste, misunderstand the distinction between an LCA of a product and an LCA for solid waste. This study addresses the function of solid waste management, from the cradle of waste to the grave of waste.

7. The products from the research, both the waste management database and the decision support tool, should be of considerable use to waste management planners. Other groups may also become potential users, such as the LCA community.

8. The project has provided a good survey of existing data for both costs and performance of solid waste management operations.

9. Many of the process modelling modules already developed represent advances in their field and deserve individual publication.

10. The project is appropriate for federal support. The existing budget should be appropriate for the completion of the project, subject to the improvements suggested below being implemented.

11. To enhance the significant progress already made in this project, the reviewers identified areas for possible improvements. These related to: project objectives, use and limitations; project focus; credibility; communication; LCA issues; technical issues; software development.

12. The intended uses and users of the project's products need clearer definition.

13. Clear guidance should be given that, like any LCI/LCA study, this is not a stand alone tool. Other tools are needed to assess human and environmental safety, legal compliance, technical feasibility, etc.

14. There is concern that the DST will be misused for making product or material comparisons. It must be made clear that this tool is not appropriate for such comparisons.

15. The project needs to be more focused if it is going to complete its objective in the available timescale. The temptation to try to include everything in the DST should be resisted. Two areas where focus can be improved are: removing source reduction from the model (it does not fit within the boundaries of this model) and omitting impact assessment (since no generally accepted methodology exists). We therefore recommend that the project limits itself to producing a Life Cycle Inventory (LCI) for integrated municipal solid waste management.

16. Credibility is vital for widespread acceptance and use of the DST and database. This relies on a fair and consistent treatment of the various options for waste handling and treatment. The same input and output categories must be used for all of the options.

17. At present only a small set of emission categories are considered. If an overall environmental assessment is required, more categories need to be included. If the limited data set is chosen for reasons of data availability, then only these data should be used for all processes.

18. While considerable effort has gone into the modelling of individual process modules, more attention needs to be paid to how the modules fit together in the LCI. The project has at its disposal the necessary LCA expertise to address this.

19. The functional unit and almost all boundaries of the system under study need to be redefined. The cradle of waste and the grave of waste, as the starting and end points for the study, also need clarification. Assumptions made about excluding infrastructure or particular operations or materials need to be justified.

20. The software development needs to be more closely tuned to the needs of the potential users. We recommend that user groups be used more extensively in this process.

21. Attention needs to be paid to how the software products of the project will be disseminated, and then maintained. We recommend that the project assembles a business plan on how this will be accomplished.

22. We recommend that liaison between the project team and the stakeholders be separated from the overall leadership of the project, possibly by using an external consultant. This will lead to better representation of the stakeholder viewpoints to the project team, and *vice versa.*

The detailed comments of the Peer Review Panel follow this summary.

DETAILED COMMENTS

Project Achievements to date:

1. Combining the concepts of Integrated Solid Waste Management

(ISWM) and Life Cycle Assessment (LCA), and attempting to model both the costs and environmental burdens of any combination of waste collection and treatment options, this is a large and ambitious "state-of-the-art" project.

2. The project team have assembled a diverse and talented group of individuals, who are working in an organised and co-ordinated way. The team's expertise is generally broad enough to span the range needed for this challenging project.

3. Through its "stakeholder group" the project has also developed into a virtually unprecedented inclusive process, by including representation from state and local government, industry, academia and environmental groups. This is essential if the products of this research are going to achieve widespread use and credibility.

4. A side-benefit of having stakeholder input into this project is the useful education of many stakeholder representatives in the field and problems of solid waste management. Such two-way educational benefits often generate substantial long-term benefits by raising the level of understanding among the parties concerned.

5. The project takes an integrated approach to municipal solid waste management. Given the diversity of wastes entering municipal systems, the variety of technologies and options that can be brought to bear on the problem, local variability in the problem, and the serious economic and environmental impacts of municipal solid waste management decisions, a truly integrated, systems approach will have advantages over previous approaches based on the so-called "waste management hierarchy." By attempting to identify the optimal combination of waste management options for a given region this project will help to prevent "problem shifting" from one environmental medium to another, or from one location to another.

6. The project is attempting to provide a balanced technical perspective on municipal solid waste management, with appreciation of the divergent opinions on the subject and the need for sound technical background for making solid waste management decisions. The work has been neither "pro-recycling" nor "anti-recycling" in its approach, but has taken a disinterested technical perspective on developing data and models which should help illuminate relevant policy and planning discussions.

7. Municipal solid waste management in the USA (and elsewhere) has suffered from a lack of systematic and integrated development and research in comparison to water supply and wastewater problems. The problem-focus of the project is important and relevant; the project addresses the right problem.

8. By using Life Cycle Assessment, the project is taking an appropriate conceptual approach. Suggestions that this project is not a "true Life Cycle approach," as it does not include the

production of the products that eventually become waste, misunderstand that this project looks at the Life Cycle of solid waste management, rather than the Life Cycle of individual products or packages. LCA considers the environmental burdens of providing a given service or function - in this case the function is solid waste management.

9. The project has provided a good survey and synthesis of existing cost and performance data from the field. It has also identified where data gaps exist. In some cases, such as with composting, it has put in place a program to generate the data necessary to fill the gaps.

10. Several process modules have been completed or nearly-completed which will provide considerably better and more accessible models of these processes than are currently available. These process models should have considerable application for local and regional planning purposes.

11. In terms of scientific and engineering advancement, many of the process models represent advances to the field worthy of publication as technical reports and in the peer-reviewed technical literature. Advances in combustion and composting process models are particularly noteworthy.

Project Objectives, Use and Limitations:

12. The intended users and uses of this project's products need to be better defined. Some confusion is evident among stakeholders, and to a lesser degree, among the project team, regarding the intended users and uses of the project's model and database products. There is a significant difference in the modelling and data needs for local- or regional-level planning, compared to state and federal policy-making. The primary function of the modelling tool is for planning local and regional solid waste management systems on a case-by-case basis, rather than generating overall "average" solutions, and this should be made clear.

13. The project will provide both a decision support tool and a waste management database, and the user groups for these two products will not be identical. For example, the LCA practitioner community will be interested to use the database for specific information on waste treatment processes. Care is needed to ensure that each product meets the needs of its intended users.

14. Although it is conceptually appropriate, the limitations of the Life Cycle approach should be clearly stated in the documentation. As with other uses of Life Cycle Inventory (LCI) or Life Cycle Assessment (LCA), there is a temptation to assume that this tool will provide a complete overall environmental assessment, which is not the case. LCA does not address human and environmental safety, nor can it predict actual environment impacts. These require use of different tools, such as risk assessment. Neither will LCA ensure regulatory compliance. The decision support tool (DST) being developed assumes that these

other requirements have already been fulfilled independently. This should be explicitly stated.

15. Given the above limitations, the project documentation needs to define how the projects data and model products are intended to aid local solid waste planners, and where their unique contributions will lie. Essentially, given that risk assessment and other tools ensure that all alternative treatment plants and processes are safe for humans and the environment, and legal, this model will help select the combination of options that is most efficient in terms of energy and materials consumption, and production of emissions to air, water and solid waste.

16. The usefulness of the DST will become clearer from the case studies, although there is already a body of experience in Europe and elsewhere on the use of LCI for planning solid waste management systems (e.g., Barcelona, Spain; Gloucestershire, UK; Paris, France; London, Ontario, Canada). This knowledge could be of use to the project team.

17. The project needs a concise and accurate goal statement. The current goal (page 4 of overview document) states that the information and tools developed through this study are intended for use in determining ... relative cost and environmental burdens of alternative SWM strategies or operations. The project is not including a full set of emissions, however, so the stated goal of determining environmental burdens will only be partly met. Either all relevant emissions should be included, or if a limited subset is included the goal statement should acknowledge this, and justification for this choice given.

18. The distinction between a solid waste LCI (as in this study) and a product LCI should be clearly stated, otherwise confusion over this will continue. Currently, there is considerable concern in the stakeholder group that the model will be (mis)used for product or material comparisons. Clear guidance that this is not the intended purpose should be given.

A diagram such as the one offered below might help explain this difference.

Figure 1. Distinction between an LCI tool for Solid Waste and an LCI for products/packages.

Project Focus

19. It is vitally important for the project to retain a limited focus. It is tempting for large projects such as this one to continually add "new features" and new missions in response to comments from stakeholders and funding agencies. Such "mission creep" is dangerous to the success of the project and is ultimately a risky and mediocre approach to accomplishing the new features sought. By seeking to accommodate new features, uses, and users, large projects often become distracted, threatening their original core missions.

20. This was a common concern of the project review panel. The project should focus on accomplishing its already ambitious objectives. A clearly stated goal is essential, and the development of the project continually checked back against this. The project clearly has good links to other ongoing projects, such as the US car LCA project and the Environmental Technology Initiative on Life Cycle Management. These projects should not become diversions, however, and data from them should only be used where they are of direct relevance to achieving the goal of this project.

21. The focus can be improved by excluding source reduction from the present project. If the aim of this project is to assess how solid waste can be managed once produced, source reduction occurs before waste generation, so should not be considered. In any event, source reduction needs to be considered on a product by product basis, not across the whole waste stream (i.e., by a product LCI approach). In discussions with the project team, there was agreement that source reduction be excluded, although it is included in some of the current documentation.

22. Other recommendations for improved focus include limiting the study to a Life Cycle inventory (LCI) by excluding a specific

impact assessment step at this time. This, and other potential extensions, are more appropriately accomplished only after the foundation is well established.

23. Similarly, the case studies should be used as an opportunity to demonstrate the intended uses of the products and should not become embroiled in interesting, but distracting, side-issues.

Credibility.

24. If the decision support tool is to achieve widespread acceptance and use it must give, and appear to give, a balanced assessment of the different waste management treatment options available. The modules used in the final model should therefore provide a consistent set of emission estimates which are the same for all modules. (This was also a concern of the stakeholders.) Although a similar basic set of emissions is used at present, it appears that some additional emissions are included only for certain treatment options where they are considered "relevant." Emission and consumption categories used must be the same for all operations, including transport. Any uneven treatment invites confusion and could be construed as bias in any evaluation.

25. This conspicuously even-handed approach must apply to both the text and the software tools. For example, in section 10, waste to energy is identified as a treatment option in which the volume of material going to landfill is "significantly reduced." The same is true for composting and recycling, so why make a particular point of it here? In the software at present, some screens report the recycling rate, but not recovery rate or overall diversion rate. Attention to detail here is needed to counter any claims of "pro-recycling" or "anti-recycling" bias.

26. Some concern about potential "mis-use" of the model was expressed both by the research team and stakeholders. This is an important problem, which seems well appreciated by the project team. Perhaps the best guard against abuse is clear and consistent documentation for the model and its data, and the development of as much technical consensus as possible in the model's development. This is clearly the track the project team is already on.

Communication and Terminology.

27. Several of the issues and misunderstandings that have arisen in the project so far may be solved by tighter use of terminology and careful attention to presentational material (text, diagrams and oral presentations). For example, "recycling" is used where "recovery" is meant (e.g., in remanufacturing section); "impact" is used instead of "loading" or "release."

28. Presentations should be clearer in terms of distinguishing (a) model parameters (constants), (b) model decision/design variables, and (c) model constraints for each process module. Model/optimisation objective functions are fairly clear, however.

29. Improved diagrams, in particular a system diagram showing the system boundaries would be particularly helpful. The current Figure 1 is misleading and has probably fuelled confusion over whether this project is looking at the manufacture and design of products before they become waste. We recommend that this figure be redrawn without the three so called "upstream" manufacturing boxes at the top. These are used to calculate the "avoided burdens" or "offsets" from the use of recycled material, and should be placed at the bottom, or side of the main system box. We recommend that the term "upstream" be replaced totally, since this also suggests changing the way that products or materials are originally manufactured before they enter the waste stream. In this system they are essentially downstream not upstream issues due to "co-products" of the system. The terms Òavoided burdensÓ and ÒoffsetsÓ can also create confusion and should be avoided or carefully qualified. (The treatment of co-products, as they leave the system boundary, is discussed further below in bullet #39.)

30. A separate diagram, showing the system boundaries, for each process module would also improve clarity in the written material.

Life Cycle Assessment Issues.

31. Considerable care and attention to detail has gone into constructing the individual modules of the waste management system model. Before further effort is expended on this, attention needs to be paid to the overall features of the LCA system; in particular, the goal definition and scoping stage, which includes defining the functional unit and system boundaries.

32. There is considerable expertise in the area of LCA within the project team. We recommend that more use be made of this expertise so that the above LCA issues can be addressed.

33. In line with established LCA guidelines and practice, we recommend that the ISO 14040 series of draft standards be more closely followed, with regard to structure, format and terminology. In the landfill project these formats have been followed and the functional unit and system boundaries are very well explained. This approach could be followed for the other modules.

34. To improve the transparency, and thus credibility of the DST, all assumptions made in the LCA study should be explicitly defined, and the reasons for these choices discussed and justified. As in all LCA studies, there are many decisions that need to be made about system boundaries, allocation methods, exclusions, etc. In the current text, some of these assumptions are not explicitly stated, while those that are stated are often not discussed or justified. In most cases there are no right or wrong answers, yet all boundary and allocation decisions should be explicit, transparent, justifiable and consistent.

35. The functional unit needs to be redefined since it is not "1 ton of MSW" as currently defined. Possible functional units could be: "The management of one ton of MSW from the defined area, to acceptable modern standards," or "The management of the total MSW from the defined area to acceptable modern standards." (Acceptable modern standards will need defined also.)

36. The Life Cycle of waste needs to be clearly defined; i.e., the "cradle" of waste, and the "grave" of waste. Defining the point when waste becomes waste (e.g., when it loses value; when it is placed in a collection bin; at the boundary of the property), will help the project in defining which processes and materials should be included and which are outside the boundaries of the current study. For example, currently the washing of recyclables is included within the system boundaries, but the subsequent use of plastic bags for collection is not. Similar clarification is needed in defining the ÒgraveÓ of waste, e.g., justifying the time-limit of waste as waste in a landfill, and the point at which waste become material Òco-productÓ in the recycling stream.

37. Defining the cradle of waste will also help make it clear that "source reduction," prior to the generation of waste, cannot be addressed in this model. A possible exception would be the inclusion of source reduction of garden waste by back yard composting. If this is to be included it will require appropriate definition of the cradle of waste.

38. The physical boundaries of the system also need better definition. For example, when and how does composted material leave the system? Does it leave the system as compost, in which case any subsequent releases from compost into soil will not be included. Alternatively, are the fields to which the compost may be applied also within the system? Similarly, is a landfill inside the system or outside the system? Clear diagrams showing the system boundaries and the flows across these boundaries would likely help both the project team and potential users of the tools.

39. "Offsets," sometimes called "avoided burdens," should be discussed in terms of "treatment of co-products" and the necessary expansion of systems boundaries, as per ISO 14041. The recovery of useful products from solid waste, and the replacement of virgin or other materials, need to be applied in a transparent and consistent way. For example, at present a boundary expansion is applied to material that is recycled, and for energy recovered, but a decision has not been made on whether co-product allocation is appropriate for compost, which may replace soil conditioners, etc.

Note: "Offsets" can be more accurately explained in terms of co-products and system expansion (as per the ISO 14041 standard). For example, to ensure a fair comparison between system "A" and system "B," which includes a co-product "C," a boundary expansion

1

method is applied. The boundary of system “A” is expanded to include a co-product “C.” In effect A+C = (B). This allows for A to be directly compared with B (as the contributions of C cancel out - or are “offset”).

40. Previous studies, especially in the area of plastics waste recovery, have shown the importance of the substitution ratio (the amount of recycled material needed to replace a given amount of virgin material in the system expansion). The DST needs to be able to include this factor. The current method assumes equivalency between recycled and virgin material, whereas this assumption must reflect reality.

41. Choice of allocation methodology (e.g., by mass or volume) for dividing inputs and outputs between the different materials within MSW will significantly affect the overall result. The choices made need to be discussed and justified. Currently this is simply presented in Table 2, page 12 of the overview document.

42. Many decisions, either implicit or explicit, have been made to simplify the LCA study. Often this has involved exclusion of particular input or output categories. As suggested in recent reports on LCA simplification (e.g., Report of the SETAC-Europe Working Group on Screening and Streamlining LCA, 1997), such exclusions should at least be discussed in terms of how they may affect the overall result and justified. A simple sensitivity analysis would demonstrate whether the omission will have a significant effect on the overall result. A good example of this method is provided in the report in Appendix A “Combustion offset discussion,” and a similar format could be used elsewhere.

43. Particular examples of decisions needing justification include:
Input/output categories included. Material consumption is not considered. Only a restricted range of emissions is included, seemingly on the grounds of data availability rather than any environmental reason. A distinction is made between fossil CO_2 and non-fossil CO_2, without discussion of the relevance of this distinction.

Inclusion/omission of infrastructure. Infrastructure is included in the landfilling project, where it is shown to be of significance, but is excluded from collection, sorting, incineration and other options. Other studies on the significance of infrastructure such as roads, incinerators, etc., do exist in the literature (e.g., within the UK Environmental Agency LCA project), and can be used to justify choices made in this project.

Inclusion/omission of ancillary materials. For example, the lime used in emission control in the incinerator is not currently included, but no justification for this is given.

Omission of other waste types. Construction and demolition wastes are not included in the model but can be a significant part of the solid waste stream.

Omission of waste management operations. Litter collection systems are not specifically included or excluded.

44. A mixed approach is currently taken to Impact Assessment. Some of the emissions are converted into Global Warming Potentials, but no other attempt is made to convert the inventory categories into potential environmental impacts. Since there is no agreed methodology for conducting a Life Cycle impact assessment, we recommend that this study limits itself to a Life Cycle Inventory, with no impact assessment attempted. This will also help improve the project focus.

45. Data quality is addressed in the database through data quality indicators. Representativeness of the data should be added as a data quality indicator to those already used. Some attention should be given as to how the data quality will be communicated to the user of the DST, to give some idea of the robustness of the reported result.

46. The boundaries of the cost model are different from those of the environmental LCI model. The reasons for this are given, but the consequences of narrowing the cost calculation to that paid by the municipality need to be made clear. For example, use of bring systems for collecting recyclables may lead to lower collection costs for the municipality, but if householders have to use cars to deliver the materials the overall cost to the community may actually rise.

Technical Issues.

47. Due to the size and diversity of the project, the review team is unable to provide detailed technical review for every process module. Further technical review of each module is necessary, however, for the credibility of the project. We therefore recommend that the module models (composting, combustion, landfills, etc.) be peer-reviewed and published separately. Such peer-review would probably be accomplished best in the form of refereed publications, such as environmental engineering journals. Independent review and publication of these module models early on in the project would greatly enhance the technical credibility of the project's final products.

48. As part of this peer review process, the methods suggested for modelling each of the waste management processes should be compared to previous attempts, and improvements noted. In the current documentation there is insufficient discussion of alternative modelling methods and the reasons why these particular methods were devised or selected.

49. The individual process models/modules would appear to have independent utility. This is an exciting prospect (and one attractive to some of the stakeholders). This perspective also points towards making the individual parts of the model modular, replaceable, and easy to update in the future. However, care should be taken that developing an ability to independently use

the modules for purposes beyond this project's intent might distract the project from its core objectives.

50. The approach to the modelling of each process has been methodical and comprehensive, taking into account all possible factors. Some economy in time and effort in the future might be possible by conducting a simple scoping study to determine which of the many variables considered will have significant effects on the final result. Then time and effort can be focused on ensuring the validity of any data used for these variables.

51. Care is needed in the reporting of significant figures in the spreadsheet, reports and presentations, otherwise this will give a misleading impression of the model's accuracy.

The following specific points are offered by the peer review panel as suggestions for improvement in individual modules:

Waste generation:

52. Consideration needs to be made as to how municipalities will be able to obtain waste analysis data cheaply, regularly and reliably, so that they can input these data into any decision support tool. There are examples of simplified waste analysis procedures (e.g., from ERRA - the European Recovery and Recycling Association, Brussels) already available, if the EPA does not have its own system.

53. To clarify the sources of waste considered by the study, we recommend that "Institutional waste" be specifically included, rather than relying on the user to include this as a form of commercial waste.

54. Some treatment or explicit exclusion of the effects of solid waste utility pricing (variable rate pricing/"pay as you throw" systems) should be included. Seattle and other cities have begun to use the solid waste rate-structure to encourage and enforce recycling objectives. Such policies can have significant effects on consumer waste generation and disposal.

Collection

55. A more generic and flexible transfer station module should be considered. Transfer stations serve a particular service area and must be flexible in accommodating whatever that region produces.

Sorting:

56. Some of the process modules neglect the presence of nuisance materials (non-recyclable material accidentally included in the waste stream). These nuisance materials can have important consequences for the quality and price of recycled products, as well as operational costs.

Incineration:

57. The methodology to allocate the major gaseous emissions based on the volume of flue gas produced is an interesting development. This needs to be compared with other methodologies and peer-reviewed through publication, prior to use in the model.

58. The representativeness of the limited number of waste-to-energy plants used as data sources for the model needs to be assessed. Otherwise the data may not represent reality.

59. The inclusion or exclusion of subsequent treatment of ash from MSW incineration needs to be clarified. In Appendix A page 5 it is included, while on page 33 of the overview document it is excluded.

