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Life Cycle Analysis for the Management of Post-Recycled MSW at the Hudson Falls WTE Facility and Regional Landfill Options

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Nomenclature

CH_4	methane
EPA	Environmental Protection Agency
GHG	Greenhouse Gas
Kwh	kilowatt-hour
LCA	life cycle assessment
Mg	megagram
MMBTU	million metric British thermal units
MSW	municipal solid waste
MSW DST	Municipal Solid Waste Decision Support Tool
MWh	megawatt-hour
US	United States
WTE	waste-to-energy

Executive Summary

Win-Waste Innovations engaged RTI International to apply the MSW DST[1] to investigate the life cycle environmental impacts of managing 133,976 metric tons of post-recycled municipal solid waste (MSW) per year at their Wheelabrator Hudson Falls NY waste-to-energy (WTE) facility as compared to disposal at a landfill.

The management scenarios analyzed were defined as follows:

1. WTE: post-recycled MSW collected and treated at the Wheelabrator Hudson Falls WTE facility with power production, recovery of metals for recycling, and landfill disposal of combustion ash.
2. Landfill: post-recycled MSW collected and transferred within the region to a landfill facility with landfill gas collection and power production.

Results from the scenario analysis exhibit life cycle energy and greenhouse gas benefits for the WTE scenario as compared to the out-of-region landfill disposal scenario. Results for greenhouse gas (GHG) emissions for each scenario and the total savings or net GHG reductions for the WTE scenario as compared to the landfill scenario are shown in the table below:

Parameter	Units	WTE	Landfill	Total Savings of WTE vs Landfill
GHG Emissions	$MTCO_2e$	39,986	173,840	133,854
	TonsCO2e	44,805	191,659	147,754
Net GHG Reduction	Ton CO_2e per ton MSW processed			1.00

[a]Using the 20-year methane global warming potential of 82.5 per the IPCC Sixth Assessment Report (IPCC, 2021).

Key factors that influence results include:

- transportation distances from the point of collection to the Hudson Falls WTE facility is significantly shorter than to out-of-state landfill facilities,
- amount of energy recovery by the Hudson Falls WTE facility displaces utility electricity,
- ferrous metal recovery from combustion ash creates recycling benefits,
- assumed landfill gas collection efficiency directly impacts the amount of methane released to atmosphere landfills (which is a key contributor to landfill GHG emissions), and
- assumed utility grid mix offset by electricity production reduces direct emission from fossil fuel electric generation facilities and emissions associated with the mining of coal and extraction of oil and or natural gas used in generation.

[1] Available at: https://mswdst.rti.org/

1. Introduction

Win-Waste Innovations engaged RTI International to apply the MSW DST[2] to investigate the life cycle energy and greenhouse gas impacts of managing the 133,976 metric tons of post recycled MSW at their Wheelabrator Hudson Falls, New York WTE facility as compared to landfill disposal. The MSW DST was developed in cooperation between RTI and its partners and the U.S. EPA. The tool is designed to facilitate planning of solid waste related activities on a municipal, regional, or national scale and can be used to assess the cost and life-cycle environmental emissions and impacts of MSW management strategies. The MSW DST has undergone extensive stakeholder input and peer review (as well as a separate peer review by the EPA) and is regarded as a cutting-edge software tool that can help solid waste planners make better-informed decisions.

The methods used in the MSW DST to calculate the energy and environmental results are built on the principles of life cycle assessment (LCA). LCA is a type of systems analysis that accounts for the complete set of upstream and downstream (cradle-to-grave) energy and environmental aspects associated with industrial systems. The technique examines the inputs and outputs from every stage of the life cycle from the extraction of raw materials, through manufacturing, distribution, use/reuse, and waste management.

In the context of integrated waste management systems, an LCA tracks the energy and environmental aspects associated with all stages of waste management from waste collection, transfer, materials recovery, treatment, and final disposal. For each of the waste management operations, energy and material inputs and emissions and energy/material outputs are calculated (see **Figure 1**). In addition, the energy and emissions associated with fuels, electrical energy, and material inputs are captured. Likewise, the potential benefits associated with energy and/or materials recovery displacing energy and/or materials production from virgin resources are captured in the life cycle results.

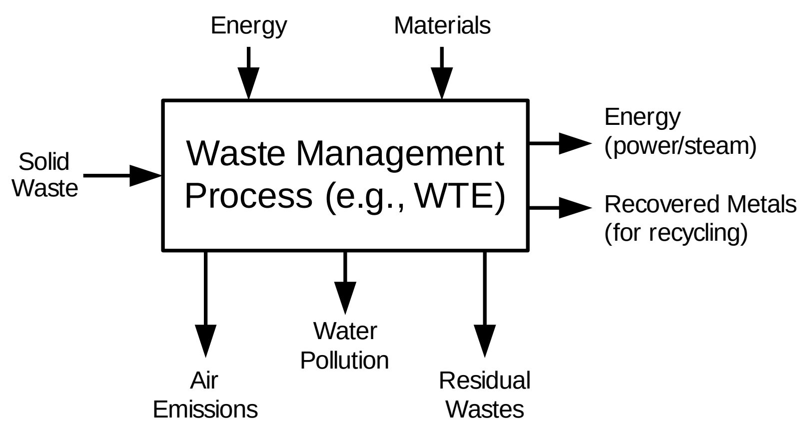

Figure 1. Life Cycle Inputs and Outputs for a Waste Management Process.