Composting:

60. The composting module is still in data collection mode, so significant work remains to be done here. Fundamental decisions need to be made as to the system boundaries for composting, however: (a) is compost application included within the system boundary? (b) will co-product allocation be applied where compost replaces another product? These need to be discussed, decided and justified as they will probably have a greater effect on the final result than any data refinement.

Anaerobic digestion:

61. This has not been developed into a module of the model yet, though will need to be considered if the final model is to be able to consider all possible waste treatment options.

Landfilling:

62. The landfill study, unlike the rest of the project, includes the environmental burdens of infrastructure. There is a need for consistency. Rather than remove infrastructure from the landfill study, where it appears to be significant, its omission from the other modules should be justified.

63. Non-state-of-the-art landfills are not included in the scope of the separate landfill study, but should be addressed. Many local users will have non-state-of-the-art landfills for some time.

64. The model assumes a loss of landfill gas of only 10%. While this may be true for some state-of-the-art facilities, most experts would assume a higher rate of loss. Similarly it assumes that the cover of the landfill remains intact for 500 years, which will not always apply.

65. It should be noted that the raw materials data in the landfilling

module do not include materials processing. Also the steel data used is quite old, since the BUWAL Report no132 has now been replaced by BUWAL 250.

Recovered material co-products:

66. Some concern was expressed with the quality and timeliness of data for some materials, particularly plastics, which have shown rapid variation over the years. Data used for the treatment of co-products should be comparable in time across the different materials. There are many commercially available databases which may provide suitable data if they are not forthcoming within the project.

67. Alternative methods for the treatment of co-products, e.g., by co-product allocation methods, should also be considered (as per the ISO 14041 standard).

Recovered energy co-products:

68. Care needs to be taken in assessing the co-products due to energy recovery and electricity generation, especially with regard to hydro-electricity and nuclear power. The text states (Remanufacturing page 12) that there is virtually no LCI impact from hydroelectricity. This is because land use and biodiversity issues are not included within the study - but need to be considered in the overall assessment. Mention of methane and CO_2 emissions associated with hydro power would be prudent, even if they cannot be readily determined.

Cost modelling:

69. The cost modelling methodology appears straightforward. However, it would be valuable to have the cost modelling methods used in the project reviewed by a professional engineering cost estimation firm highly experienced with municipal solid waste projects. Such a review should be neither expensive, nor time-consuming.

70. It should also be made clear in any documentation that the cost estimates from the modelling are likely to be a worst-case estimate, since costs are aggregated over all individual operations. A fully integrated waste system is likely to identify ways to optimise costs over time, which may not be reflected in the cost model.

71. It is not clear how costs will be modelled where there is a combination of public and private company operations. An increasing number of solid waste management schemes use this combination, so clear guidance is needed on how the issue is to be handled.

72. Benefits of deferring landfill exhaustion. A significant justification for recycling has been the deferral of landfill replacement costs. This is not currently represented in the

model, although it has been studied extensively in the environmental engineering and economics literature. This raises some issues of dynamic control, that can probably be treated fairly simply for the purposes of this project. A suggested treatment from Dr J. Lund is given in the Appendix.

Software Tool Development

73. In discussing the model and its use, emphasis should be placed on its use as a simulation tool. The optimisation capability is important to the project, but most users will first want to learn the tool in simulation mode, and will ultimately want to test and refine the modelled system in simulation mode.

74. If the DST is to be used in optimisation mode, it is important that the user be given a range of different options, rather than being presented with a single optimised solution. This will allow the user to understand the trade-offs which will occur between the various choices. The user should also be given some indication of the robustness of the suggested solution, which will reflect the data quality of the modules used.

75. User advisory groups should be formed for each intended use of the initial project. Specifically, these should include the local and state agency clientele for the model. This user group should be very distinct from industry stakeholders with national and state policy concerns. The formation of an active local user group would help keep the model focused on this relevant application scale. To some extent, this will be accomplished through the case studies, but should be more extensive. The more extensive user group(s) also would be useful in developing and implementing a longer-term vision for the model.

76. Some attention should be paid to ensuring that the model cannot come up with non-feasible solutions. This was a concern expressed by the stakeholders present. This should be possible by incorporating various checks within the program, and may already have been incorporated, although the review could not cover this area.

77. It should be emphasised in all literature and in the model itself that this is a decision support tool, not a decision making tool. The model will not "prescribe solutions" as was suggested in some of the presentations. It will provide more and better data to aid decision-making.

78. To aid future upgrades and maintainability, the process modules should be as modular as possible. Input and output data structures for each module should be clearly documented.

Project Funding

79. Pragmatically, the project is appropriate for federal support. Only a federal effort could accomplish the level of consistency and scope needed to accomplish this project's intended uses.

80. If the project is focused in the ways suggested, the budget, manpower and expertise proposed for the completion of this project seems to be roughly commensurate with the project's objectives.

Next steps for the project.

81. An important next step for the project involves developing and implementing a more realistic vision for how this software and data will be employed and supported over the long term, after this particular project has ended. This project will end in a year or so, but most of the benefits of this project will occur in the years after that. For these benefits to occur, there must be a well thought-out follow-up plan. The current project philosophy of "build it and they will come" is probably not realistic.

82. The project needs a longer-term "business plan." How will the project products be disseminated, supported, and improved over time? Who will do this and how will it be funded? Relying on the private consulting sector is almost certainly inadequate, and perhaps counter-productive. It is almost impossible to identify any private sector efforts of this magnitude that have remained open, broadly effective, and publicly available for a long period. Part of the business plan should include upgrade paths for the software and data produced by the project.

83. Delays in completing the data-set for material co-products should not delay the advancement of the project. In almost all cases, substitute data sources are available, albeit of lower or less relevant quality. The data-set for such a large project will never be strictly complete or up to date, but is still likely to be more than adequate for most purposes. One way to get around this difference in data quality between the waste management operations and the material co-products is to have them as separate modules. The DST would calculate the LCI for the waste management system itself, and then separately give the likely consequence of co-product allocations which will be from material and energy recovery. Since these co-product processes are likely to occur at locations remote from the region under study, having them separated out allows them to be evaluated separately.

84. Immediate products of this project should include refereed journal papers of model modules, databases, and (a little later) case study reports.

85. Presentations should be honed, refined, and focused, consistent with the project's finite goals.

86. A concise and brief project description and a set of answers to frequently asked questions should be developed for improving communications with potential users and other stakeholders.

87. Efforts should be made to separate and co-ordinate the details of

the project research from external affairs. It is suggested that a stakeholder liaison position be established to help co-ordinate the project with users and other stakeholders. This liaison should be an individual consultant who can move freely between the project's management, the project research team, and the various user and stakeholder groups. The liaison should be able both to better represent the project to stakeholders and represent stakeholder concerns to the project.

P.R. White

31st October 1997

Appendix.

Treatment of deferral of landfill replacement costs, suggested by Dr J. Lund.

The initial mathematical program, with decision variables of annual landfill disposal rates X_t and landfill lifetime T, is:

Minimise $z = + R\, e^{-rT}$ + non-landfill costs,

Subject to: $\leq$ landfill capacity

... other constraints.

Here R is the replacement cost of the landfill, c is the unit landfill operating cost, and r is the continuous inflation-corrected discount rate.

This problem, in its relatively pure form, is non-linear and dynamic. It can be solved by sequential linear programming. For the purposes of this project, it is unrealistic to incorporate the dynamic variation in Xt, and a steady-state equivalent disposal rate X can be substituted, as provided by the non-landfill portion of the model. Let $X_t = P_t\,(X/P_0)$, where P_t is the population (say) at time t (as estimated from population forecasts) and P_0 is some reference population, at the time of the steady-state model. This allows the mathematical program to be re-formulated as:

Minimise $z = + R\, e^{-rT}$ + non-landfill costs,

Subject to: $X \leq$ landfill capacity

... other constraints.

Here only X and T are decision variables. This version, though compatible with the steady-state municipal solid waste system model is still non-linear with respect to T, and could be solved by sequential linear programming with only a little difficulty.

It can be simplified further into a pure linear program if an initial landfill lifetime T' is assumed to be near-optimal to begin with. In this case:

Minimise $z = + R\, \partial e^{-rT}/\partial X * X +$ non-landfill costs,

Subject to: $X \leq$ landfill capacity

... other constraints.

$\partial e^{-rT}/\partial X$ is approximated as a linear coefficient, using the landfill capacity constraint.

Attachment 4:
November 1999 Peer Review Report

Application of Life-Cycle Management to Evaluate Integrated Municipal Solid Waste Management Strategies Peer Review, November 1999

Project Team Responses to Comments

RECOMMENDATIONS

Overall Recommendation.

The peer review panel recommends that the DST is almost ready to be released, and that the release of the work should not be unduly delayed. Major data and software improvements are likely to be implemented over time, and these improvements will be more effective with the benefit of experiences after release. The project team should be prepared to "launch and learn". The project, model, and data have incubated long enough (with a few exceptions as noted). Further growth and improvements are far more likely to be fostered among real users than in a research environment.

> **RESPONSE:** The research team strongly supports releasing the decision support tool in the public domain with the following cautionary note. Given the complexity of the problem and related issues, and the extensiveness of the prototype software package, it is highly likely that significant questions from potential users may arise and therefore would require significant technical support to have any practical value to making it available on the public domain. We want to be careful of avoiding a situation in which a release results in bad publicity because users are frustrated by the lack of technical support.
>
> The research team raises this point based on our experience with stakeholder groups (that well represent the users as well as other interested parties in the software) because many had recurring confusions about just the solid waste management problem, life cycle issues, modeling approach, and solutions. Our experience with more knowledgeable groups indicates that it requires at least a day of one-on-one description, demonstration, and question and answer session to disseminate the minimum of information necessary to understand the products from this project.
>
> The plan is that the tool will be released in a way that provides for a revenue stream that will cover the costs associated with training, technical support, and future updates and/or improvements. The price will be kept to a minimum but will reflect the needs indicated by peer reviewers as well as stakeholders that training, technical support, and future updates provided. In addition, case studies can be conducted, similar to what is occurring now, where knowledgeable individuals (such as research team members) are contracted to model a community, state, or geographical regions solid waste management practices, and evaluate changes to current practices that help to minimize cost and life-cycle environmental burdens. In addition, we will be providing extensive documentation, user's manuals, and illustrative examples through case study documentation.

Pre-Beta Launch Requirements

1. Explicit simulation capability

The primary mode for early applications will be simulation, using the software to model existing system configurations and specific modifications to current facilities and policies. This is necessary for the software to develop local credibility and is conceptually straight-forward for local users. This simulation capability <u>must</u> be made the primary mode of use before the software is released. Furthermore, simulation must be the primary mode described in documentation and software. The current software can reasonably be adapted to operate in simulation mode.

There are four levels at which this software can be used:
a) Data collection and organization: This entails local users collecting, organizing, and documenting their data and understanding of the system. Even if no models are run, the systematic collection and review of local data is likely to be of immense use for local operational and planning purposes.
b) Simulation of existing infrastructure and sensible alternatives: This mode of use essentially uses the software to examine specific alternative strategies for facilities and operations at the preliminary planning level of analysis. The advantages of this mode compared to contemporary "analysis" is the greater transparency, consistency, speed, ability to replicate, and even-handedness of the model's analysis. Simulation is likely to be the main use of this software. Most users will gain confidence and understanding of the software through simulation.
c) Optimization: Optimization mode suggests promising and often innovative configurations and designs for MSW systems. This is the mode that the model is currently explicitly designed for and entails the software automatically developing an integrated solid waste management system design which is highly promising for achieving a formally stated objective (such as cost minimization or diversion maximization). Optimization capability is a major advantage of the current software, allowing users to find promising and innovative solutions that achieve explicit objectives.
d) Modeling to Generate Alternatives (MGA): Often several very different physical solutions are available to obtain very similar technical and environmental performance. The current software supports an MGA mode of analysis that identifies a wide variety of solutions that achieve similar performance. This is an extension of optimization, and is likely to be a well-used feature for experienced users.
These levels of use are likely to be sequential, so it is important that the early levels of use be the most thoroughly supported.

RESPONSE: By setting unit process constraints to limit the available unit processes, diversion targets, and participation and capture rates by sectors, users can simulate their current system. The different levels to which the simulation ability can be taken are as follows:

A. Keep the interface and model as is and provide clear documentation and examples on how to achieve the mass flows and costs of their system. RTI's experience with case studies should serve as the most realistic examples of what can be done. Keeping with the "launch and learn" recommendation by the peer review panel, it is most practical to utilize the existing simulation capabilities with some additional documentation for communities to "simulate" different scenarios. This is our plan for the first version of the tool.

B. More ability for the user to constrain the system at the level of the individual item could be added to the tool. For example, OCC could be banned from landfills or constrained to only flow to recycling in the commercial sector. The code that generates the LP model and creates the solution output, as well as additional user interfaces would have to be implemented to allow for this ability. We hope to provide this capability in the second version of the tool.

2. *Improved transparency relative to ISO standards:*
ISO 14040 requirements for life cycle assessment reporting are not met consistently. A more thorough presentation of system boundaries, omissions, limitations, assumptions and allocation rules should be provided in the User's Manual. Particular areas for attention are

information on the unit processes that are used within the process models, and the way that energy and emission credits are allocated and applied. There also needs to be a clearer explanation of how carbon dioxide credits are applied in paper manufacture, recycling and disposal.

> **RESPONSE:** Much of the information listed above is available in various project documents including the system description document, process model documentation, and final project report. We will incorporate the information from these other project documents into the User's Manual to improve transparency relative to ISO standards.

3. Guidance on interpretation of results:

This is a major piece of software that entails a somewhat different way of viewing local waste management (quantitatively). Therefore, significant user guidance will be needed. Such guidance should include:

a) Limitations - need for additional analysis. The DST provides probably the best available overall analysis and characterization of integrated municipal solid waste management alternatives. This tool, however, does not eliminate the need for additional economic and technical analysis by a municipality or regional authority. The DST provides a set of preliminary results that should be examined more closely by experts. It should be explicitly stated in the users manual that the DST does not provide a risk assessment, nor does it attempt to assess human or environmental safety. It should also be stated that the DST does not consider facility siting or permitting issues.

b) Uncertainty. What is the general level of uncertainty expected from model results? Some qualitative guidance is needed, since know model results are not perfect. Maintaining a consistent level of significant figure reporting in results will help with this.

> **RESPONSE:** The Users Manual includes information on how to interpret results, the limitations of these results, and applicability of results in decision making. Language will be added to the manual about the need for additional economic and technical analysis as the decision support tool is a screening tool. Guidance will also be included on how to interpret model output data and its uncertainty.

4. Clearer guidance to users:

The User's Manual needs to be improved considerably. It should provide a better orientation to the reader of the overall project and model architecture. Very limited guidance was given to users regarding the analysis of existing MSW facilities. MGA must be explained more clearly.

> **RESPONSE:** Three manuscripts have been written, which collectively address most of these issues (e.g., model architecture, implementation, typical use, and MGA applications). The issue regarding analysis of existing MSW systems is addressed in the response to the simulation capabilities described above. The Users Manual will be improved to include more instructions on running typical scenarios. Additional descriptions on MGA will also be added to the User's Manual.
>
> As part of the commercialization process, we are planning to have training sessions for users where we will demonstrate how to set up a scenario, use the model's features, and interpret model results.

In the report on the *Application of LCM to Evaluate Integrated MSW Management Strategies* the description of the relationship between the Database and the DST is confusing. It was understood only after a long discussion at the peer review meeting that the database was not directly linked to the DST. In other words, changing a parameter in the Database would not automatically update the relevant process model. Figure 1-1 of this report should be redrawn and a better description of inputs and outputs provided.

> **RESPONSE:** Agreed. The database and decision support tool are not linked. The documentation will be modified to clarify the relationship between the database and tool. Figure 1-1 will be appropriately modified.

5. Consistency check across options

Some process models might not handle emissions, energy calculations, material recovery, and cost calculations consistently. This should be checked, and exceptions noted. Compost credits and use of state-of-the-art versus average data are specific concerns in this regard.

> **RESPONSE:** All process models will be reviewed for consistency and any exceptions will be documented in the User's Manual and Final Project Report. In these documents an overall table will also be generated (or existing table modified) to provide summaries of the process models and whether state-or-art or average data are used. For compost credits, no data are available to estimate the credits and thus the plan is to implement footnotes that provide more of a qualitative description of potential compost offsets.
>
> Note that all facilities, as represented in the process models, were designed to be in compliance with current regulations. Furthermore, we are modeling a ton of MSW as it behaves in an existing facility and not how the facility may have behaved in the past. It is true in the case of even a Subtitle D landfill, for example, that collection efficiencies can vary from <50-100% and still be in compliance. But this is site-specific and not average.

6. Justification for choice of optimization parameters and the list of 32

The reasons behind the selection of the list of 32 LCI parameters, and the six optimization parameters are not clear. They should be explicitly stated. Currently three parameters relating to global climate change are available for optimization. This seems to weight climate change unduly heavily. One parameter for global warming potential would seem sufficient, allowing optimization of other areas.

> **RESPONSE:** There are 32 parameters chosen to be included on the decision support tool screen output, and these parameters were chosen because data were available across all waste management processes for these 32 parameters. This ensures an equitable comparison of waste management processes for these parameters.
>
> Although all 32 parameters are optimizable, only nine can currently be optimized:
>
> - Cost
> - Energy
> - Carbon equivalents of greenhouse gases
> - Particulate Matter (Total)
> - Carbon Monoxide
> - Carbon Dioxide – Fossil
> - Carbon Dioxide – Biomass
> - Sulfur Oxides
> - Nitrogen Oxides
>
> These nine parameters were chosen because we believed them to be the major parameters of interest to the users of the tool. In future versions of the tool, all 32 parameters could be made optimizable. However, this would increase the model size and computation time significantly.

The solid waste parameter is not well defined and is misleading. Apparently, the municipal solid waste managed by a landfill facility is not counted as part of the total solid waste. We would recommend that residual solid waste originating from the solid waste stream should be inventoried in addition to solid waste related to energy production and other process steps. Total final (or inert) solid waste should be available as an optimization parameter given that integrated MSW management is the focus of the DST.

> **RESPONSE:** The solid waste that results from the LCI calculations represents solid waste from a large variety of sources associated with energy production, material recycling and reprocessing, as well as any other source of solid waste. This solid waste is not necessarily MSW as defined for this project and this will be clarified in the documentation. To minimize the amount of MSW landfilled, the user should constrain the model to maximize landfill diversion. The model results do include a report on the mass of waste that is buried in a landfill.

7. Reality check on cost assumptions
As recommended in the review two years ago, there should be a check on the cost calculation methods made across all process models.

> **RESPONSE:** The process models have been designed to provide flexibility to the user to change the cost assumptions made in individual process models. In conducting the case studies, RTI has been checking the cost numbers with users to make sure that the default model numbers are realistic for the community in question.
>
> The calculation methods for process models were based on detailed process flows and designs. There were some adjustments made to ensure linearity of coefficients, and the calculation methods **and the results of these calculations** for each process model have been reviewed by industry sources for that process.

8. For each run provide print out of input data, changes and assumptions
Supporting the model's use in simulation and optimization models, a complete model run should include the input data (or variations of input from default input data), as well as commentary with the input data explaining user input choices. This should clarify model runs and mitigate against model abuse.

> **RESPONSE:** An actual "print out" of all input data and assumptions used for each run, although conceptually desirable, is practically limiting as it would add approximately 10 minutes to every run. Typically, most individual runs would build upon a project that would be first defined with changes to the model inputs (such as waste characteristics and specific input parameter values). Many scenarios would then be specified with marginal changes in the scenario definition (e.g., diversion constraint, inclusion and exclusion of unit operations, and mass flow restrictions) and solved in each run. For practicality, printing input information, therefore, needs to be separated between project data input and scenario input. Some alternatives are outlined below to address this general concern:
>
> > A. Automate the retrieval of the input set associated with a particular project for perusing on screen. Once the file management system is in order, we can save in a solution workbook, corresponding to a scenario, the name and location of the project input set that was used to generate a run. From the solution manager, we can call up the input manager so that the user can view the corresponding project inputs. Changes to input values made by a user would be indicated by a visual cue, such as a different color of the input cell.
> >
> > B. Add a print utility to iterate through all of the input screens for a project and print them. This utility would cycle through the input manager and print viewed cells of a scroll area. Print headings and notes would also be printed so that the note attached to an input cell
> > can be viewed.

C. Add a print utility so that a particular input screen can be printed in addition to the notes associated with the unlocked (input) cells.

D. Add a print utility to print the model inputs that are unique to a scenario (for example, diversion definitions, diversion rates, mass flow restrictions).

E. Print out input differences (in both project and scenario inputs) between two solutions by comparing unlocked cells (which are input cells) associated with an input screen, and if different, print out the "different" screens, highlighting the "different" cell.

For the first version of the decision support tool, we plan to implement alternative D.

9. Peer review of materials data and allocation methods

The expected materials data and LCI allocation methods should be peer-reviewed separately, as currently planned.

RESPONSE: A peer review for the manufacturing LCI data used for materials is scheduled in May 2000.

10. Business plan development

Development must continue on a business plan. An executable contingency plan should be developed should marketing and development partners not be immediately available. Such a contingency plan might include unrestricted and unsupported release of all project products to states and research universities for further independent development and potential use. A great deal of useful work has been accomplished with this project. It would be a shame and waste of taxpayer funds to have it sit on a shelf when others could use it responsibly.

RESPONSE: Business plan preparation by our current partner organization (SWANA) is scheduled for the Fall of 2000, assuming that they decide to go forward with the commercialization. We are also currently preparing a contingency plan to ensure that the decision support tool and other research products are made available.

11. Beta release plan, funding, and technical support

Serious planning, funding, and technical support is needed for the Beta release of the program. Workshops in several supportive states and professional conferences as well as telephone support from low and high-level experts are likely to be needed to provide for a realistic Beta release. The goals of Beta release should be to a) provide realistic user feed-back, b) catch bugs in the model and input data sets, and c) provide early insights for marketing the products.

RESPONSE: We are currently preparing an EPA grant package to support beta-testing of the decision support tool and if awarded, a plan for beta-testing the tool will be formalized. The beta testing would include training workshops and support. In addition, a Cooperative Research and Development Agreement (CRADA) is planned between EPA and the partner or partners to ensure that the tool and database are kept credible, objective and based on best science. EPA will continue to play a key role in resolution of any potential issues associated with the application of the decision support tool or LCI data.

Pre-Beta Launch Suggestions
The following are <u>suggestions</u> for the project <u>before</u> Beta release.

1. Stop work on derived database
While there are multiple uses for the data contained in the process modules, the current efforts to derive data sets should be postponed. A clear focus to finalize the DST is a much better allocation of project resources at this time. The database product can essentially be divided into two products, a database of model inputs and a database of outputs derived from the process models. The input database is going along well and should be completed. The database of model-derived outputs is premature and work on this should be stopped until experience has been gained with the models.

> **RESPONSE:** The derived database has been shelved, and we are in the process of developing a database that includes only the primary data used in the process model. This database will be reviewed in the peer review in May 2000.

2. Build in and document ability to include new process models for innovative technologies
The long-term value of this software lies in its ability to stimulate thinking and consistent and reasonable analysis of innovations in integrated solid waste management. This should both accelerate adoption of promising new technologies and limit distractions from un-promising technological proposals. Thus, the software and documentation should provide for expansion of the system to include new or modified process models over time. Otherwise there is a danger that the tool will become limited to outdated technologies, and not be forward looking.

> **RESPONSE:** The process models were developed in spreadsheets and therefore their structure is "visible." One may build a similar process model for a new treatment technology. Also, the extensive documentation on each process model would serve as a guide to the development of a new model. Its linkage to the optimization model would require significant modifications, in the model variables and equations as well as in the code that implements the model. Again, the structure of the optimization model is described in detail, and documentation of the code is also provided.
>
> Some brief documentation will be added to the User's Manual on the steps that one should follow to add a new technology could be provided. It should, however, be noted that such changes are recommended only for extremely knowledgeable users with extensive background in solid waste process modeling, linear programming, simplex solver implemented by CPLEX, and visual basic programming.

3. Form a users' group
It is felt that the most successful strategy for disseminating these products will be word-of-mouth experiences among users and potential users. Pursuant to this, it is important that a users' group be formed and that this group meet periodically (at MSW professional conferences) and have web, list-serve, and other means of communications. The early formation of a users' group should help and will provide an opportunity for stakeholder involvement and could act as an external champion for the DST. It would be useful to have an engineering consultant as part of the user group.

> **RESPONSE:** Good idea and one that we also have in our minds. We will be planning to form a users' group as part of the commercialization process.

4. Improve DST output presentation

Most users will want to use the model to compare alternatives. The DST output should allow users to explicitly compare alternatives, rather than users creating their own comparative spreadsheet tables.

> **RESPONSE:** We agree and are currently implementing side-by-side comparisons of scenario results in the solution summary screens.

5. Clarify limitations of steady state modeling in terms of cost and environmental burdens

The model approach assumes the same technology and performance over an infinite time horizon. It should be stated that the environmental performance of existing MSW infrastructure may differ significantly from newly available technology. Replacement of existing infrastructure that is more polluting would be favored but the steady state nature of the modeling does not account for changes in technology. This limitation should be highlighted.

> **RESPONSE:** The process models do not assume the presence of existing infrastructure but rather they assume the construction and operation of the state-of-the-art facilities that operate in compliance with all regulations. The issue of a steady state model is discussed in the limitations section of the User's Manual. The current text on this issue can be expanded to include not only economic issues but also issues of environmental performance.
>
> We will include the limitations section in the User's Manual and other documentation about the implications of steady state modeling for cost and environmental burdens.

Post-Beta Launch Suggestions

1. Continued technical support

Success of this project in the post-Beta launch phase will require continued technical support, implying some need for continued funding. There will be ongoing need for small modifications, documentation, and expenses which are more conveniently and expeditiously done with some continued funding. Continued funding will also demonstrate a Federal commitment to the work, which will be desirable for interesting the States, local governments, and the solid waste management profession.

> **RESPONSE:** We agree and have been working to secure funding for a period after the primary project expires to support beta-testing and refinement of the decision support tool and well as to provide updates and necessary modifications to the documentation, in particular the User's Manual.

2. Produce stand-alone process models

As emphasized in the previous peer review, the process model components of this project are <u>major</u> products and should be made available on a stand-alone basis as well. There is a good possibility that these process models, representing practical state-of-the-art representations of major municipal solid waste management processes, will be of greater use separately than they are together. The failure of the project to establish specifications and procedures early-on to develop these as stand-alone modules is unfortunate and should be remedied as soon as possible.

> **RESPONSE:** We agree that the process models have value as stand-alone models and the development of stand-alone process models can occur after the current version of the decision support tool is completed. The decision to develop an integrated waste management tool led us to develop highly linked process models, but the spreadsheets can

be developed into stand-alone models by an advanced user with Excel skills. The specifications and requirements of stand-alone models were substantial and a decision was made to pursue this after the current version was developed.

3. Users' conferences, training, web-site, and workshops

The success of this project will rely on the enthusiasm of local and state users and their consultants. Training, user conferences, a web-site, and workshops, perhaps held in conjunction with national and regional solid waste conferences will be very useful, if not essential, to broaden and sustain a user base. This is a worthy and relatively inexpensive continued support activity.

RESPONSE: We agree and are working items such as these into our plans for commercialization.

4. SI units.

The tool has potential applications internationally but will be severely limited by non-SI units. Providing a feature that allows the user to select between SI and English units would be helpful. Of course many model parameters would have to be revised before using the DST in another country (e.g., electricity grid mix)

RESPONSE: Including SI units in the process models is a massive undertaking since all the equations and spreadsheets are written for English units. However, it is possible to include SI units in the display of results with relatively less effort. Since the user would still have to use English units for process models input data (in the Input Manager), it is unclear how useful inclusion of SI units in the results display would be to users outside North America.

We do not intend to include SI units in the first version of the decision support tool. As the tool is launched and we find a need to provide SI units for users outside of North America, we can certainly consider adding in utilities that will provide for this option in a second version of the tool.

DETAILED COMMENTS

LCA issues.

Scope and Goal Definition

It is important that the applications of the DST are consistent with the life cycle model. During the peer review, it was mentioned that the model could be used to explore local air pollution issues relating to a MSW system. The inventory models, however, do not account for the spatial or temporal distributions of air pollutant emissions. The model will calculate total NOx emissions but will not specify whether they originated from electric power generation of waste collection vehicles.

RESPONSE: This limitation is documented in the User's Manual. Although a typical user would not be able to distinguish between local versus global emissions in using the decision support tool, a more sophisticated user could. The information is calculated in the process models but must be manually analyzed to gain an understanding of local versus global emissions.

Functional Unit

The functional unit was well-defined and appropriate.

RESPONSE: Thank you.

System Boundaries
A decision was made to exclude capital equipment from the system boundaries. This assumption is often made in life cycle assessment studies. In the landfill model the environmental burdens associated with the capital equipment were evaluated. The total energy consumption for construction were found to represent 25% and 2% of the total landfill LCI for scenarios without and with energy recovery, respectively. Were the capital equipment contributions in other process models also evaluated? A decision was made to omit this component for all facilities but the consequences may be more significant for one management option relative to another. This should be discussed.

> **RESPONSE:** Capital equipment is generally excluded for LCI system boundaries because it is not typically significant. However, based on estimates that we have run to date, this appears to be a concern for sites where landfill gas control is not in use (i.e., smaller, older landfills – In the U.S., we have a requirement that larger sites collect and control landfill gas. Where landfill gas control does occur and if energy recovery is in place, then the exclusion of capital from the LCI is not significant.) Regardless, we will continue to evaluate this issue through ongoing case studies.
>
> If capital equipment contributions are found to be significant, then we can strengthen the documentation about this limitation for the first version of the decision support tool. Also, we can plan to include capital contributions for all unit processes (to maintain consistency) in a future version of the tool. However, we first need to determine if it really has an impact on the LCI results.

Data Quality Requirements
ISO states that the following data quality issues should be addressed:
- Time-related coverage
- Geographical coverage
- Technology coverage
- Precision, completeness and representativeness of the data
- Consistency and reproducibility of methods
- Sources of data
- Uncertainty of information

Time-related coverage, geographical coverage, and technology coverage for each management option should be provided. The use of average versus state of the art technology in models should be clarified.

> **RESPONSE:** We will include in the User's Manual and the Final Project Report a Table that summarizes the time-related coverage, geographical coverage, and technological coverage for each of the process models. In the technological coverage cell, the use data representing industry average or state-of-the-art technology will be specified.

Remanufacturing or Materials Recycling

Remanufacturing is more traditionally used to describe the process for refurbishing retired products. Retired products are disassembled and usable parts are then cleaned and refurbished. New products are reassembled from both old and new parts. The term material recycling and reprocessing would be more appropriate.

> **RESPONSE:** We will change the name of this unit operation from remanufacturing to material recycling and reprocessing.

Source reduction modeling

The EPA waste management strategy begins with source reduction. The purpose of the DST, however, is to address the management of waste already generated. Source reduction is accomplished by analyzing specific product systems (e.g., household batteries). Life cycle design and DFE approaches are the most appropriate for achieving source reduction not the DST. The DST can calculate the environmental burdens and costs for managing a defined quantity of MSW. Consequently, it could be used to determine *only* the end-of-life solid waste management implications for a particular source reduction strategy. A source reduction strategy, however, could reduce solid waste in the end-of-life stage of a product life cycle, but increase the solid waste generation during manufacturing or material production.

> **RESPONSE:** After discussing this issue with EPA, a decision has been made to include a simple source reduction calculator in the decision support tool. In using this calculator, the user will input the mass of specific materials source reduced and the tool will estimate the LCI benefit associated with this mass reduction. This estimate will be based on our materials manufacturing data sets and will use an industry average mix of virgin and recycled materials manufacturing processes to calculate the benefit. Note that the only source reduction activities that can be captured in this manner are reductions in the mass of materials used through product redesign or lightweighting. Materials substitution can also be analyzed but only for those materials for which we have data.
>
> When using the source reduction calculator, the user will also need to appropriately modify the waste generation and composition data and rerun the decision support tool to obtain a new solution. The LCI benefits of the source reduction activities will then be presented in a separate box (or next to waste management results) so users can assess its significance. The limitations of this approach are well understood by the project team and will be documented in the user's manual.

Technical Issues

Documentation

1. The project team has developed individual reports for each process model as well as an overall report and user's manual. These reports are critical resources that accompany the DST. In many cases, very thorough documentation is provided that details the methodology. For example the landfill report provides the full set of model equations used to characterize this system. The user's manual, however, must be improved particularly given that users will refer to this document more frequently and in many cases they may not have access to the full set of project reports.

> **RESPONSE:** The User's Manual will be updated and improved to provide more details about the individual process models. However, to make the manual readable, we can only summarize the details of each process model. The process model documentation will be made available as appendices to the User's Manual and the Final Project Report.

2. One weakness of the documentation is the lack of literature citation and discussion. For each process and systems model developed, there is a long history of literature and work. These USEPA products should briefly discuss how they have advanced the field from previous work. The project reports by Ham are an example of good practice in this regard.

> **RESPONSE:** The reviewers did not have copies of all process model documentation since some of these were already peer reviewed during the 1997 peer review. Many of the process model documents such as remanufacturing (i.e., material recycling and reprocessing) did

provide similar coverage. However, not all of the process models did provide the same level of documentation regarding the literature review. In many cases the lack of cited literature is a reflection of the fact that there has been very little previous work of the nature of the process models developed in this project.

We plan to summarize the methodology, development of process models, and provide key references in the Final Project Report. We will also include all process model documents as appendices to the report.

3. All spreadsheet entries and tables would benefit from having table numbers and captions, as they would in a technical report (e.g., Table C.1.3). This makes reading and documenting the spreadsheets much easier.

RESPONSE: This is an excellent idea but would require a complete reconfiguration of the actual process model and a near complete rewrite of the documentation. We will not implement these changes in the first version of the decision support tool but will consider them for future versions.

Margins of Error

1. The modeling framework developed should make it very easy for serious users to examine the effects of reasonable uncertainties on the outcomes of an analysis, using sensitivity analysis. For the first time, we will be able to make consistent and reasonable assessments of the importance of uncertainties throughout a MSW system in economic and life-cycle emissions and energy terms. The modeling to generate alternatives feature of the software should be especially useful here.

RESPONSE: Thank you and we agree. We have also received very positive feedback from stakeholders on incorporating this feature in the decision support tool.

2. As a further development issue, reformulation of the linear program in the DST might allow easy sensitivity analysis of some specific, but necessary, assumptions, using standard range-of-basis output from the linear program. For instance, ascertaining the range-of-basis for waste composition would be a very nice automatic sensitivity analysis result to have.

RESPONSE: Although this may be a useful development item, it is beyond the scope of our current efforts. We have a list of potential future develop items and we will add this item to that list for future consideration.

Economies of Scale

1. As stated by the project team, the DST does not consider economies of scale directly. The review panel spent a great deal of time looking at this issue to assess its importance and possible work-arounds. Our first conclusion was that economies of scale problems were not usually important for most processes. Landfilling and combustion tend to have economies of scale, especially for smaller facilities (say less than 300 tons/day). The problems here (with landfilling in particular) are if capacities are small (where costs are more non-linear) AND if there is substantial waste diversion, since the landfill process model develops the unit cost for the DST based on an assumed total waste load.

RESPONSE: Agreed. We expect that the user will be able to recognize when a facility size in a solution is giving an infeasible facility size in a practical context. In such cases the user can rerun the model, once with that facility excluded from consideration and again with a lower limit on the size. This would provide a way to compare the effectiveness of a strategy with and without that facility while ensuring practical size limitations. Language is provided in the User's Manual regarding the limitations of the decision support tool to assess economies of scale and we will review this text to ensure that it is clear.

2. Our considered impression is that economies of scale should not be a major problem. In the exceptional cases where the calculations would be unrealistic due to economies of scale, a reasonable user or observer would notice that the landfill or combustion capacities were unrealistically and impracticably small.

RESPONSE: Agreed and see response above.

Data and Data Architecture

1. More explicit discussion and diagrams are desirable to explain the data architecture and intents for the entire project (databases, DST, and process models). The entire project does not seem to have an engineered data architecture, but rather seems to have let things grow from each separate task (a common problem in large projects). What has been done in the way of data architecture should be documented, and additional development should be founded on a common standard data architecture. This will make programming, documentation, transparency, and maintenance of the products much easier.

RESPONSE: Much of the data for this effort has been compiled from the ground-up rather than from a top-down data architecture. The reason for this is because the data collection and process model development activities occurred simultaneously and often under different circumstances by different parties. For example, much of the landfill model was funded and developed outside of the project.

At this stage of the project, establishing a standard data architecture would only help future data development. What we can do is to more clearly document and diagram the existing data architecture of the project in the User's Manual and Final Project Report. This architecture can then be followed by future data development activities.

2. It would be a useful feature to force users to enter metadata when they change from the default settings. This would provide documentation for model runs and improve the run's transparency.

Waste Generation and Collection

Why are there so few residential collection sectors? Applications to medium and large regions, particularly those involving several jurisdictions, will likely require more residential sectors.

RESPONSE: Two waste generation sectors were originally intended to serve urban and rural settings (i.e. city/county refuse collection). We agree that more sectors could be useful for certain analyses. However, the addition of more sectors to the decision support tool is a major modification and at this time is not practical. Note that users may "creatively" model additional residential sectors by utilizing any unused multi-family sectors.

Composting

1. Like most of the waste management processes composting is a multifactoral input process. Multifactoral in this context means that different decomposable waste fractions are mixed during collection or before the compost plant and treated together. Therefore different ways of managing the waste lead to different compost products, environmental interaction and cost situations. The variable input causes enormous problems to model it adequately. The key sentence (laboratory study page 2-2) "Little is known about the yields and production rates of CO2, NH3 and VOCs <u>of different solid waste components</u> during composting" is absolutely right.

RESPONSE: We agree.

2. Numerous material balances of compost facilities have been made in Germany and elsewhere, but with a given input mixture of organic material. Normally, variation of the input material and its influences of the behavior have not been subject to research work. This is crucial for waste management planning and had been solved so far with empirical knowledge and expert judgement. Therefore the laboratory study and its methodological approach has to be considered as an important contribution to the international discussion about this topic. However, care needs to be taken in using the laboratory VOC data in the MSW compost process model. These data represent emissions from the three waste components tested only and are not representative of emissions from the entire waste stream.

RESPONSE: We agree that the compost model is a crucial first step at modeling a very complex and variable process. We can add a note in the limitations section of the Users Manual to alert users to the developmental nature of the compost results.

3. No benefit associated with the use of compost has been considered in the model. This needs to be corrected to ensure equal treatment compared to other recovery options where credits are given for recovered energy or materials. If compost is produced as a product it may replace some other product like mineral fertilizer or soil improvement material. If it is not used as a product then composting is a final disposal activity and not recycling, and the effects of disposal (e.g. in landfill) need to be included within the model.

RESPONSE: We have heard multiple times that some beneficial use of compost should be considered. While there are some qualitative statements to this affect in the compost literature, we have not to date found any data to support the assertion. The finding of our compost researchers was that there was no offset created by the use of compost product. In recent discussions with EPA's Office of Solid Waste, a resolution was reached where we will qualitatively state some potential beneficial uses of compost product in footnotes.

As more research is done on this issue, data justifying compost product offsets may become available. The compost model can be updated to include this offset.

4. Aerated static piles should be considered for yard waste composting. A Scarab-type pile turner, rather than a front-end loader, is most commonly used in yard waste composting.

RESPONSE: In recent discussions with EPA's Office of Solid Waste, we determined that we could model an aerated static yardwaste compost facility using the existing yardwaste compost model and slightly modifying it's design. The user will have the ability to select a windrow or aerated static pile design for yardwaste composting.

5. Cost data used in the compost process model do not appear to be as rigorously developed as for other process models (e.g. use of 1993 Tchobanoglous data for rolling stock).

RESPONSE: Certain cost parameters, such as rolling stock, are used consistently throughout all process models. We think we have been careful to ensure the same rigor in development of cost data for all process models. In addition, the user always has the option of using site-specific or more recent data.

Processed-Refuse Fuel and Refuse-Derived Fuel

1. The energy production from waste is calculated as electricity. The performance of a WTE facility will change considerably if energy could be used in a more efficient way. WTE facilities are often built in connection with energy intensive industry. Since all calculations show that LCI results are very much linked with the energy performance it is suggested to extend the model also to heat production and adequate substitution models.

> RESPONSE: It is true that steam generated from a WTE facility could be recovered for direct use and that would increase the efficiency of energy recovery. However, when the WTE process model was developed, we consulted with stakeholders representing both the DOE and the WTE industry. All agreed that energy recovery as electricity was by far the most common alternative. Adding the potential to recover steam is an excellent suggestion for a future version of the decision support tool.

2. For transparency reasons it would be very helpful to get LCI results for the WTE and the energy offset model separately. Also the ISO standard asks for a separate documentation for all cases where allocation is involved. This is the case for the calculation of any energy benefits.

> **RESPONSE:** A table of this nature is presented in the paper that is to be published shortly in the Journal of the Air and Waste Management Association. We will add this table to the User's Manual and Final Project Report**.**

Landfilling

1. It must be recognized that modeling a landfill for the purposes of LCA is one of the most difficult exercises. Any effort to the improve the current status of landfill models is highly appreciated.

> **RESPONSE:** Thank you.

2. It would be very helpful to characterize the three types of landfill at the beginning of the document. Then it would be easier to trace the differences of the three types throughout the document.

> **RESPONSE:** The first paragraph of the first section of the process model documentation was rewritten to state:
>
> "The model is designed to calculate the cost and LCI for one ton of waste in consideration of user input and default values for each of three types of landfills: a traditional (synonymous with conventional) landfill, a bioreactor landfill and an ash landfill. While the term model is used throughout this document, there are actually three models, one for each type of landfill. The formats of each of the three models are similar, and areas of divergence are addressed throughout this document."

3. It is not clear why the production processes of soil, sand, HDPE, geotextile, PVC, and concrete have no raw material input of crude oil but of natural gas, coal and uranium.

> **RESPONSE:** Crude oil was accidentally omitted. Data are available and were inserted into the process model documentation. All raw material consumption data have been deleted from the actual process model so that the landfill model is parallel with the other process models.

4. Electricity consumption is not specified as an input for the mentioned production processes. This may cause symmetry problems for the evaluation and optimization of "electricity consumption" as a key parameter.

RESPONSE: The approach used for the landfill process model is the same as that used for all other process models and only the total energy for the entire process (i.e. burial of a ton of MSW in a landfill) is presented. The information requested by the reviewer is available in the process model and a sophisticated user could obtain this information.

5. The system boundaries applied for the implementation and operation of the landfill are not clear (see chapter 4). The activities for the closure of the landfill are related to the implementation of the landfill, i.e. the investment of the landfill. If closure is part of the system then also the installation of the landfill (earth work, mineral layers, other layers, collection and purification systems for leachate, etc.) should be part of the system. There is no reason to include the installation of the gas collection system and exclude the leachate collection system. But this decision is in conflict with the general rule to exclude environmental impacts of the investment. The recommendation is to leave the closure of the landfill outside the system boundaries.

RESPONSE: We agree that the current system boundary may appear somewhat unclear. Throughout the decision support tool, the LCI of facility construction was excluded. This assumption was consistent with common practice at the time that the system boundaries for this project were defined in about 1995. Since that time, I sense that there has been a movement to include the capital investment.

In the case of the landfill, the LCI of construction was excluded to be consistent with all of the other process models. The LCI of closure was included because closure typically proceeds incrementally during landfill operation. For example, a site with a useful life of 20 years may have final cover on part of the site within 5-10 years. Thus, closure was actually viewed to some extent as an activity that supported operations.

We completely understand the peer reviewer's suggestion that the LCI for closure be excluded as it is parallel to construction. However, this would lower the overall LCI of the landfill which would be quite controversial as we would then be accused of biasing the model towards landfills. Thus, our suggestion is to leave the system boundary as it is currently defined for landfills. The most important part of life-cycle assessment is to carefully define what was done and this has obviously been done or the reviewer would not have even known to raise the issue.

5. If all investment and maintenance activities are left aside then a sensitivity calculation for the environmental impact of the landfill investment and maintenance would be helpful including installation, operation, closure and post-closure phase. Indeed our estimations showed that these activities can contribute considerably to the overall environmental burden of landfill activities especially for small landfills. Nevertheless because of methodological correctness investment and maintenance must be treated similarly over the whole waste management system.

RESPONSE: Note that the reviewer has not provided a reference for "our estimations" so it is hard to evaluate these estimates. It is very difficult to use the landfill process model to evaluate the contribution of construction, closure, etc. to the overall LCI as the model was not set up to work in this manner. However, I did use the EREF Landfill LCI model to evaluate this issue and the results are presented in Tables 1 and 2 below.

The following text will be added to the process model documentation to explain the significance of this issue:

"The LCI for the construction phase of the landfill was not included in the landfill LCI. Originally, this system boundary was adopted for all process models. Much later, questions arose as to whether this was the appropriate boundary for the landfill. The EREF Landfill LCI model was used to evaluate the significance of the construction phase of a landfill to the overall landfill LCI. This evaluation was conducted for landfills with and without energy recovery and the results are presented in Tables 1 and 2, respectively. When landfill gas is recovered, the effect of construction is generally small. However, when landfill gas is not recovered for energy, the effect of construction on the landfill LCI is more significant for some LCI parameters. To further evaluate the significance of construction, the results for the landfill LCI, for a landfill that does not recovery energy, were compared to the total LCI for a solid waste system in which waste is collected and buried in a landfill. These results are presented in Table 3. These data show that the construction component of the landfill LCI is relatively significant for certain LCI parameters. As such, it is suggested that subsequent versions of the landfill process model, as well as all other process models, include the construction of capital facilities unless it can be conclusively demonstrated that these facilities do not represent a significant component of the LCI for a solid waste management strategy."

During the ongoing case studies, we will also document the impact of this assumption of the results of the decision support tool and if there is any potential impact on decision making.

Table 1 Landfill LCI: Landfill Gas is Recovered for Energy

(results are for the behavior of one ton of MSW for 100 years)

Component	Unit	**Total**	**Construction**	**Operation**	**Closure**	**Post-Closure**	**Landfill Gas**	**Leachate**	**% of Construction to Total**
Air Emissions									
CO2 fossil	lb.	-203.7	2.830	7.468	3.417	0.342	-218.380	0.6	-1.39
CO2 biomass	lb.	503.7	0	0.000	0	0	501.940	1.8	0.00
Methane	lb.	16.3	1.81E-03	0.004	1.73E-03	1.73E-04	16.253	1.24E-03	0.01
CO	lb.	2.3	1.82E-02	0.047	3.35E-02	3.44E-03	2.234	2.33E-04	0.78
NOx	lb.	0.3	5.09E-02	0.106	9.05E-02	8.97E-03	0.034	1.74E-03	17.42
SOx	lb.	-1.2	9.32E-03	1.51E-02	1.30E-02	1.29E-03	-1.222	2.47E-03	-0.79
Total Particulate	lb.	-0.8	8.09E-03	1.15E-02	8.04E-03	8.05E-04	-0.843	2.02E-03	-1.00
Hydrogen Chloride	lb.	-1.72E-02	5.32E-05	3.65E-05	4.72E-05	4.69E-06	-1.74E-02	7.33E-05	-0.31
Hydrogen Sulfide	lb.	2.20E-03	7.09E-06	1.63E-05	7.15E-06	7.16E-07	2.17E-03	4.51E-07	0.32
Water Emissions									
BOD	lb.	4.45E-02	3.47E-04	8.34E-04	3.64E-04	3.65E-05	-8.28E-04	4.37E-02	0.78
COD	lb.	0.166	2.81E-03	7.05E-03	2.99E-03	3.00E-04	-6.98E-03	0.1599158	1.69
TSS	lb.	3.83E-03	1.55E-03	3.83E-03	1.65E-03	1.65E-04	-3.77E-03	4.07E-04	40.38
NH3	lb.	2.13E-02	5.00E-05	1.23E-04	5.26E-05	5.27E-06	-1.97E-04	2.12E-02	0.23
PO4	lb.	5.28E-04	8.55E-07	1.26E-09	8.32E-07	8.23E-08	-8.81E-11	5.26E-04	0.16
Water Metals									
Arsenic	lb.	3.96E-07	0	0	0	0	0	3.96E-07	0
Barium	lb.	9.28E-06	0	0	0	0	0	9.28E-06	0
Cadmium	lb.	3.42E-08	0	0	0	0	0	3.42E-08	0
Chromium	lb.	7.16E-07	8.14E-10	7.87E-09	3.28E-10	3.25E-11	-3.50E-09	7.11E-07	0.11
Lead	lb.	7.79E-08	0	0	0	0	0	7.79E-08	0
Mercury	lb.	1.37E-09	0	0	0	0	0	1.37E-09	0
Selenium	lb.	3.42E-08	0	0	0	0	0	3.42E-08	0
Silver	lb.	1.71E-07	0	0	0	0	0	1.71E-07	0

Table 2 Landfill LCI: Landfill Gas is Burned in a Flare

(results are for the behavior of one ton of MSW for 100 years)

Component	Unit	**Total**	**Construction**	**Operation**	**Closure**	**Post-Closure**	**Landfill Gas**	**Leachate**	**% of Construction to Total**
Air Emissions									
CO2 fossil	lb.	14.65	2.83	7.47	3.42	0.34	0.00	0.59	19.32
CO2 biomass	lb.	503.72	0.00	0.00	0.00	0.00	501.96	1.76	0.00
Methane	lb.	16.886	1.81E-03	3.71E-03	1.73E-03	1.73E-04	16.877	1.24E-03	0.01
CO	lb.	3.164	1.82E-02	0.047	3.35E-02	3.44E-03	3.062	2.33E-04	0.58
NOx	lb.	0.421	5.09E-02	0.106	9.05E-02	8.97E-03	0.163	1.74E-03	12.09
SOx	lb.	6.53E-02	9.32E-03	1.51E-02	1.30E-02	1.29E-03	2.42E-02	2.47E-03	14.27
Total Particulate	lb.	3.05E-02	8.09E-03	1.15E-02	8.04E-03	8.05E-04	0	2.02E-03	26.52
Hydrogen Chloride	lb.	2.26E-02	5.32E-05	3.65E-05	4.72E-05	4.69E-06	2.24E-02	7.33E-05	0.24
Hydrogen Sulfide	lb.	2.22E-03	7.09E-06	1.63E-05	7.15E-06	7.16E-07	2.19E-03	4.51E-07	0.32
Water Emissions									
BOD	lb.	4.53E-02	3.47E-04	8.34E-04	3.64E-04	3.65E-05	0	4.37E-02	0.77
COD	lb.	0.173074	2.81E-03	7.05E-03	2.99E-03	3.00E-04	0	0.159916	1.63
TSS	lb.	7.60E-03	1.55E-03	3.83E-03	1.65E-03	1.65E-04	0	4.07E-04	20.36
NH3	lb.	2.15E-02	5.00E-05	1.23E-04	5.26E-05	5.27E-06	0	2.12E-02	0.23
PO4	lb.	5.28E-04	8.55E-07	1.26E-09	8.32E-07	8.23E-08	0	5.26E-04	0.16
Water Metals									
Arsenic	lb.	3.96E-07	0	0	0	0	0	3.96E-07	0
Barium	lb.	9.28E-06	0	0	0	0	0	9.28E-06	0
Cadmium	lb.	3.42E-08	0	0	0	0	0	3.42E-08	0
Chromium	lb.	7.20E-07	8.14E-10	7.87E-09	3.28E-10	3.25E-11	0	7.11E-07	0.11
Lead	lb.	7.79E-08	0	0	0	0	0	7.79E-08	0
Mercury	lb.	1.37E-09	0	0	0	0	0	1.37E-09	0
Selenium	lb.	3.42E-08	0	0	0	0	0	3.42E-08	0
Silver	lb.	1.71E-07	0	0	0	0	0	1.71E-07	0

6. Referring to the landfill gas production, it would be helpful to include a table of the gas yields of the different waste components in the default case because the ultimate gas yield is based on the methane yields of individual waste components. This table might help the user to understand differing numbers and follow the recommendations in chapter 6.2.1.

RESPONSE: We agree – the text in bold and the Table have been added to section 6.2.1 "The default value for the ultimate yield (Lo) of the landfill gas is calculated from the user input composition for a typical ton of MSW and methane yields measured under laboratory conditions as presented in Table X."

Table X. Methane Yields Measured Under Laboratory Conditions[a]

MSW Component	Methane Yield ($L\ CH_4$/dry kg)
Grass	136
Leaves	30.6
Branches	62.6
Food Waste	300.7
Coated Paper	84.4
Newsprint	74.3
Corrugated Containers	152.3
Office Paper	217.3

a. Methane yields were measured in 2L reactors in the laboratory. experimental conditions are described in the following references

b. Eleazer, W. E, Odle, W. S., Wang, Y.-S. and M. A. Barlaz, 1997, "Biodegradability of Municipal Solid Waste Components in Laboratory-Scale Landfills," Env. Sci. Technol., 31, 3, p. 911 - 17.

c. Barlaz, M. A., 1997, "Biodegradative Analysis of Municipal Solid Waste in Laboratory-Scale Landfills," US Environmental Protection Agency Report #EPA 600/R-97-071, Washington, D.C.

8. As stated at the workshop the assumed gas collection efficiencies with a maximum of 95 % and a weighted average of 88 % is considered much to high. In a German survey no operating gas collection system had a higher efficiency than 70 % using an active sampling systems (active = with the help of pumps). In regard of the operation of landfills in Germany it was assumed that during the first ten years only 30 % is collected and the rest vented. This period is followed by an active sampling period of about 40 years with a maximum of 70 % of sampling. Afterwards only passive sampling with a flare is economically feasible or no sampling at all is applied. Since the gas production is higher the first ten years an average sampling efficiency of 50 % is unlikely to be exceeded.

RESPONSE: The methane collection efficiency of 88% represents the weighted average of the collection efficiency over the period of gas collection. Four gas collection periods are defined:

Period 0: 0-2 years – gas collection system not installed
Period 1: 2-5 years – temporary or incomplete gas collection system prior to installation of final cover
Period 2: 5-40 years – second gas collection and treatment system in place. This system is installed in 5 years by which time regulations require that there be a gas collection system in place
Period 3: 40-80 years – third gas collection system in place. Year 40 represents the end of the post-closure monitoring period for the average ton placed at 10 years, where 10 is half of the assumed useful life of a landfill.

The assumed gas collection efficiencies for years 2-5, 5-40 and 40-80 are 60, 95 and 90%, respectively. The weighted average of these values is 88%. Note that gas produced prior to year 2 will be vented to the atmosphere.

The explanation in the documentation has been improved. We recognize that all of these values represent engineering judgment as quantitative data on collection efficiencies are not available. The defaults used represent the collective judgement of people in the landfill industry.

It is certainly assumed that we are operating a state-of-the-art landfill and aggressively controlling the gas. In this respect, it is not clear to me whether a survey of German landfills is relevant as no information is presented on the state of the landfills. There are certainly older sites and some active sites with lower gas collection efficiencies. However, this model is for one ton of MSW in a Subtitle D landfill.

As an exercise, we used a different gas model with slightly different inputs. In this approach, the collection efficiency was assumed to be 0% for years 1 and 2, 60% in year 3 and 90% thereafter. If it is assumed that gas is collected until the end of the post-closure monitoring period (20 year site plus 30 years), after which it is vented, then a collection efficiency can be calculated from the methane actually collected divided by the methane produced. The calculated efficiency is 72%. However, if the methane is collected for 100 years, then a weighted average collection efficiency of nearly 90% would result. If the EPA is more comfortable with this as a default, then they need to provide this input to the project team. In truth, the collection efficiency is based on engineering judgement at this time. The EREF effort, which included a lot of thinking and discussion, resulted in a value of 88%.

The following note will be added to the input cell for gas collection efficiency:

"The collection efficiency should represent a weighted average value for the life of gas production. The current default value of 88% is based on a site with very aggressive gas collection at 90-95% efficiency for the duration of the period of significant gas production. If a gas collection system were terminated while there was still significant gas production, then a significantly lower collection efficiency value would result. For many landfills in the US, it is assumed that the collection efficiency is about 70%. However, this value can be adjusted based on an understanding of the design and operation of the gas collection system in place."

9. Flare, turbine, boiler and internal combustion engine have no emissions of heavy metals or organic compounds which makes them look very environmentally friendly.

RESPONSE: The emissions for the combustion devices listed in the reviewer's comment are the same emissions as are reported for all other processes in each process model. This list of emissions was selected so that consistent LCI data could be reported across all process models and the entire solid waste system. Additional emissions could be incorporated into a second version of the model as additional data become available.

10. For transparency reasons it is necessary to have access to intermediate results of the landfill gas emissions without energy offset, the energy offset separately and the total. This is important to judge about technical options for the use of landfill gas.

RESPONSE: The format in which results are reported for the landfill process model is consistent with the format in which they have been reported for other process models where energy is recovered. When energy is recovered from landfill gas, the production of some energy from fossil fuels is avoided. This is mentioned in the landfill process model documentation and described in detail in the electrical energy process model documentation. The user has the capability to select the specific fuel mix that is offset This selection may be based on the national grid, one of nine regional grids, or a user specified fuel mix. The following text will be added to section 6.4 on Landfill Gas Treatment and as a cell note in the decision support tool where the user specifies the landfill gas management strategy:

"The landfill LCI is highly sensitive to the selection of the gas treatment scenario. Where landfill gas (LFG) is recovered for energy, there are significant offsets that are allocated to the landfill. These offsets are not realized if LFG is not recovered for energy. "

11. System boundary problems arise with the use of "materials consumed in bioreactor landfills" (chapter 7.7). It is not clear which activities belong to operation and which belong to investment goods. Investments should be outside the system boundary.

RESPONSE: In the case of a bioreactor, the extra piping that is used for water distribution is installed as the landfill is filled. Therefore, this piping is considered to be part of landfill operations as opposed to construction or closure activity. Thus, we think that the inclusion of this item is even more clear than the issue raised in item 5. Here too, the exclusion of this piping could result in a charge that we are biasing the model towards bioreactors.

12. The review of the chapter of cost for landfilling (chapter 2) cannot be done with the necessary detail. An expert of economics should review the cost functions. It only should be stated here that the economics of scale are especially relevant for landfilling and may have a severe influence on the result.

RESPONSE: The economics associated with the landfill process model were reviewed by Dr. Greg Richardson early in the project. Dr. Richardson has designed numerous Subtitle D landfills and he reviewed all of the default cost information. This was an informal review without documentation. Perhaps more importantly, the results of the cost calculations have been distributed widely amongst our stakeholders, including many that represent the landfill industry. We are quite certain that we would have received comments if the cost estimates were inaccurate. In addition, we spent significant time on the cost curve (Fig. 1 of the process model documentation) during the peer review meeting in November, 1999. Here too, we do not recall comments from any stakeholder expressing a concern with the results presented by the cost curve.

13. The terminology for the wet landfill is inconsistent. In various places it is called a wet landfill, bioreactor landfill, and enhanced bioreactor landfill. The preferred terminology is bioreactor landfill. Perhaps a better name for the “traditional” landfill would be “conventional”.

RESPONSE: The text has been reviewed and bioreactor landfill has been used throughout. Within the landfill process model and documentation, we will continue to refer to a “conventional” landfill as a “traditional” landfill. However, at the first use of the term “traditional” in the documentation, we will indicate that this is synonymous with “conventional.” The term “conventional” will be used in the overview document.

It is also noteworthy that the term traditional has been used at stakeholder meetings for years. These meetings have included representatives from both industry and local government. There has never been a comment suggesting that the term “traditional” was inappropriate.

14. The default values for the bioreactor landfill are not consistent with field data: Horizontal trench spacing should be 50 ft; Vertical well spacing should be 100 ft; Recirculation percentage should be no more than 75%; External storage for a bioreactor landfill should be greater than a dry landfill; Leachate organic constituents in the bioreactor tend to concentrate to higher levels during the first few years of operation.

RESPONSE:

a. The default value for horizontal trench spacing will be changed from a 100’ influence to a 25’ influence (Input-D643/Bioreactor C1618).

b. The default value for vertical well spacing will be changed from 1 per acre to 0.72 per acre which is equivalent to a 100’ well spacing with a circular area of influence. This was calculated as follows:

   area of influence = r^2. If r = 100’, then A = 31400 ft^2 or 0.72 acre.
   (Input D649/Bioreactor 1630).

c. We disagree with the statement that the recirculation percentage should be 75%. In extensive discussions with landfill designers and representatives of Waste Management, one of their major concerns is that bioreactor landfills will be water limited. Therefore the default value will remain at 100%. Of course, We also recognize that this may be as site-specific as is annual rainfall and both parameters are user inputs. We propose to add the following cell note to Input cell D531:

   “The fraction of leachate recirculated is site-specific as is the annual amount of rainfall. At this time, there are very limited data on the % recirculation that can be achieved over the long term due to the very limited operating experience at full-scale bioreactors. Site specific data should be input by the user if available”

d. We agree that external storage for a bioreactor landfill should be greater. The default cost for leachate storage for a bioreactor landfill will be set as double that of a traditional landfill (Input cell D116).

e. With respect to the behavior of organic constituents in leachate from bioreactor landfills, the logic was to leave the concentrations the same as for traditional landfills and to increase the rate at which both the BOD and COD decrease in bioreactor landfills relative to traditional landfills. This logic is reflected in the current defaults. As most, if not all of the leachate is recirculated, particularly during the early years, the leachate strength is of no consequence to the landfill LCI since no energy is expended for leachate treatment.

15. Landfills are usually built in increments of small cells with greater frequency (say every three years) to avoid large capital expenditures. This practice may incur economy of scale problems during modeling. The expenditure would only involve the actual construction of the cell not ancillary costs such as land purchases, scalehouses, etc.

RESPONSE: Incremental construction of the landfill was not considered in this model. In this respect, all capital costs associated with construction were assumed to occur initially. However, as described in the response to item 12, the results of the cost model are consistent with typical landfill tipping fees. This suggests that the issue raised by the reviewer does not significantly impact process model results. This response will be added to the "Limitations" chapter of the User's Manual.

16. Compaction densities in the model are the same for MSW and ash landfills. The value used seems more appropriate for ash then unburned MSW.

RESPONSE: The default densities were adjusted in response to earlier review comments. The MSW density remains at 1500 lb/yd^3 while the ash density has been increased to 3500 lb/yd^3.

17. The landfill model might take more effort to incorporate some of the cost dynamics discussed in the previous peer review. As discussed in the previous review, this might not require a great deal of effort. However, the current representation is fine for most circumstances, especially for a reasonable user.

RESPONSE: We looked at the issue of incorporating cost dynamics after the last per review at the suggestion of one of the peer reviewers. The incorporation of cost dynamics was not consistent with the steady-state linear model that we have developed and could not be easily implemented. The fact that the entire decision support tool is based on steady state has been explained in the "Limitations" chapter of the User's Manual.

18. The landfill cost model is overly complex in comparison to other cost models, which gives the appearance of unfair treatment. It may be more desirable to use the resulting cost curve (Figure 2-1 in the development document) to determine $/ton. If different data are available to the user, the $/ton default value can be changed, rather than the excessive number of default values. Because it is unlikely that the user will have all of the default values, they may use a combination of default and local numbers and get erroneous costs. More likely, they may not make the effort to localize the model.

RESPONSE: The user has the capability to input a default cost and bypass all of the inputs. However, as explained in the User's Manual, even if these defaults are not used for cost, they are used for LCI calculations. Thus, bypassing the defaults completely is not a recommended strategy. At a minimum, the user should select the landfill gas management strategy as the LCI results for the landfill process model are highly sensitive to whether LFG is recovered for energy, flared or released to the atmosphere.

Thinking

Perhaps the most difficult aspect of this project is that its effective use requires MSW professionals to think differently and more quantitatively. In most medium and large cities other municipal functions, such as water distribution and drainage, have already gone through such changes. For water supply systems, SCADAs give constant 15-minute updates of the system and almost all major changes are modeled using software such as EPANET or KYPIPE. For major changes and improvements to be made in MSW systems, such a change in thinking is needed. This project's software is an important step in improving how we think about MSW systems. Many local and policy MSW professionals will find this change difficult until they realize the benefits of this over the current *ad-hoc* approach. Quantitative analysis will come out with some results which are counterintuitive to "old hands" in the field. Sometimes these counterintuitive results are errors, which can be readily found and corrected. Other times counterintuitive results will lead to genuine insights (improving our intuition) and genuine improvements in our systems.

RESPONSE: Thank you. We agree and hope that the decision support tool proves to be a valuable learning tool for solid waste practitioners.

Next Steps

Business Plan

1. A business plan is necessary for this project's products to be made available in a sustainable and organized way. A contingency plan needs to be made in case the current partner organization does not continue with the project.

RESPONSE: Business plan preparation by our current partner organization (SWANA) is scheduled for the Fall of 2000, assuming that they decide to go forward with the commercialization. We are currently preparing a contingency plan to ensure that the decision support tool and other research products are made available if the plans with SWANA don't materialize.

2. If plans do not go forward in a timely way to commercialize these products, USEPA should put these important and useful products forth in other ways. These products might usefully be placed at the disposal of State agencies and academic researchers who might be able to further develop and/or support their application. For this type of transfer to be accomplished, this USEPA sponsored work (software, databases, and documents) should be placed in the public domain.

RESPONSE: The research team strongly supports releasing the decision support tool in the public domain with the following cautionary note. Given the complexity of the problem and related issues, and the extensiveness of the prototype software package, it is highly likely that significant questions from potential users may arise and therefore would require significant technical support to have any practical value to making it available on the public domain. We want to be careful of avoiding a situation in which a release results in bad publicity because users are frustrated by the lack of technical support.

The research team raises this point based on our experience with stakeholder groups (that well represent the users as well as other interested parties in the software) because many had recurring confusions about just the solid waste management problem, life cycle issues, modeling approach, and solutions. Our experience with more knowledgeable groups indicates that it requires at least a day of one-on-one description, demonstration, and question and answer session to disseminate the minimum of information necessary to understand the products from this project.

The plan is that the tool will be released in a way that provides for a revenue stream that will cover the costs associated with training, technical support, and future updates and/or improvements. The cost will be kept to a minimum but will reflect the needs indicated by peer reviewers as well as stakeholders that training, technical support, and future updates provided. In addition, case studies can be conducted, similar to what is occurring now, where knowledgeable individuals (such as research team members) are contracted to model a community, state, or geographical regions solid waste management practices, and evaluate changes to current practices that help to minimize cost and life-cycle environmental burdens. In addition, we will be providing extensive documentation, user's manuals, and illustrative examples through case study documentation.

3. Business plan development should address the fates of the process models and their documentation. These models merit separate marketing and development outside of their use in the DST.

RESPONSE: We agree and will be looking into how the process models can be developed outside of the decision support tool. This is likely to be an area that is outside of the scope of the the commercialization effort and will be more the effort of the existing research team parties.

Launch Plan

1. A Beta-test plan is probably vital to the success of the launch of the software. Training and technical support will likely be needed to accompany the release.

RESPONSE: Beta testing is planned for in a separate cooperative agreement. Once the new cooperative agreement is in place, a plan for beta-testing the tool will be formalized.

2. A DST-lite version of the DST with very few options might be useful as a teaching and training tool. Use of dialog-box-type interfaces might also help normal users and help impose more data discipline on users.

RESPONSE: We agree and think this is a good idea and we will keep it in mind for future funding.

3. Documentation should be carefully proofed for errors prior to release.

RESPONSE: We agree and all project documentation is undergoing careful review and editing to ensure minimal errors and consistency.

4. The product should be marketed with an EPA "seal of approval."

RESPONSE: EPA's Office of Research and Development is planning on having a Cooperative Research and Development Agreement with the partner or partners in conjunction with the launching of the decision support tool and LCI Database. This is to ensure that the technical credibility, objectivity and basis on sound science are maintained. In addition, EPA will maintain a key role in resolving any potential issues with the application of the tool and database.

5. A voluntary oversight committee should be assigned to ensure that the model is maintained.

RESPONSE: The current planning for the dissemination and maintenance of the decision support tool is to have some sort of oversight group to ensure that the model is being properly distributed and maintained.

Attachment 5:
May 2000 Peer Review Report

Life-Cycle Management of Municipal Solid Waste

May 22-24, 2000
Peer Review Comments and Responses

This peer review focused on the evaluation of materials life cycle inventory data, the life cycle inventory database, case studies and a few outstanding issues dealing with the life cycle Decision Support Tool (DST) that had been previously peer reviewed.

Overall Comments:

In general, the Project Team has been very successful in developing high quality products that will make significant contributions to both integrated municipal solid waste management and the life cycle assessment field. While a project of this sophistication and complexity can always be enhanced, the current set of products should be finalized as soon as possible so that they can be widely disseminated. This review found that the general approach and LCA methods are scientifically sound, the data gathered represent the state of the art, and the case studies demonstrate the utility of the DST.

- The achievements of this project are significant and the tools have the potential to provide significant new insights into solid waste management strategy development.

- The underlying data are generally credible and very well documented.

- The LCI data set represents a significant achievement that will be valuable to a wide range of users. The data appear to have been carefully developed, are credible, and are generally well documented.

- The case studies are important parts of the DST documentation in that they demonstrate the use and value of the DST. The case studies provided to the peer review team address a wide range of MSW management issues. The case studies were not yet complete at the time of the review. The case studies, as presented to the panel, were not sufficiently focussed or refined to effectively communicate the value of the DST or demonstrate its intended uses.

- Maintain Focus! Consistent with the two earlier peer reviews, I feel that a major challenge to this type of ambitious and potentially wide-ranging project is to maintain focus on a relatively specific and narrow set of program users and uses. In this case, my understanding is that the major use of this program is for use by local MSW managers to assess the costs and emissions of local waste management decisions. While the model might have a role in other and broader analyses, it is a mistake to ask too much of this initial product. The project should maintain focus on its most important and direct objectives, concentrating on model verification, data checking, and Beta release in the next few months.

- Avoid distractions from successful and timely release of DST and Database. As with any ambitious and already broad project, there have been and remain persistent and tempting opportunities and demands to broaden product objectives for this project. This has been a persistent peer-review concern as well. Some examples of recent distractions are: source reduction, carbon sequestration, and perhaps over-emphasis on numerous case studies for Chapter 5. While the distracting issues are important, they are not central to this project's objectives of providing a useful MSW management tool for local waste managers which provides both economic and life-cycle information.

- Include all reviews and responses in final report. There is much of value in the comments of the previous peer reviews, including many specific comments and suggestions for improvements that cannot be made in this phase of work. These should be included in the report. Including these comments and responses to them should help indicate the degree of technical depth and breadth of this project, help clarify the limitations of this project, and contribute some technical credibility to this project's accomplishments.

- User stakeholders are very enthusiastic about DST capabilities. As with the previous peer-reviews, I found the stakeholder comments to be must useful. These comments show a clear awareness of most of the strengths and limitations of the project. They also show great enthusiasm for the release of this product. One official from a large city indicated that, "We needed this product five years ago." There seems to be a realization at the local level among advanced practitioners of the need for advanced information, modeling, and database technology for MSW management.

- It is highly recommended that another round of model verification be conducted based on some unexpected results found in reviewing the Great Lakes Case Study. In addition, the following recommendations and detailed comments are provided to enhance the transparency in reporting, clarify some methods and better highlight DST limitations.

Materials Data Comments:

- The materials life cycle inventory data under review are presented in the report titled "Data Sets for the Manufacturing of Virgin and Recycled Aluminum, Glass, Paper, Plastic, and Steel Products". These data have been assembled from a variety of sources, with significant input from material processing industries. The data carefully follow guidelines established for collection and presentation of life cycle inventory data by organizations such as the Society for Environmental Toxicology and Chemistry (SETAC). Significant effort has gone into documenting the data and making the information as transparent as possible. In addition, I was impressed by the level of effort that went into making the disparate data consistent (e.g., using consistent electrical grid data).

RESPONSE: Thank you.

- This high quality data set will undoubtedly be valuable to a wide range of users and I strongly recommend the release of the data report as a separate, stand-alone document.

RESPONSE: Thank you.

- The handling of energy of material resource is an important methodological question in this application of life cycle inventory data. I am concerned that the handling of material of energy resource, while consistent, may bias how the DST evaluates certain materials. For example, for paper products, the current decision rules allow an energy credit to be taken for combusting paper wastes but does not count the wood in paper products as an energy input. In contrast, the energy embodied in plastic products is counted as an input. This means that the energy benefits of plastics recycling will be given additional benefits that are not accrued to paper recycling. This is justified based on the presumption that wood is not commonly used as an energy resource, only as a material resource. Yet, the DST claims an energy credit for combustion of paper products. This strikes me as inconsistent. I recognize that changing the decision rule on energy of material resource may not be possible, or even appropriate. If the decision rule is not changed, however, I recommend that the discussion of the potential significance of this approach (Section 2.2.1) be expanded.

RESPONSE: The justification for excluding for excluding wood from energy of material resource was based on the presumption that wood is not commonly used as an energy resource in the U.S. We will add text to the documentation noting the potential impact of this approach.

- The data in this report have been assembled from a number of sources following SETAC guidelines and according to ISO standards. The data appear to have been carefully developed and when necessary, modified to reflect conditions within the United States.

RESPONSE: Thank you.

- The term “products” in the materials LCI report title is misleading and should be changed to “materials”.

RESPONSE: Agreed. The term “products” has been renamed “materials”.

- The abstract of the data set report should reflect that the data are available as an electronic database.

RESPONSE: Thank you. This change has been made.

- It would be useful to include a statement in the report to the effect that industry organizations were intimately involved in creating the data, and that although shortcomings exist, these are the best data currently available.

RESPONSE: Thank you. This change has been made in the abstract and Chapter 1 of the documentation.

- ISO Protocol: The materials data sets indicate that the LCI methodologies used conform to the ISO Protocol for undertaking LCIs. The report should include as an appendix a description of the ISO 14040 standards.

RESPONSE: Thank you. We are not able to reprint the ISO 14000 standards in this document. We will, however, include information about the standards and contact information for ordering a copy.

- Data should be as complete as possible. It appears that in some cases (e.g., landfill air emissions) only the data used by the DST have been included while the original source contains many more chemical species.

RESPONSE: Agreed. If we find that additional data is available for a process above and beyond what is in the DST, we will add to the database pending review and approval by the research team and EPA.

- All source citations should be verified. Several are incomplete (e.g., author name missing) or appear to be in error.

RESPONSE: Agreed. We will do a final check of references and source citations prior to release of the documentation and database.

- One notably positive dimension of the materials data sets and decision support tool is the transparency of the assumptions and information provided. The materials data set manual provides clear discussions of assumptions. It also provides background references for all data sources. Similarly, background information and assumptions for the default positions in the decision support tool are available for review. Data sources are clearly acknowledged and assumptions are relatively clearly stated. The materials use data sets follow the ISO protocol for LCIs, and inclusion of simple charts that summarize data quality is helpful.

RESPONSE: Thank you.

- Substantial limitations surround the data, which only the most sophisticated and knowledgeable users would be in a position to recognize and take into account to make necessary adjustments. For example, emissions from energy use assume energy mixes that may not be relevant to local circumstances. The regional energy-use data employed may be too aggregated and averaged to accurately reflect local circumstances. Also, the tool gives the user no means of distinguishing which environmental loadings are local and which are regional or national. Recycling of aluminum, for example, might yield net reductions in air emissions relative to production and use of “virgin” aluminum. However, those net reductions will occur at the manufacturing plant, not in the community undertaking to recycle aluminum containers. The local community may still have other reasons to include aluminum recycling, but the community should not assume such activities contribute to, for example, local air quality improvements.

RESPONSE: Agreed. We have added text in appropriate project documents to reflect that the materials data and results represent more national or global emissions and that this needs to be considered when making local decisions.

- The LCIs for recycled content seem to assume constant energy savings ratios regardless of recycling levels. This assumption may be unwarranted in some instances. For example, energy savings in making glass from cullet decline after certain threshold levels of recycled content are achieved.

RESPONSE: Yes, the LCI data sets assume a linear (and constant) energy savings regardless of recycling levels. This will be noted in the limitations.

- The PE category under plastics should be eliminated, since PE does not exist as a separate commodity. Table 6-4 (page 6-14) should be modified or eliminated since it is intended to show a "reality check" comparison with other data values, but the other data sources identified are all actually a single source.

RESPONSE: The PE category has been removed and Table 6-4 has been modified to remove the comparison to Young's data set, which also is based on the APME data.

- When data are unavailable, leave cells blank rather than putting in a placeholder value.

RESPONSE: Data cells will be left blank where data are unavailable.

- The report states that the "use step is assumed to be identical regardless of whether the product is made from virgin or recycled materials". While this assumption applies in many instances, it does not apply in all cases. For example, recycled content plastic bags may underperform those from virgin plastic in some instances.

RESPONSE: There are likely some instances where this assumption does not hold. A note will be added to the limitations in the documentation alerting readers and users to this potential issue.

- Data Presentation: Data should not be presented to more than a few significant figures. To do otherwise gives the illusion of a certainty and precision that does not exist.

RESPONSE: All data will be reported in scientific notation to 3 significant digits.

- Page 1-6, final bullet point: Should this read "For example, reviewers can compare the LCI totals....for another project, but do NOT have adequate information to compare process-level...."

RESPONSE: Thank you. This change has been made.

- The material production data sets for primary and secondary aluminum, glass, paper, paper, plastic and steel are a very valuable deliverable from this project. The project team has assembled the best available data to represent the production of these materials in the US. Many of these data were not previously available publicly. Consequently, the publication of these data will greatly facilitate the future development of life cycle assessment studies.

RESPONSE: Thank you.

- Change the title of the report to avoid misinterpretation of its scope. "Manufacturing" in LCA terminology refers to second major life cycle stage that addresses parts fabrication, component assembly processes, etc. Combined with the term "Products" also used in the title it implies that the inventories cover the production of plastic cups, steel cans, aluminum engine blocks, etc. I would recommend the term "Material Production" instead. In addition, I would recommend considering the use of the terms "primary" and "secondary" as an alternative to "virgin" and "recycled." Primary and secondary may apply more widely to the materials that you have modeled although neither set is optimal for all materials.

RESPONSE: Thank you. These terminology changes have been made.

- Suggested alternate title: "Life Cycle Inventory Data Sets for Material Production of Aluminum, Glass, Paper, Plastic, and Steel

RESPONSE: Thank you. This title change has been made.

- More discussion of the assumptions made in calculating recycling offsets or credits needs to be provided. Two modeling parameters were introduced: recycled material input ratio and materials substitution ratio. These two parameters should be described in better detail. Apparently, the materials substitution ratio is always assumed to be one. Many applications exist where this in not the case because of differences in the properties of materials with greater recycled content. The project team and the reviewers indicated that data for this parameter are scarce. Regardless, the assumption should be explicitly stated and justified. The recycle material input ratio can also be better described using an example.

RESPONSE: Thank you. Although these assumptions are described in other project documentation, we will add text to the materials data documentation as well.

- I have a concern with the use of the term remanufacturing. Remanufacturing is more traditionally used to describe the process for refurbishing retired products. Retired products are disassembled and usable parts are then cleaned and refurbished. New products are reassembled from both old and new parts. The term material recycling and reprocessing would be more appropriate. If EPA is still inclined to use the term remanufacturing, it should point out the other usage of this term.

RESPONSE: Thank you. The term "remanufacturing" has been changed to "reprocessing".

- Material recycling is very difficult to model when the boundaries are extended to include reprocessing of recovered materials. The quality of the recycled material is dependent on the products comprising the MSW stream and management pathway (including collection methods, processing technologies). It is not reasonable to assume that the recycled materials will always displace virgin materials. Contamination and product use can significantly degrade the physical and chemical properties of the material. Many different grades of quality exist for most materials. These issues should be better highlighted in the report.

RESPONSE: Agreed. These issues will be added to the text on data limitations.

- Offsets for recycling are calculated by subtracting inventory profiles for 100% secondary material production from the profiles based on primary materials production. The report indicates that "composite materials" are often used in the manufacturing of products. Various products consist of a combination of primary and secondary content. Data indicating typical ratios for several material applications where given in Table 2-1. It is not clear in reading the report that the composite case is not used to compute offsets. This needs to be stated more explicitly.

RESPONSE: Some market average mixes of primary and secondary resources used were available for a few of the materials studied. We have included them in the data sets but they are not used in the recycling offset calculations. This will be clarified in the documentation.

- Space conditioning is neglected. This assumption is reasonable to make but the statement that space conditioning is usually less than 1 percent of the total energy consumption is not accurate. It varies by material but 10% may be a better number to use here (see the 1994 Manufacturing Consumption of Energy Survey of DOE).

RESPONSE: Yes, space conditional was considered to be insignificant and excluded from the data sets. We will verify the general contribution of energy used for space conditioning to the LCI totals and revise our statements as appropriate.

- The project utilizes inventory data from multiple sources. These sources can have significant and/or subtle differences in their methodologies. This may be most noteworthy for the various paper material production inventories which were derived from two different studies: Franklin and Environmental Defense Fund. The report should provide a caution of the comparability of these and other data.

RESPONSE: Agreed. This caution will be added to the limitations section in Chapter 1 and to the paper chapter.

- The project is to be highly commended for having developed North American LCI inventory data for the major material categories on a consistent basis and in a standardized format.

RESPONSE: Thank you.

- Section 2.2.1, paragraph 1, should state what the 'conversion factors' represent (e.g. higher or lower heating values of the fuels, as the case may be).

RESPONSE: Thank you. Text will be added to Section 2.2.1 noting that the conversion factors represent the higher heating values of the various fuel types.

- Page 2-6, 3rd paragraph starting "Air or waterborne emissions…". Is the reverse true? Do the data sets include all parameters reported to regulatory authorities? For example, a number of effluent parameters (such as benzene, benzo-a-pyrene, napthalene, phenols, and total cyanide) regulated in the U.S. for Cokemaking in the Iron and Steel Industry are not included in the steel data sets.

RESPONSE: For the most part, data collected for regulatory purposes is not used because it is collected at the facility level and it is extremely difficult to allocate to the different products produced at the facility.

- Page 2-6; last sentence in Section 2.2.2.1. This applies to all the data (since this is an LCI and not a risk assessment or even impact assessment) and should probably be included in the general limitations section rather than here.

RESPONSE: Agreed. This sentence will be removed and added to the general limitations in Chapter 1.

- Page 2-7, Section 2.3.4, first sentence needs clarification.

RESPONSE: The point of the first sentence in that section is to alert the reader that the data sets for secondary materials are not complete in the sense that they do not include data for the collection, separation, and transport of the recyclables to the reprocessing facility. Thus the primary and secondary data sets cannot be compared directly. The first paragraph of this section will be rework to more clearly convey this point.

- Page 2-8, last two paragraphs of Section 2.3 as written may suggest that 100% (infinite) recycling for all materials has been used in the overall project. This may be a good place to refer to the "recycled material input ratio".

RESPONSE: Agreed. A discussion of the recycled material input ratio will be added here.

- In assessing data quality, was the number of parameters covered by the data set considered under the criteria of completeness criteria?

RESPONSE: No. The ISO guidelines define completeness as "the percentage of locations reporting primary data from the potential number in existence for each data category in a unit process." This definition was followed.

Aluminum:

- Table 3-1: the entries for chlorine and fossil carbon dioxide are reversed or improperly entered.

RESPONSE: Agreed. This change has been made.

- Table 3-1, the conversion factor (presumed to be heat content) for coal under the category "Combustion Process Energy" is slightly different (0.01116) from that in "Energy of Material Resource" (0.0197) and again slightly different from the conversion factor under "Precombustion Process Energy" (0.01044). Why is this? Is it to account for different grades of coal? Providing an explanation of the conversion factors (see comment no. 2 above) may help to clarify this. Note that if the conversion factors are heat contents of coal than they also need to be consistent with the last sentence on Page3-17.

RESPONSE: The conversion factor of .01116 for combustion assumes a utility boiler while the factor of .01044 for precombustion represents a mix of both utility and industrial boilers (the factor for industrial boilers is .01042). For energy of material resource, the conversion factor of .01977 represents feedstock energy. The differences between the conversion factors will be explained in the text.

- Does the category "hydrocarbons" mean total hydrocarbons or non-methane hydrocarbons (since methane is shown separately)?

RESPONSE: The category "hydrocarbons" refers to total non-methane hydrocarbons.

Glass:

- No specific comments about the glass data sets were received.

Paper:

- The data on paper products rely on a Franklin Associated Limited (FAL) database and an Environmental Defense Fund database. It is important that these data, on different types of paper products, be consistent, and it appears as though substantial effort has gone into making the data consistent. I am concerned, however, about the differences in electrical energy consumption reported for the two data sources. The electrical consumption reported by Franklin (e.g., Table 5.3-1) is significantly larger than that reported by EDF (e.g., Table 5.4-1). Is it possible that this is due to a methodological difference? Are the Franklin data based on total energy input to the power plant while the EDF data are based on electricity usage? If not, why is there such a large difference (the other data seem comparable)?

RESPONSE: It is possible that the differences in energy consumption are due to methodological differences between Franklin and EDF. However, we were unable to pinpoint specific methodological differences based upon the information provided by EDF.

- Throughout Chapter 5 and Chapter 6 the conversion factors used to convert from fuel units to millions of BTU's are different for combustion process energy and pre-combustion process energy (e.g. Table 5.5-1; Table 6-17). These factors are sometimes as much as two orders of magnitude different. The accuracy of these factors should be checked (and if correct, the differences explained in the text).

RESPONSE: These factors will be checked and corrected as appropriate.

- Comparison of the EPA recycled office paper profile with the BUWAL data set for recycled de-inked paper indicated a difference of only 5 % in energy. The statement that "there is greater variation in other emissions, such as CO_2" therefore was unexpected since CO_2 is correlated with energy use. This could signal a difference in CO_2 accounting?

RESPONSE: There may be a difference in the method used for CO_2 account, but again, we were unable to determine if this in fact was the case based upon the information provided by EDF.

- Table 5.4.1, numbers showing against "conversion factors" for petroleum and coke for "Energy of Material Resource" should be removed to avoid confusion.

RESPONSE: Agreed. This change has been made.

- In the tables for office paper, textbook paper, magazine paper, telephone book the units for coal consumption under "Combustion Process Energy" should be lbs. not gal.

RESPONSE: Agreed. This change has been made.

Plastic:

- Throughout Chapter 6 the key plastics inventory data developed by the EPA are compared with similar data from APME, BUWAL, and sometimes the Ph.D. thesis of Steve Young. These are essentially all the same data, since all sources are based on APME and should not be compared in this manner. These comparisons should be dropped throughout the chapter. Similarly, discussions of the "representativeness" of the EPA data based on comparison with these sources are inappropriate (e.g., §6.3.5, ¶ 2, and Table 6-7).

RESPONSE: Agreed. This change has been made.

- BUWAL should be defined when first used at the beginning of Chapter 6 (§6.1, ¶ 2) as the "Swiss Agency for the Environment, Forests and Landscape" and not redefined in later sections (e.g., §6.6.1 and §6.6.3).

RESPONSE: Agreed. This change has been made.

- Where zero emissions are indicated in the tables for plastics, does this mean that the emission is in fact zero or that the parameter is not reported in the source material? It is recommended that a distinction be made between zero emissions and "no data".

RESPONSE: The data sets will be modified to distinguish between zeros and no data.

- Page 6-8. How were parameters for which no emissions were reported in the APME report (such as heavy metals in waterborne emissions) but for which emission factors existed in the energy module treated during the manipulation of the data (subtracting European energy emissions and adding North American energy emissions)?

RESPONSE: Emissions in the energy model were added to the APME data sets (after subtracting European emissions) based on the quantity of electricity consumed.

- Uncertainties introduced from back-calculating the European electricity environmental aspects out of and adding US grid results into the APME plastics data sets should be better highlighted. Franklin electricity process modules may differ from the Boustead modules used in APME that will lead to some errors. This should be stated more clearly.

RESPONSE: Additional text will be added to the plastics chapter to better highlight the uncertainties of “Americanizing” the AMPE electrical energy data.

- The generic polyethylene data set should be dropped from the report since it is not used in the DST.

RESPONSE: Agreed. This change has been made.

- Table 6.8 should be deleted because it is not comparing independent data sets. The EPA profile is derived from the APME and APME is the source for BUWAL and Young. A new table could be created showing the changes introduced by substituting the US for the European electricity grids. For this purpose, the EPA and APME data sets only should be compared.

RESPONSE: Agreed. This change has been made.

Steel:

- The raw material use data in the Steel section (e.g. Tables 7-2 and 7-7) seem to have a unit conversion problem (the reported values are extremely low).

RESPONSE: Agreed. The units have been corrected.

- Table 7-2, for Steel under "Combustion and Precombustion Process Energy" two different values are given 2.12E+02 mmBtu and 2.12E+01 mmBtu. Which is correct?

RESPONSE: 2.12E+01 is the correct value. The other value has been removed.

Database Comments:

- The database was a convenient summary of the data. I found the database easy to follow and manipulate.

RESPONSE: Thank you.

- The software could benefit from a key word search tool that covers the entire database (as an option on the main page), in addition to the Table based organization.

RESPONSE: Agreed. This change has been made.

- The goal of the source identification information should be to allow the user to find and review the original data source. Unfortunately, many of the source documents are not readily available. If, however, the information is in the public domain, I suggest that the source documents be archived in pdf or similar electronic format. These electronic versions of the source documents should be made available through the same channels as the electronic database. If the data are not public documents, then complete contact information (address and email contact information) for the sources of the data should be made available.

RESPONSE: Agreed. Although we are not able to provide electronic versions of the source documents, complete contact information will be provided.

- The section on Data Quality Indicators needs explanatory text.

RESPONSE: Agreed. Addition explanatory text about the DQIs will be added.

- The database contains both primary data (e.g., directly provided by manufacturers) and secondary (based on model calculations). . An example of secondary data would be CO_2 emissions calculated by mass balance on the carbon content of a waste component. This combination of data sources is necessary and appropriate, however, the nature of the data must be explicitly identified in the database as primary or secondary. Secondary modeled data will allow more complete estimates to be made available. However, the inclusion of modeled emission and other data should not distract resources and attention from the projects more central products, such as the DST.

RESPONSE: The database is being updated and will make an explicit distinction being data that are primary data from sources and secondary data that have been calculated based on engineering calculations in the DST. The primary focus of resources is on completing the DST and current version of the database.

- The database should contain data on bio-carbon fixed in all materials. With the addition of this information the carbon sequestration credit currently given for wood and wood products is unnecessary and should be eliminated. (See related comments under "DST Issues" in this report.)

RESPONSE: The material LCI data sets for paper are being revised to include a data value for biogenic carbon dioxide fixed in the material. However, we disagree that the carbon sequestration credit should be eliminated. We believe it is correct to include the credit to properly track biogenic carbon dioxide emissions for paper materials. For example, if 10 tons of wood is used to manufacture newsprint, potential biogenic carbon dioxide emissions would occur in the manufacturing and waste management stages of the life cycle – as a result of wood combustion or biodegradation. Thus, the carbon credit is needed to balance biogenic carbon cycle.

- The database is well designed and will be very useful. The database should be released as soon as possible after making minor corrections and improvements.

RESPONSE: Thank you. We are working to finalize the database and release as soon as possible.

- The database should contain no data (i.e., an "empty cell") when no data exist. For example, the recycled material input ratio and material substitution ratio data cells currently contain "placeholder" data where none actually exists.

RESPONSE: Placeholder cells will be removed from the database.

- Data in the database should each have a unique source identifier. Currently some data that come from different sources but appear together in the database have only one source ID (e.g., recycled material input ratio and material substitution ratio).

RESPONSE: Agreed. There were a few errors in the source ID links in the database and they will be checked and corrected.

- Some of the most useful sources should be provided in pdf format, on CD or a web site. Making source material available would be a good additional product of the project.

RESPONSE: Unfortunately, we cannot provide electronic copies of the source documents for the project data. However, full contact information will be provided for each source.

- For the Western states, the energy splits are simply too coarse. The West Coast states use very little coal energy compared with the more interior Western States. For purposes of local emissions and state regulatory purposes, these are likely to cause problems.

RESPONSE: Allow we cannot change the western states energy grid mix at this time, we have noted this issue for potential future updates to the data. In addition, the energy model allows the user to specify a "user defined" grid mix. If you have better information about the grid mix actually used, you can enter that information as the default energy grid mix.

- The Life Cycle Database is an excellent resource for disseminating life cycle inventory data for each of the unit operations in the MSW management system. In general this database is very user friendly and well organized.

RESPONSE: Thank you.

- For materials data sets, the basis of analysis needs to be provided in the column labeled units. (e.g., aluminum sheet reprocessing requires 164.1 lb of coal per ?) Should indicate the appropriate basis: lb/ton of Al (I noted that emissions data did provide the basis.)

RESPONSE: Agreed. The basis for the material data will be provided in the column headings.

- For the substitution ratio it is better to leave the data entry blank than to input a value of 1. Unity is the default value assumed in the DST but this value is not taken from a specific reference.

RESPONSE: Thank you.

- The materials resource data are labeled virgin emissions – see HDPE pellet for example.

RESPONSE: Thank you. This error has been corrected.

- For electricity generation, the database provides the emissions per unit of fuel and the fuel mix for each grid as a percentage. These data do not indicate the technology used to generate the electricity which effect the electricity production efficiency and emissions. I assume it is representative of US utility industry. Furthermore, in order to best utilize these data it is necessary to know how much electricity is generated per unit of fuel. This will depend on the technology employed. A natural gas steam boiler generating system will have a much different efficiency than a natural gas turbine. These elements are missing from the database and the accompanying documentation.

RESPONSE: Correct, the electrical energy data represent the combustion of different fuels in utility boilers and are a U.S. utility industry average. Information about the technology assumptions employed will be provided to the extent possible.

- The Database Description and Functionality Document should be improved. Currently it does not provide very much guidance to the reader. Two sets of Figures with the same numbering are included. Two identical Figure 3 titles on page 3 refer to two different diagrams.

RESPONSE: Agreed. The database guide is being updated to provide better guidance to users.

- Assumptions made in the DST should not be included in the database. The use of a material substitution ratio of one is an example of an assumption. DST assumptions such as this should be documented in the DST report, with a discussion on the implications of the assumption.

RESPONSE: Agreed. Any “assumptions” included in the reviewed version of the database will be removed.

- The "Electrical Energy Data" contains emission data for the direct combustion of various fuels as well as for the use of these fuels to produce electricity. It should therefore be renamed "Energy Data".

RESPONSE: Agreed. We will change the terminology from “electrical energy data” to “energy data.”

- The "Required Recycle Input" values in the database should be checked for accuracy.

RESPONSE: Agreed. We found a couple of errors in the recycled material input ratios. The values will be rechecked and corrected.

Case Study Comments:

- Strategic selection of case studies: The introduction to the chapter on case studies should include a discussion of the range of anticipated applications of the DST. Since not all case studies will be included in the users’ manual, strategic decisions will need to be made about which cases to include and which to exclude and the rationale for these decisions must be explained. For example, if the DST will be applied at national, regional and local levels, examples of each of these types of cases should be provided. In addition, if the DST will be used for simulating current practices, evaluating recycling scenarios and optimizing waste management strategies, then examples of each of these types of cases should be provided.

RESPONSE: Agreed. We are currently applying the DST in a variety of local, state, and national level case studies. Text will be added to the introduction of the case studies chapter discussing what we feel to be the anticipated and appropriate applications of the DST. For now, we have decided to use the case study chapter to highlight local level studies, which include simulating current practices. This is the primary application of the DST.

- Clarity and format of presentation: The DST provides a wealth of information to users, and there are a wide variety of analyses that can be performed based on that information. The point of the case studies, however, is to illustrate very specific uses of the tool, to illustrate the "real world" application of the DST. Therefore, the description of the cases should be very focussed and follow a consistent format. Each case should begin with a description of the decision that is to be informed through the use of the tool. This should be followed by a summary of how the DST was run to address the question and a description of the results. Each case should end with an interpretation of the DST output and a critical assessment of the lessons learned from the case.

RESPONSE: Thank you. We will use this recommendation to develop a consistent format for structuring the presentation of case studies.

- The chapter in the users' manual describing the case studies should include as comprehensive a discussion as possible of the uncertainties associated with the DST. The discussion should focus on the how the user can determine whether differences between scenarios are statistically significant.

RESPONSE: Agreed. We will add text as part of the case study write-ups that discuss the uncertainties associated with the DST and the specific results for each unique case study. In addition, guidance will be provided to help readers/users determine whether results of alternative scenarios are statistically significant.

- Many of the DST results can seem counter-intuitive. For example, in the Wisconsin case study, energy consumption decreases due to the implementation of recycling programs, yet carbon dioxide emissions increase (Table 5.2-3). This is counter-intuitive and it would be useful to describe how the user can understand these counter-intuitive phenomena. Note that I am not questioning the validity of these counter-intuitive results. In fact, identifying these unexpected phenomena is one of the greatest benefits of the DST. Rather, I am suggesting that the case studies describe the process a user can go through to rationalize these counter-intuitive phenomena.

RESPONSE: Agreed. We will add more explanatory text to the discussions to aid readers/users in how to go about using the model and the detailed model results to track and better understand unexpected results. In short, the DST allows the user to easily obtain more detailed information about specific processes and this information can be analyzed to identify keep parameters that are driving the results.

- The case studies included in the user's manual will play a crucial role by exemplifying the use of the DST as well as building user confidence in the accuracy and practicality of the tool. Because they serve such important purposes, the case studies should be selected with care and assiduously prepared.

RESPONSE: Agreed. Case studies to be included in the user's manual will focus on local applications, since that has always been the primary end user group.

- Strategic selection of case studies. Since only a few case studies will be included in the users' manual, strategic decisions will need to be made about which cases to include and which to exclude. For example, if the DST will be applied at national, regional and local levels, examples of each of these types of cases should be provided. Similarly, if the DST will be used for simulating current practices, evaluating recycling scenarios and optimizing waste management strategies, then examples of each of these types of cases should be provided. Case studies that use the DST for unintended purposes should not be included in the users' manual or report.

RESPONSE: Agreed. Case studies to be included in the user's manual will focus on local applications, since that has always been the primary end user group. More information will be provided in the local case studies about how current practices were simulated.

- Clarity and format of presentation. The DST provides a wealth of information to users, and there are a wide variety of analyses that can be performed based on that information. The point of the case studies, however, is to illustrate specific uses of the tool and to illustrate the real world application of the DST. Therefore, the description of the cases should be focussed and follow a consistent format. Each case should begin with a description of the decision that is to be informed through the use of the tool. The case study introduction should be followed by a summary of how the DST was run to address the question. It may be useful to describe the capabilities of the DST that were not utilized for the analysis in addition to those that were. Each case should end with a description of results including a detailed interpretation of the DST output and a critical assessment of the lessons learned from the case.

RESPONSE: Thank you. We will use this recommendation to develop a consistent format for structuring the presentation of case studies.

- The data used by the DST contain significant uncertainties that are not specifically estimated or reported. The case studies should each contain a discussion of how these uncertainties may impact decisionmaking based on the case study analysis presented. Users should be given guidance on how to estimate uncertainty when comparing scenarios and how to determine if results are significant in light of the uncertainty present in the data. It should be pointed out that even if the available data are viewed as expected values, it may not be reasonable to assume that variation will be symmetrically distributed around these values, and thus DST results are not suitable for impact or risk assessment.

RESPONSE: Agreed. We will add text as part of the case study write-ups that discuss the uncertainties associated with the DST and the specific results for each unique case study. In addition, guidance will be provided to help readers/users determine whether results of alternative scenarios are statistically significant. Text will be added to note that the DST results are not suitable for impact or risk assessment.

- The case studies selected for reporting as part of this project should be strategically selected. Case studies should be selected where the intended DST users' specific questions can be answered using the DST. Clarity and format of presentations are important. Fewer results should be reported well, rather than an overwhelming array of results

RESPONSE: Agreed. We are focusing the case study chapter on one or two local level studies and presenting fewer results in a clearer manner.

- A major use of DST is for fostering a foundation of data gathering, checking & quality control needed for any analysis and largely unstandardized or unavailable for many local agencies. Experiences along these lines from the case studies are likely to be especially useful.

RESPONSE: Agreed. Data gathering has been a challenging part of the case studies. We will add text discussing our experiences in data gathering and any useful tips that we can provide.

- I am uncomfortable with large regional and national studies. These are not the intended scales or uses of the DST and typically will require additional external analytical work. Such studies might be appropriate uses of the DST for special cases, but such cases should be avoided for this project, illustrating typical and intended uses of this software. Stick with cases focused on intended model uses.

RESPONSE: Although there are a few special cases where we have used the DST to support regional and national level studies, such studies will not be used for illustrating the typical use of the DST. Instead, emphasis will be placed on more local-level studies.

- Case studies include examples of DST use that go outside the bounds of the intended use of the DST. While it is tempting to try to use the DST for any and all purposes that potential clients propose, ORD should resist this temptation. The tool already has limitations even for its intended use as an integrated waste management decision tool. Those limitations grow dramatically when trying to apply the tool to create air quality strategies or strategies to reduce toxic chemical exposures. The data in the tool simply cannot support these tasks in a meaningful way. At a minimum, the inability of the tool to distinguish between local and regional or national impacts (for example, from recycling activities) means that a local government cannot use the tool as a basis for deciding how to reduce NOx or other emissions. Case studies should be confined to integrated waste management cases.

RESPONSE: Again, although there are a few special cases where we have used the DST to support regional and national level studies, such studies will not be used for illustrating the typical use of the DST. Instead, emphasis will be placed on more local-level studies. In addition, the limitations associated with local versus global emissions are noted in the limitations sections of the DST user's manual.

- Case studies should be presented using a uniform template. The current case studies do not clearly state the "design problem." They do not clearly state the baseline scenario. They do not clearly show how the decision tool helped identify alternative scenarios. Specifically, the case studies should also indicate not just how the tool was used but should identify what the most simple needed calculations were and where default data were adequate. This would help potential users get a better understanding of how much detailed new inputs they would have to generate to use the tool.

RESPONSE: Agreed. We will use the recommendations from the peer review to develop a consistent format for structuring the presentation of case studies. We will also present some of the calculations and community or default data used.

- Case studies should clearly indicate the limits of identifying global versus local impacts.

RESPONSE: Agreed. This limitation is addressed in the "limitations" section of the user's manual and will also be addressed in the case study chapter when discussing the use of results.

- Application of the DST to specific case studies can serve several functions: 1) demonstrates the capability for a real MSW system, 2) highlights special features of the DST, and 3) instructs the audience on how to use of the DST. The project team has initiated a wide range of case studies each with unique objectives and circumstances. At the time of this review these case studies were in different stages of completion, but a significant number are now available for reporting. Given the overall complexity of the DST it is recommended that case studies be organized in levels of increasing complexity. The DST Users Manual includes a generic community and these case studies serve to compliment this example. Real cases are more effective in convincing users about the utility of a tool.

RESPONSE: At the time of the review, real case studies, although being conducted, were not complete. The DST users manual is designed to contain a generic community example as well as case study examples. We will add the case study examples as they are completed.

- The case studies should indicate to users that the total life cycle emissions computed are not limited to a community or regions. Emissions associated with electricity production, upstream transportation fuel production, and materials production offsets for recycling are often likely to occur outside of the local boundary. The DST and LCA data in general do not permit an accurate spatial and temporal analysis of emissions and other environmental aspects.

RESPONSE: Agreed. The results presented by the DST represent "global" emissions. Presentation of case study results will clearly note where there are emissions occurring outside of the community or region.

- Uncertainty analysis in LCA is currently very limited given the lack of data on confidence intervals and other quantitative data quality indicators. Although the DST doesn't generate uncertainty estimates, this topic should be raised in the case study report. Users need to appreciate this limitation. LCA models are constructed using best available data that is often limited to single data points. Nonetheless, our understanding is that the DST output with its uncertainty will lead to better decisions than planning and decision-making activities not utilizing the DST.

RESPONSE: Agreed. Conducting a formal uncertainty analysis given the current LCA information available is difficult if not impossible. Text will be added to the discussion of case study results to caution the reader about uncertainties in the DST and underlying data when interpreting results.

- The discussion of the results needs to be expanded clearly linking the inputs to the DST and the results.

RESPONSE: As part of the full case study reports, information about which data inputs were provided by the community is included. However, these were not included in the case study summaries to keep them short and concise. We will direct readers to the full case study reports to obtain all the information about community inputs and highlight any significant inputs that governed results in the summaries.

- Wherever possible, the way in which the results of the case studies are being used by the waste managers should be highlighted.

RESPONSE: Agreed. As the case studies are completed and their results used by waste managers, this information will be added to the case study discussions.

Wisconsin Case Study:

- The purpose of this case study was to assess the environmental aspects of additional recycling in Wisconsin for 2000 compared with 1995. The major results of this case study were presented in Table 5.2-3. The headings used in this table made understanding and interpretation of results difficult. "Net decreases" and the negative values led to some confusion, which can be easily remedied. The analysis and results should be qualified by indicating that waste generation rates and waste composition changed over the five-year period and therefore not all differences can be attributed to increases in recycling rates.

RESPONSE: Yes, the tables are difficult to understand because for some parameters there was a decrease in emissions over time, while for others, an increase. In addition, the reviewer correctly noted that because waste generation and composition also changed over time that it is difficult to attribute all decreases in emissions to recycling. These finer points will be added to future discussions of case study results.

- The waste management options modeled in the Wisconsin Case Study included backyard composting. Since the model does not contain a backyard composting module, it was modeled as a compost facility with zero processing energy/costs. By doing so the researchers extended the boundaries of the DST to within the household before waste is placed at the curb. In the interpretation of the results this should be noted together with the fact that other waste management activities which occur in the household such as the washing of containers before being placed in the recycling box are not considered. In addition, it should be noted that the emissions from backyard composting where the level of aeration would typically be lower may not be fully represented by the approximation to a compost facility.

RESPONSE: Agreed. To develop information about backyard composting, we needed to use the DST creatively. This use entails assumptions and limitations, as the reviewer correctly noted, and these will be added to the presentation of results.

Great Lakes Region Case Study:

- The "Great Lakes" case examines toxic releases from MSW management and material recovery. Because the DST was not intended to model toxic materials, this may not be a desirable case study to include in the report. In any case, I have some questions about how the case study results are computed and presented. Landfill emissions in the DST are, in my understanding, computed as totals over the user selected landfill life. However, in this case landfill emissions of toxics are reported in units of lbs/yr (e.g., see Fig. 1.5). The landfill releases shown may be total releases over the landfill life. The appropriateness and correctness of this presentation of landfill emissions should be checked. Also in the "Great Lakes" case, the legends of several figure (e.g., Fig. 1.2) describe toxic "releases" but the figures show toxic "savings" (i.e., offsets).

RESPONSE: Agreed. We are not going to highlight this case study in the user's manual because it is not what we consider to be a typical use of the DST. For landfill emissions, they are calculated based on a user-specific time frame (20, 100, or 500 years). These calculated emissions are then reported as lb/yr to be comparable to the emissions from other waste management options. We are currently re-running the Great Lakes study with more recent data and will modify the figures accordingly.

- The results presented for this case study need to be verified. In addition, a section needs to be added that will discuss the various results. Several results could not be explained and appeared to be in error. In particular: high dioxin emissions from the MRF in Figure 2.8, high lead emissions from composting in Figure 4.5, and high cadmium emissions from composting in Figure 4.6 are questioned. It would also be valuable for users to identify specific sources within a system that are responsible for unexpected results. An example showing how the user would carry out such an analysis would be valuable. It's also recognized given the sophistication of the DST the user may not have the expertise required for pinpointing key sources.

RESPONSE: We are re-running the scenarios for this study based on more recent data that we have acquired. We will also track and verify the unexpected results noted and modify as appropriate. Our process for doing this will be documented as a guide for users.

METHODOLOGICAL ISSUE COMMENTS:

Source reduction: ***(See overall response below)***

- Source reduction can be an important solid waste management strategy and therefore the DST must be able to characterize, as accurately as possible, the costs and benefits of source reduction, relative to the costs and benefits of other waste management strategies. Currently, the DST accounts for the end-of-life benefits of source reduction, i.e., if source reduction reduces the flow of municipal waste, then the DST tracks the cost and environmental benefits of that reduced waste flow. Currently, these are the only cost and environmental benefits of source reduction tracked by the DST. There was extensive discussion of whether additional cost and environmental benefits of source reduction should be evaluated by the DST. In particular, the question was raised about whether the DST handles recycling and source reduction in a consistent manner. The DST calculates environmental offsets for virgin material resource use avoided by recycling yet it does not calculate similar offsets for source reduction. I recommend (consistent with panel discussions) that the DST not attempt to characterize offsets for source reduction. Although, in principle, this underestimates the potential benefits of source reduction, it is not possible to accurately estimate offsets associated with source reduction. A source reduction strategy may involve material substitutions, changes in manufacturing practices and other phenomena that would be extremely difficult to calculate offsets for. Since the source reduction offsets cannot be accurately estimated, I recommend that the DST not attempt to characterize these offsets. Rather, I recommend (consistent with panel discussions) that the DST treat source reduction by estimating end-of-life (waste management) benefits and alert the user (qualitatively) that there may be additional benefits that are difficult to quantify.

- Source reduction can be an important solid waste management strategy and therefore it is desirable for the DST to be able to characterize, the costs and benefits of source reduction, relative to the costs and benefits of other waste management strategies. Currently, the DST accounts for the end-of-life benefits of source reduction, i.e., if source reduction reduces the flow of municipal waste, then the DST tracks the cost and environmental benefits of that reduced waste flow. Currently, these are the only cost and environmental benefits of source reduction evaluated by the DST. During the peer review there was extensive discussion of whether additional cost and environmental benefits of source reduction should be evaluated by the DST. I recommend (consistent with panel discussions) that the DST not attempt to characterize offsets for source reduction. Although, in principle, this underestimates the potential benefits of source reduction, it is not possible to accurately estimate offsets associated with source reduction using the DST. A source reduction strategy may involve product specific material substitutions, changes in manufacturing practices and other behaviors for which it would be extremely difficult to calculate offsets. Since the source reduction offsets cannot be accurately estimated, I recommend that the DST not attempt to characterize these offsets. Rather, I recommend (consistent with panel discussions) that the DST treat source reduction by estimating end-of-life (waste management) benefits and alert the user that there may be additional benefits that are difficult to quantify and that are not assessed by the DST.

- Source reduction is an important topic with implications for waste management, but really deals with waste generation. The waste management aspects of source reduction are already included in the DST. End-of-life offsets and costs are already included.

- The model does not include upstream offsets for source reduction. This would require product life-cycle analysis for each potential source-reduction alternative, a potentially intractable problem and not well suited to the waste-life-cycle approach of the model. It seems to me that a more promising approach would be to use the DST to handle the waste portion of product life cycles, with upstream source reduction offsets calculated separately as part of product life-cycle analyses. Source reduction has become a distraction from completing the valuable aspects of the DST and should be considered for more extensive treatment in a separate effort. The source reduction issue should not hinder release of the DST or its related databases. It might be valuable to local users to have an illustrative and simple application of the DST to handle the waste portion of a source reduction action, supplemented with a separate simple upstream analysis. One particular methodological limitation is in the treatment of source reduction. The decision support tool includes both upstream and downstream environmental dimensions for recycling activity. For source reduction, only downstream—waste management—effects are included. This presents a substantial—and possibly irremediable—challenge. This asymmetry between how recycling and source reduction are handled may disadvantage source reduction as a waste management option, since only its downstream benefits are calculated. However, it is not at all clear how one would overcome this asymmetry. Let me briefly explain this challenge. In the case of recycling, one has some means of establishing a baseline case against which to compare a recycling scenario. The baseline case is the prevailing manufacturing process to produce the standard virgin product output. (Note that in some instances, such as in steel making, the baseline would be the BOF production system that uses around 25 percent scrap in the standard feedstock mix.) The recycling option assumes some specified level—from a few percent to 100 percent—recycled content. One is able to compare materials commodities—aluminum sheeting, linerboard, and so on—that, in turn, are used to make hundreds of distinct products. In the case of source reduction, no baseline materials-use case can be established nor is there a single source-reduced alternative against which to compare some baseline in many cases (there are a few exceptions to this general point). Source reduction often involves changes in the individual product, not in the material feedstocks. A juice producer, for example, may currently sell product in a glass container. In exploring source-reduction options, the juice producer may explore the relative merits of a two-way returnable system, substitution of glass with an HDPE plastic container, substitution into an asceptic packaging system, lightweighting of the glass container, reformulation of the juice to a concentrate form in a frozen spiral-wound paperboard container with metal ends, and so on. An individual manufacturer wishing to source reduce—and evaluate the environmental loadings of different options—could perform an LCI using their particular product and package system as the baseline and then contrasting that to a finite set of alternatives. At the macro-level of a local waste manager, one is faced with thousands of individual products (over 30,000 in the typical grocery store; 60,000 in a “superstore”). To offer an even modestly meaningful upstream assessment of source reduction benefits, one must know the individual product loadings at point A. One would then need to know in what ways these various (thousands of) products would be source reduced—through lightweighting, materials substitution, returnable systems, and so on. Clearly, this is not a set of calculations within the scope of the decision support tool. What the tool does do, and which offers some utility to the waste manager, is enable the user to calculate the downstream benefits that accrue from having less waste generated through a source reduction program. This can be tailored to material or waste category—for example, one could evaluate the downstream implications of a vigorous program to promote mulch mowing and leaving grass clippings on the lawn. Still, one is left with the upstream asymmetry relative to recycling. One possible option would be to provide several case studies that took specific source reduction efforts—such as use of returnable pallets or promotion of double-sided paper copying—and present an comparative LCI for these options over the standard alternative (in the examples here, one-way pallets and single-sided copying). These case studies could be drawn from existing LCI research efforts that have examined various source-reduction options. However this asymmetry is handled, the decision support tool manual and other documentation should clearly identify this limitation.

- This project focuses on the management of MSW from a community -- given certain amount and composition of waste generated how should it be managed. Source reduction is an important strategy that eliminates the generation at the upstream from waste management. It is not realistic to provide source reduction modeling capabilities in this project. Source reduction analysis requires full product life cycle analysis. It is not possible to develop unit operations that describe all life cycle stages for all products with this project. Source reduction modeling should use product function as a basis of analysis. The functional unit in this project is a quantity of MSW to be managed. The merits of source reduction are documented in the DST report and can also be reemphasized in the case study documentation. The DST has the capability of evaluating the end of life management implications of a source reduction only.

- I agree with the peer review team’s comments on source reduction. However, I do think our Peer Review team’s comment, minimizes the political reality of needing to incorporate the Office of Solid Waste (OSW) into this process. Bottom line, the OSW is essential to ensuring that this tool is used in the solid waste industry. I understand that the Office of Research and Development has really attempted to work with OSW on this issue. Nevertheless, I strongly endorse incorporating the use and environmental benefits of simple source reduction activities such as two-sided copying, in the report. Additionally, I believe it is worth explicitly stating the importance of further research and the value of incorporating source reduction into the model as a prioritized next step.

- Of all the waste management strategies available, source reduction or the production of less waste in the first place clearly represents the best alternative. Source reduction encompasses a wide range of activities ranging from decisions by householders to reuse items within the home, through to product design decisions involving lightweighting of packaging and material substitution made by manufacturers. It is thus extremely difficult to capture the effect of the full spectrum of source reduction activities in a decision support tool for waste management. It can be argued in fact that each product design modification (including those that fall under the broad category of source reduction) warrants an LCI study of its own. The DST like the majority of other LCI models for waste management currently accounts for the "end of life" benefits of source reduction, as manifested in terms of the changes in the quantity and quality of the waste that appears at the curb. The other benefit of source reduction is the avoided production of the item that has been eliminated from the waste stream or "offsets". The DST already contains data can be used to estimate the offsets up to the point of material manufacture (used to calculate offsets for recycling). However, it does not contain data on the burdens associated with the fabrication, use, and maintenance of the item that has been eliminated and cannot provide the full effect of source reduction. It is recommended that this limitation of the DST with respect to evaluating the effects of source reduction clearly be explained in the project documentation. It should also be noted that the "current state of the practice" with respect to the application of waste management to LCI is to draw the system boundary from the point of waste production (typically, the curb) to the point of final disposition. Source reduction activities lie outside this boundary.

RESPONSE TO SOURCE REDUCTION COMMENTS: The DST currently does not allow a user to evaluate the full benefits of source reduction. The DST does allow the user to modify the waste generation and composition input data (based on externally calculated source reduction potentials) and calculate the potential cost and LCI benefits realized from the waste management system. However, potential upstream (i.e., raw materials extraction and processing, materials manufacturing) benefits are currently not captured.

One reason why the upstream benefits associated with source reduction were not implemented in the DST was because the system boundaries were defined to start with waste set out at a curbside or dropoff collection site. Thus, activities such as backyard composting, source reduction, and manufacture of collection bags and recycle bins were outside of the boundaries. This boundary was selected based on recommendations from the project peer review panel.

A second reason why the upstream benefits associated with source reduction were not implemented in the DST was because the project peer review panel felt that to adequately evaluate source reduction, a life cycle model of materials manufacturing operations was required. Since we were only using existing data and not developing models for the materials manufacturing operations, it was felt that we could not adequately model source reduction. The view of the peer review panel was consistent with the recommendations of the project team based on careful and detailed consideration of this issue.

LCI data are used in the DST to calculate the potential LCI benefits of recycling. These same data can also be used to obtain rough estimates of potential LCI benefits resulting from certain source reduction activities.

Source reduction activities that ***can*** be handled in this manner include:

i) Reduction in the use of a specific materials through product redesign or lightweighting.
ii) Substitution of specific materials for others (applies only to those materials for which we currently have data).

For material reductions through product redesign or lightweighting, if the redesign of an aluminum can reduces the amount of material used, then we would calculate the LCI benefits associated with the smaller quantity of aluminum used. The quantity of source reduced aluminum would have to be estimated by the user. Note that the user would also need to evaluate whether any significant changes were made in the production process to accommodate the new design. If significant changes are needed, then it is more appropriate to do a full LCI of the new process.

For material substitutions, we can only handle scenarios for which we currently have manufacturing LCI data (aluminum, glass, paper, plastic, steel). As an example, we have data to calculate the LCI benefits (or additional burdens) associated with replacing a defined quantity of aluminum with PET. However, we cannot calculate the LCI benefits (or additional burdens) associated with replacing a defined quantity of aluminum with a wood-plastic composite because manufacturing data for this composite material is not currently in our data set.

Source reduction activities that ***cannot*** currently be handled by the DST include:

i) Substitution of specific materials for which we do not have manufacturing LCI data.
ii) Backyard composting (no data to support emissions from backyard compost or substitutes such as fertilizers and pesticides).
iii) Household reuse of materials (no data to support emissions from household processing of materials, such as washing).

In addition to the effects that source reduction may have on the LCI component of the DST, there may also be a cost outlay from the local government to promote and educate others about source reduction. Therefore a cost factor will need to be assigned to source reduction.

To implement source reduction in the DST will require that a spreadsheet be developed for user to input the quantities of specific materials source reduced. The user will then need to appropriately modify the waste generation and composition input data.
The DST can then be rerun to find optimal solutions for the new quantity and composition, while also calculating the LCI benefits of the user-specific source reduction. We suggest that the benefits of source reduction be presented separate (or side-by-side) to the overall DST solution.

Implementing source reduction in the above manner in the DST will require the following modifications to the DST:

i) Add an input worksheet for users to specify the mass of materials source reduced. Also add a note to users to be sure to adjust the waste generation and composition input data appropriately based on their specified level of source reduction
ii) Add a worksheet for calculating the LCI benefits of source reductions.
iii) Add a box in the user interface so the user can view the LCI benefits estimated for their specified level of source reduction.

By implementing the changes described above in the DST, we will enable users to generate a rough estimate of source reduction benefits and compare source reduction benefits to the cost and LCI of the waste management system. The approach we are proposing to evaluate source reduction is consistent with that used in EPA's Waste Reduction Model (WARM).

Carbon Sequestration: ***(See overall response below)***

- One of the potential uses of the DST is to evaluate fossil and non-fossil based emissions of greenhouse gases, and the sequestration of carbon. The use of the model for this purpose requires the tracking of fossil and non-fossil emissions of carbon and the tracking of non-fossil carbon in products in the underlying data for the DST. Currently, the DST and the underlying database separately track fossil and non-fossil carbon dioxide emissions and treat non-fossil carbon in products as non-fossil carbon dioxide emission credits. Methods for crediting carbon in products are controversial and a number of alternative methods for crediting this sequestration were discussed. It is likely that different groups will seek to use different methods for crediting carbon in products, therefore, I recommend (consistent with panel discussions) that the DST and the underlying data be made compatible with <u>multiple</u> approaches to crediting carbon sequestration. This will require <u>separate</u> tracking of non-fossil carbon dioxide emissions and non-fossil carbon in products in both the DST and the underlying database. With this information, users of the DST should be able to use either a default method for crediting carbon in products or a method that they input. I have no recommendation regarding what the default method of handling carbon sequestration should be, but I strongly recommend that the DST allow the user to have the option of defining a method for handling carbon sequestration.

- One of the potential uses of the DST is to evaluate the global warming potential associated with different MSW management strategies. The use of the DST for this purpose requires the tracking of fossil and non-fossil emissions of carbon and the tracking of non-fossil carbon in products in the underlying data for the DST. Currently, the DST and the underlying database separately track fossil and non-fossil carbon dioxide emissions and account for non-fossil carbon held in products as non-fossil carbon dioxide emission credits. Methods for crediting carbon in products are controversial and a number of alternative methods for crediting this sequestration were discussed. It is likely that different groups will seek to use different methods for crediting carbon in products, therefore, I recommend (consistent with panel discussions) that the DST and the underlying data be made compatible with <u>multiple</u> approaches to crediting carbon sequestration. This will require <u>separate</u> tracking of non-fossil carbon dioxide emissions and non-fossil carbon in products in both the DST and the underlying database. With this information, users of the DST should be able to use either a default method for crediting carbon in products (such as currently employed in the DST for wood and wood products) or a method that they input. If pressed to endorse one of the two methods currently employed by different branches of the EPA for crediting carbon sequestration, I would recommend the method of the Office of Research and Development and currently implemented in the DST for wood and wood products. This method is consistent with the way carbon is tracked throughout the DST model. However, by tracking all bio carbon fixed in materials, the need for any sort of "credit" is obviated.

- On the scale of the entire project, the carbon sequestration issues we have seen seem minor. The panel has collectively arrived at the following recommendations:

    a) Separate bio-CO2 emissions and bio-Carbon fixed in products in database. This will allow the user overriding any defaults to perform carbon sequestration caculations as they see fit.

    b) Add DST text on difficulties and controversies. This issue is not clear, and the alternatives and controversies should be laid out. I think this might belong in an appendix.

    c) The current ORD representation of carbon sequestration seems to make the most conceptual and theoretical sense.

    d) We prefer USEPA to come to some agreement, rather than having different EPA offices supporting different methods.

- Carbon sequestration is a complex issue and makes carbon accounting difficult. On one level sequestration is easy to understand -- trees fix carbon and release it during combustion. Paper products also yield carbon dioxide (predominately) upon combustion and their decomposition in a landfill produces a mix of carbon dioxide and methane. The proposed modeling approach is consistent with this overall set of processes. In the case of recycled paper, no carbon dioxide is sequestered in the process of making new paper from secondary sources. Recycling paper, however, does avoid the generation of carbon dioxide or methane from the combustion and landfill disposition of waste paper. The proposed OSW model is less favored although the offset analysis would apparently lead to the same end result. The ORD model better defines the actual carbon flows. The report should also indicate that the methods of forest management also will influence the overall carbon balance. After trees are harvested the remaining biomass will begin to decay and release carbon back to the atmosphere. This phenomenon is difficult to model.

- It is now widely accepted among practitioners that in evaluating the impact of recycling on the environment the "offset" or "avoided" burden associated with the manufacture of virgin material should be considered. In the case of paper recycling, the manufacture of virgin paper, which starts with forestry, should therefore be considered. Forestry entails the planting and harvesting of trees for the production of pulp. Trees grown for paper production, absorb CO_2 during their growth, thereby fixing a certain amount of atmospheric carbon (some of which may later be released during the paper production process when for example the bark (hog fuel) is combusted for energy). Thus, in calculating the net release of CO_2 from the production of virgin paper the amount of CO_2 fixed during the forestry stage should be subtracted from the <u>total</u> CO_2 released during the rest of the paper production process. If it is assumed that the forestry is sustainable, the amount of CO_2 fixed at the forestry stage will be a positive number; if it is not, it will be a negative number. Using this approach, it does not matter whether the CO_2 released from the remainder of the paper production process is biogenic or fossil. In fact if a distinction is made for the purpose of assigning a GWP of zero to the biogenic emissions, then this will result in double counting. (A GWP of zero is given to biogenic emissions to account for the fact that CO_2 is absorbed during the production of biomass, thus if it is released later it represents a net zero emission). The main difficulty associated with this approach is the estimation of the amount of CO_2 fixed during the forestry stage. To overcome this difficulty, a number of LCI studies have used what may be viewed as an approximation. CO_2 fixed during the forestry stage is not accounted for but instead biogenic emissions during the remainder of the paper production process are assigned a GWP of zero. Based on the analysis above, it follows that the difference between the ORD and OSW methods lies not in the fundamental approach (both attempt to account for CO_2 emissions during the forestry stage), but in the assumption of sustainability. The ORD approach implicitly assumes that the forestry is sustainable, thus uses a positive value for CO_2 fixed during the forestry stage, while OSW assumes a net decline in forests, and thus uses a negative value for CO_2 fixed during the forestry stage (which translates into a 'credit' for recycling).

- If we were to do a life cycle of a carbon atoms on the earth, we would see a mass balance. Carbon is in the air as carbon dioxide, it is incorporated in the biomass of plants, which then decay and release that carbon as carbon dioxide. There is a small fraction of carbon in other forms such as methane but this eventually degrades again to the lowest energy form of carbon. The only carbon that can increase the carbon dioxide in the atmosphere is carbon originally captured in fossil fuels. Thus the only carbon that should be included the DST as an environmental cost is the carbon dioxide emitted from the combustion of fossil fuels. The sooner this can be straightened out the better.

RESPONSE TO CARBON SEQUESTRATION COMMENTS: Based on the comments we received from the peer review we have decided to keep our data as is. There currently is a lot of debate about carbon sequestration and how to properly track carbon emissions and carbon storage/sequestration. Should a widely agreed upon approach be reached that is different from our methodology, then we will work to modify our methodology and revise the data sets accordingly. Note that the only material for which carbon sequestration is an issue is paper.

DECISION SUPPORT TOOL COMMENTS:

- To repeat a primary recommendation from the previous peer-review: The primary mode for early applications will be simulation, using the software to model existing system configurations and specific sensible or proposed modifications to current facilities and policies. This is necessary for the software to develop local credibility and is conceptually straight-forward for local users. This simulation capability must be made the primary mode of use before the software is released. Furthermore, simulation must be the primary mode described in documentation and software. The current software can reasonably be adapted to operate in simulation mode.

  As a digression, there are four levels at which this software can be used:

  a) Data collection and organization: This entails local users collecting, organizing, and documenting their data and understanding of the system. Even if no models are run, the systematic collection and review of local data is likely to be of immense use for local operational and planning purposes.

  b) Simulation of existing and sensible alternatives: This mode of use essentially uses the software to examine specific alternative strategies for facilities and operations at the preliminary planning level of analysis. The advantages of this mode compared to contemporary "analysis" is the greater transparency, consistency, speed, ability to replicate, and even-handedness of the model's analysis. Simulation is likely to be the main use of this software. Most users will gain confidence and understanding of the software through simulation.

  c) Optimization: Optimization mode suggests promising and often innovative configurations and designs for MSW systems. This is the mode that the model is currently explicitly designed for and entails the software automatically developing an integrated solid waste management system design which is highly promising for achieving a formally stated objective (such as cost minimization or diversion maximization). Optimization capability is a major advantage of the current software, allowing users to find promising and innovative solutions that achieve explicit objectives.

  d) Modeling to Generate Alternatives (MGA): Often several very different physical solutions are available to obtain very similar technical and environmental performance. The current software supports an MGA mode of analysis that identifies a wide variety of solutions that achieve similar performance. This is an extension of optimization, and is likely to be a well-used feature for experienced users.

These levels of use are likely to be sequential, so it is important that the early levels of use be the most thoroughly supported.

RESPONSE: Thank you and we will incorporate this discussion of uses in the users manual and other appropriate project documentation. Regarding simulation, we start all case studies by developing a baseline of current conditions. This is simulation and it will be highlighted to a greater extent as the primary mode of use.

- Most municipal MSW services involve a substantial and often dominant role for contracted private MSW services. Over half of all disposal capacity and a substantial portion of waste collection is provided by the private sector. Local public works officials do not have access to private-sector data that may be key to using the DST effectively. Some discussion of options for handling private contracting information must be included.

RESPONSE: We agree that there is often a significant role for contracted private MSW services in municipalities. Currently, the DST models cost as though it accrues to the local government. We will look into ways for the user to address private services and provide recommendations. For example, one suggestion that we've had from our stakeholders is to use the DST as a means to develop information to review private contract proposals.

- As stated in the previous peer review, more residential sectors are needed.

RESPONSE: In working through case studies, we have not found the 2 residential sector limitation a significant problem. However, more residential sectors would allow for greater modeling flexibility and it is something that we have on our list for future improvement.

- Commercial waste generators also need to be able to produce yard and other waste categories.

RESPONSE: Thank you. We have added this to our list as an item for future improvement.

- Separate local from non-local emission and offset results. Eventually, there will be a need to separate (albeit necessarily imperfectly) local from global offset results.

RESPONSE: Thank you. We have added this to our list as an item for future improvement.

- The decision support tool, while potentially useful to improve integrated waste management decisions, has four notable limits or constraints:

    a) **Module Options Are Too Constrained**. Users are confined to two single-family residential, two multifamily residential, and a number of commercial program categories. Many large cities have multiple different residential districts that range from high-density single-family, to medium-density suburban, to peripheral, near-rural suburban densities. Moreover, many cities have wide demographic variations that affect waste generation rates and discards composition. The tool can be juggled to accommodate these variations, but only with some difficulty and with some intransigent limits. This constraint needs to be rectified over time by reprogramming to allow more residential programs.

    b) **Commercial Category Is Asymmetric with Residential Categories.** Unlike the residential sector categories, the commercial category does not allow the user to enter data for yard waste. This is a substantial and unrealistic limitation. The commercial waste sector includes institutions, industrial or commercial parks, and so on. Many of these facilities are located on campus-like settings, or, at a minimum, have landscaping around buildings and walkways. The current DST offers no prospect for including this yard waste in the analysis unless one designates one of the residential modules as commercial. This is an inadequate remedy, since the number of residential modules is already constrained. This constraint needs to be rectified over time by reprogramming to include yard waste as a variable in the commercial categories.

c) **Waste-handling Options Are Too Limited.** Materials destined for recycling are assumed to enter a modified "closed-loop" cycle. This assumption is less constraining for metals and paper, since the "closed loop" endpoint selected for inventory assessment purposes for these materials is the pre-conversion metal sheeting, linerboard, and paper rolls rather than a designated set of final consumer products. For glass, however, for understandable technical reasons, the inventory assessment uses glass containers as the assumed end product for purposes of LCI analysis. As municipalities struggle with challenges of mixed glass handling, long-distance shipping, and other constraints, many communities are diverting their recycled cullet to transportation and other construction uses. The LCI for such uses is likely substantially different from and LCI for glass container production. This limitation will give end users an inaccurate picture of LCI outcomes for glass recycling. This constraint needs to be addressed in the relatively near future.

d) **Important Waste-stream Subsets Are Not Included** in the Data Sets or Decision Tool. The decision tool includes no data or modules for analyzing construction and demolition debris. Many local waste managers include this waste category in their waste collection and disposal programs—at least at the household level. A growing number of cities have waste diversion programs for these materials. The decision support tool does not provide a means of evaluating options for the handling of this waste category. This constraint will limit the general utility of the decision support tool and should be addressed in the near term.

RESPONSE: Thank you. Although we have not found that the existing options provided by the DST have created significant problems, adding more options and waste streams would make life easier and we have added these our list as items for future improvement.

- The DST and supporting data do not include some key environmental aspects—such as habitat or landscape transformation—that may be key decision variables. This is not a fatal flaw, since the tool is a support tool, not the generator of a final decision. Local officials can supplement information from the support tool with other relevant factors in making the final decision. However, this constraint should be noted in the manual.

RESPONSE: Environmental aspects such as habitat alteration and landscape are currently not part of the DST but may be key decision variables to municipalities, as the reviewer notes. In cases such as this, wee suggest (as does the reviewer) that the municipality supplement the DST information with information about other key decision variables that are not modeled by the DST. We will note in the users manual and other project documentation that the DST that other key information, outside of the DST results, may be needed when evaluating waste management strategies.

- Decision Support Tool Use: The tool needs additional work to provide greater utility.

RESPONSE: Work is continuing on the DST to make it more user friendly. For example, two specific items that are being added to the DST is the capability to graphically display mass flows and the side-by-side comparison of results from multiple scenarios. Additional improvements will be made as funding permits.

- The DST should be modified to provide a print out of input data, changes, and assumptions for each running of the model. This will allow users to track and recall what the inputs and assumptions were that led to different outcomes.

RESPONSE: Users can currently print out the input data sheets. However, this would create a pile of spreadsheets about an inch thick. We are working to devise a way to automatically print only those data sheets that have been modified so that users and reviewers can more easily see what the input data and assumptions are behind different scenario results.

- Additional tests would be valuable to communicate the potential economic benefits that the solid waste manager could incur by using LCA. The peer review committee pointed out the need for symmetry between residential and commercial waste categories. In my opinion, all material types, not just yard waste, need to be available to enter into either of the generator categories. This is essential since over 50% of most community municipal solid waste is commercial waste. Additionally, several more residual factors need to be available for the solid waste managers? use in the model. I would suggest at least 6. Finally, changing the word "sectors" to "generators" would be more understood by solid waste managers.

RESPONSE: Thank you. Making the residential, multifamily, and commercial sectors symmetrical in terms of waste categories is an item we have added this to our list of future improvements. We are deciding upon a new term besides "sectors" to use so that it is better understood. Using the term "generators" is a good option.

- The model needs to develop additional sensitivity to allow for the situations when the government contracts for services with the private sector and therefore does not know the actual full cost of the services they are contracting for. Contracting for solid waste service is and will likely continue to be more and more prevalent. As for updating data and the model, obviously this is an industry with rapidly changing technology and various diversified material types and complicated packaging, processing and recovery issues. Therefore it will require regular updating or become obsolete.

RESPONSE: We are currently looking at privatization issues such as this noted by the reviewer as part of our case studies. Guidance will be provided to the DST user as to how to handle such issues. In regards to the need to update the DST, we agree and are working to establish a mechanism to regular updates to the data and model.

- The DST is able to calculate the financial cost and the environmental cost for an almost infinite number of solid waste management alternatives. The fact that it can calculate both types of costs is its single greatest attribute. But the interests of the users varies in how much they care about one or the other. A local agency, for example, will care very much about the financial cost, and would view the environmental cost as secondary. I can see the local town council asking the environmental question, but I cannot see the council deciding on a specific alternative based on global environmental effects. In contrast, should this model be used by some super-national agency such as the United Nations, their interest will be strictly environmental, and they will try to convince local governments to initiate programs that have the least environmental cost, with little regard for the financial cost. Perhaps you or your contractors should do some thinking about just who the users will be and address this in different publications.

RESPONSE: One of the greatest values of the DST is its ability to illustrate the interconnectedness of waste management activities as well the ability to illustrate tradeoffs between cost and environmental objectives. We believe that the DST can be used to create MSW management strategies that result in cost savings *AND* environmental improvement. The two goals aren't always mutually exclusive and our intent is to promote the use of the DST with these two aspects in mind to create sustainable waste management strategies.

- SI units are needed.

RESPONSE: Thank you. We have added this to our list as an item for future improvement.

COMMERCIALIZATION COMMENTS:

****Note: no responses have been provided to these comments. Peer reviewers were asked for their thoughts and recommendations regarding commercialization of the research products and these are their comments.**

- Having developed and used a number of menu-based software packages I feel strongly that such software should have an introductory "splash" screen that introduces the user to the software and gives some basic guidance on its use. This first screen should inform the user that the tool is run from the menus that appear at the top of the screen and direct the user to any available electronic Help facility as well as reference available documentation (which always seems to get separated from the software).

- My experience in developing and distributing a somewhat similar MSW planning tool was that many users are intimidated by the many adjustable parameters that are incorporated in the model. These users are often at a loss as to what model parameters are important to modify so that the model will represent local conditions and those that can be safely left as default values. Thus it is very important to provide the user some guidance in this area. Ideally, the documentation would contain a discussion of output parameter sensitivity that included a list of parameters that should be examined for local accuracy in all cases and others that should be examined if certain local conditions prevail. The inverse of the above comment is also sometimes true. Users often fear that they have not correctly modified this type of model to represent their local system, particularly if they have had to adjust many parameters to properly simulate current operations. User confidence can be enhanced if they are told which model parameters generally do not need to be modified.

- The development of a business plan, and contingency business plans, will be important to the successful deployment of this product. The peer-review panel individually and collectively provided many suggestions along these lines. A wide range of options should be explored and data updating and support are essential to long-term utility. The software needs a name as part of this process; the specific name is less important than providing some name.

- Key parties for the successful deployment of these software are:

    a) **The States:** State agencies have the wherewithal and regional accountability to maintain data and, through their regulatory roles, provide incentives for standard collection and use of data and model analysis. The States have a moderate amount of money and variable amounts of expertise and motivation for involvement.

    b) **MSW professional societies (SWANA, ASWANO, APWA, etc.):** Professional societies are the primary means of disseminating MSW knowledge to MSW practitioners nationwide. They are in a position offer short courses and develop national interest and application of the DST and related software.

    c) **Utility consultants:** The industry of consultants to MSW agencies and managers provides a great deal of expertise and guidance to local and state agencies. Many of these consultants currently use very simple proprietary spreadsheet models for their analysis. Such analyses usually are not transparent and might not be of the quality available from the DST. Adoption of a high-quality publicly-available and transparent software would raise the standards of the industry considerably and should foster the ability to discuss recycling and other waste management issues. Consultants will perform many of these analyses, have a good amount of money, but are institutionally ill-suited to collectively supporting non-proprietary or transparent software.

d) **MSW-savvy environmental groups:** MSW is a complex subject. There are opportunities for false-economies in recycling, creating more environmental damage than good in some cases. Environmental groups provide an important ability to check and test analysis assumptions.

e) **Environmental Foundations:** Environmental foundations have little ability to act locally, but have interest and funds for national and state efforts to improve waste management.

Ideally, a collection of these groups might be brought together to provide the funding, technical ability, and professional and environmental legitimacy needed to disseminate and support these products. It is important to realize that substantial programming and documentation support will be needed in the first years of the products field application and release. Local training and implementation of the DST by consulting experts acting under the auspices of a regulating state agency with involvement of national professional and environmental organizations, and perhaps funded by state, foundation, and local contributions might provide the widest range of benefits for waste management and regulation.

- Beta-testing is, at this point, probably the best way to better understand the tool's utility. The beta-testing should be done focusing on the intended users and purposes of the tool.

- Subsequent Maintenance and Marketing. Without adequate upkeep, the DST and its supporting data sets will quickly become dated. It is imperative, if the tool is to have any longevity, that some means exist for rigorously updating and reprogramming the tool and its support data sets. A likely context for this updating and maintenance would be within a university setting. For local governments to make use of the tool, it needs to be both low cost and relevant training and assistance must accompany the tool. One way to achieve these goals is to seek private foundation support for the effort

- Long term success of the DST will depend on the management plan for updating data and process models. Without a mechanism for such revisions the model will eventually become obsolete within 3 to 5 years.

- EPA, NCSU, RTI, Franklin Associates and other LCA consultants, Industry Trade Associations each have contributed a great deal of expertise and resources in this project. The strategic plan for launching and maintaining the LCA MSW tools and database must incorporate all the existing capabilities plus add the dimensions of technical support, marketing, and training. The role of NCSU and other academic institutions are required to keep the model up to date by incorporating the latest optimization methods, unit process models, and computational methods. New LCA data will be needed from either consultants, government labs, industry trades associations, or universities. Currently, consultants serve this role best and will probably do so into the foreseeable future. RTI serves a key project management function. EPA has the resources to support new research, convene key stakeholders and arrange for peer review. The training and technical support requires significant resources that should eventually be tied to a revenue stream in licensing the DST. SWANA could potentially facilitate the training, marketing and distribution. EPA Regional Offices could also help in this capacity.

- In order to implement and continue to update this valuable tool and the vast information it contains, it is essential to come up with a plan for continuation. My general comment is to include national and local program partners from both the public and private sector. We should learn from our colleagues in the public sector. Almost every sports stadium in the country now carries a private sponsor's name. In addition to such large private sector sponsors, in many cases, there is also state & local government money available. Additionally, foundation money should be considered. Bottom line is, creative partnership will be necessary to carry this model to the point of broad application.

- The ORD research project has culminated in the production of two equally valuable outputs: the DST and the Municipal Solid Waste Life Cycle Assessment Database. While the audience for the DST will consist largely of waste managers, the audience for the database will primarily be LCI practitioners. In developing the business plan, the two audiences should be kept in mind.

- It is anticipated that the DST will also generate significant interest and gain users outside the United States (as have a number of other EPA models).

- The key to the success of the DST will lie in the ability to provide adequate training, technical support and assistance with the interpretation of the results of the model. Resources for the development of "Version 2" do not necessarily need to be committed until a strong base of users has been established.

- Target Audience: My understanding is that municipal solid waste managers are the target audience for this project. Additionally, what I learned during the peer review is that the focus of the model is to ascertain the environmental impacts of various solid waste management decisions; that is, it is not an economic model but rather a life cycle management model. This leads to what I believe is a fundamental question: are solid waste managers responsible for environmental impacts and the life-cycle implications of their choice? Or is their basic job responsibility to run a cost-efficient solid waste program for their jurisdiction? My bottom line fear is it will take significant training and infrastructure education for most solid waste managers to see the benefits of life-cycle management to their day-to-day operation. Secondly, the very nature of the comprehensiveness of the model necessitates extensive model and computer knowledge.

  My suggestion would be to gear the materials, particularly the DST, to an audience with a very rudimentary understanding of computers and modeling concepts. Therefore, the documents need to be more user-friendly and less intimidating to the average solid waste manager. This is not to say that local solid waste managers would not see the benefits of using the model; however, it is a major paradigm shift. It clearly is asking the manager to think way outside of the box, an undertaking which always requires effective training, clear demonstration of the model's benefits, patience, and money. Lastly, although I inherently understand and support the notion of this tool being used on the local level, in order to produce results which are real to the community using the model, I am wondering if the more effective way to sell the model is by use of national or possibly regional results.

  Possibly the EPA, even using default data, could show an example of what would happen using a given scenario nationally, by inputting the chosen data, e.g., we could divert an additional 20% from disposal by increasing recycling and composting while lowering many environmental pollutants and reducing total systems costs by 10%. The solid waste manager could then say, ?Wow, if the model does that nationally, I wonder what could it do for me locally? Therefore, I fully understand why, technically, our May Peer Review Team including myself endorses the use of the model locally, from a sales and practical application. The old "USA model" could serve as a valuable tool to engage solid waste managers. Bottom line: it's selling the big picture benefits e.g., 8 trillion less pounds of X pollution in our air nationally, etc., etc. My town contributes 3,500 lbs. of that total. To accomplish that, I need to look at this model.?

  Lastly, it is essential to get the targeted audience, the intended user of the model, involved initially and throughout the entire process. I do wholeheartedly believe that this would have made a significant impact on the direction and approach of the project. That is, this and the previous Peer Review Teams had a disproportionate academic balance. Obviously, these members were incredibly valuable. However, I believe the absence of practicing solid waste managers was a flaw and needs to be addressed in order to successfully sell the model.

- It was quite clear to the peer review panel, as it has been to the other boards and the many other people who have seen and understand the project, that this is a really worthwhile effort. Seldom have I seen a greater potential for an ORD project to make an immediate and lasting impact for the benefit of the people of the United States. My private conversations with the stakeholders assures me that they are not just going along here. They truly care about this project and find that the application of the Decision Support Tool (DST) will level the financial and environmental playing field. This is all anyone would ask, and this is what they see as the greatest benefit of the DST. Your problem now is not how to improve this model (although I will make some suggestions on how to do so!) but rather how to sell it to the people who will be most influential in implementing its use.

In that regard, I see three audiences:

a) U. S. EPA Office of Solid Waste (Washington): In the case of the Office of Solid Waste, the problem is that this tool shows conclusively how the hierarchy of solid waste management solutions, so near and dear to the hearts of the OSW, is not an absolute truth. For those who have bought into the hierarchy as being the best for the environment, the DST is not an easy sell because the DST shows how alternatives that do not follow lockstep in the hierarchy may be not only less expensive, but will be better for the environment. Nevertheless, it seems to me that the strongest argument you have is that you are helping them improve the environmental quality by showing how the solid waste management hierarchy can best be used in solving solid waste problems. You have to impress on them that pollution prevention is an integral part of the DST in that it can be used to study the disposal and recovery of materials as it would best be managed with multiple and diverse pollution prevention alternatives. That is, if there is a possibility of how to reduce waste, the DST will show how the residual waste from such a program can then best be managed. The DST should become a part of and not a competitor to the OSW philosophy of hierarchical solid waste management.

b) State and local solid waste agencies: The second group that has to be convinced is the state and local agencies. For that, you need help. SWANA is the ideal group that has credibility with the agencies, and the connections with SWANA should be strengthened. In my correspondence with John Skinner, I get the impression that he is interested in participating in this project. He is worried about the financial ramifications, and for this it would be good to have some EPA financial backup. In short, I don't think you personally are able to sell the DST or the Life-Cycle Inventory (LCI) to the local agencies. You need help, and SWANA is the best choice. An alternative might be the International Solid Waste Association (ISWA), based in Copenhagen. If you need help with contacting them, I would be pleased to work with you on that since I know most of the actors at ISWA. The disadvantage is that ISWA does not have a strong association with the local and state agencies in the United States.

c) Consultants and academicians: The third audience you have to address is the consultants and the academicians. The consultants will jump at this opportunity and all you have to show is that it works. They are always up for another free tool to impress their clients. The academicians can be consultants also, of course, but more than that, they will be able to help with the publicity. In that regard, you should make this program available to them, including the source codes. The greatest mistake made in marketing the original Waste Resources Allocation Program (developed originally by MITRE Corporation) was keeping it so secret. They thought they would be able to make money by running it, and they did not let others have copies of it until it was too late and nobody cared. Having the academicians play with improving the model will be much to its benefit (much like the Line phenomenon).

In each case, the way you present the tool will have to be different and will have to respond to their specific interests.

- Model maintenance. This point echoes the committee report: you cannot allow this project to die for want of upkeep and maintenance. There are lots of precedents for how the United States governmental agencies can assist the public by providing a resource. The USGS is a prime example. They have developed many hydrologic models that are useful and well maintained. There is no reason that the U. S. EPA cannot similarly fund a continuing support for the DST and the LCI. Without knowing what the alternatives might be, it would seem reasonable that the Research Triangle Institute could be contracted to provide for this continuing support.

- Private collectors. The point was made at the peer review that a large fraction of our present solid waste collection in the United States is by private contractors, and there was a question of whether or not these contractors would be interested in using the DST. The answer is that although most of the collection programs are privately run, they are still contracted by the communities. The decision makers are the local leaders and solid waste managers, and they can run the DST to write specifications that require the private haulers to perform in a specific way. That is, the DST is still a valuable model even though the actual collection might be privately contracted.