All waste management processes that comprise an integrated waste management system consume energy and materials and produce emissions. Some processes, such as WTE, recover energy and materials. The benefits associated with energy or materials recovered are captured in a life cycle study.

Taking 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.

2. Scenarios Modelled and Key Data and Assumptions

The MSW DST was used to estimate and compare the cost and environmental impacts of the following waste management scenarios:

1. WTE: post-recycled MSW collected and treated at the Wheelabrator Hudson Falls WTE facility with power production, recovery of metals for recycling, and landfill disposal of combustion ash.

[2] Available at: https://mswdst.rti.org/

2. Landfill: post-recycled MSW collected and transferred to a landfill facility with landfill gas collection and power production.

Defined management scenarios were modeled using the MSW DST based on 133,976 metric tons of post-recycled MSW. The amount of MSW collected and sent to each waste management process by scenario analyzed is shown in **Table 1**.

Table 1. Mass Flows[a] of MSW for the Scenarios Analyzed

Process	WTE	Landfill
Waste Collection	133,976	133,976
Transfer Station	87,084[b]	46,892
Truck Transfer	87,084	46,892
WTE	133,976	0
Metals Recovered for Recycling	1,756	0
Ash (landfilled)	38,880	0
Landfill	38,880[c]	133,976

[a]Metric tons
[b]Waste received from transfer station
[c]Ash remaining after WTE combustion

The following tables and figures present the key input data and assumptions used for scenario modeling. **Figure 2** illustrates the composition of waste assumed for the analysis. In **Table 2** a listing of key assumptions is provided by process modeled using the MSW DST. Note that the MSW DST does not model a specific facility (e.g., landfill) per se. Rather it models the management by various means, in this case, 133,976 metric tons of post-recycled MSW. For most processes, emissions are instantaneous or occur within a short time-frame (< 1 year). For landfill disposal, however, a 100-year time period is used to calculate emissions. That is, emissions from the landfill are counted from the time of waste placement through a 100-year time period.

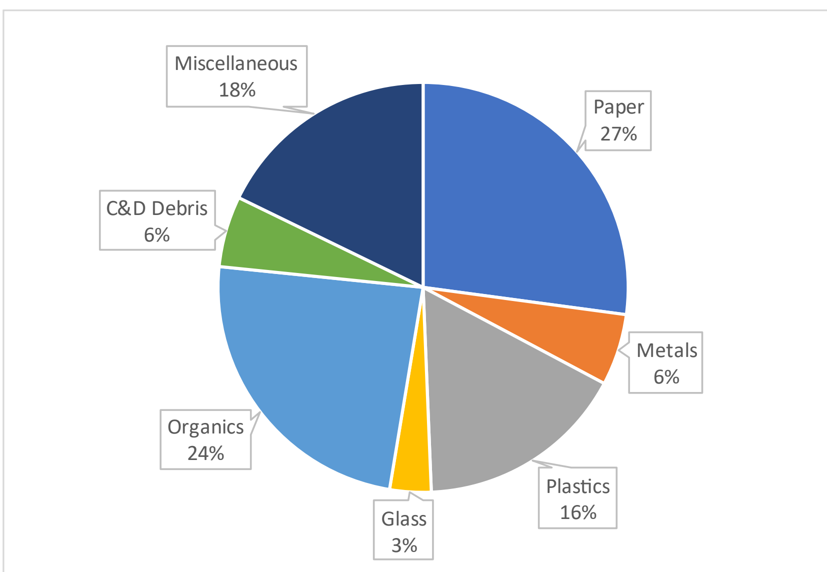

Figure 2. Waste Composition

Source: NYS DEC, 2023

To quantify reductions associated with power production from WTE and displacement of utility power production the U.S. EPA (2023) eGRID New York Upstate (NYUP) emission rates as listed in **Table 3** were used. Since eGRID only includes emission rates for carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NO_x) and sulfur dioxide (SO_2), emission rates for other pollutants utilize default factors in the MSW DST. In addition, resource (e.g., coal) extraction and processing-related emission factors to complete the life cycle profile for energy resources utilize default factors in the MSW DST.

Table 2. Key Assumptions

Parameter	Assumption	Source
General		
Waste Quantity Processed	133,976 metric tons	Hudson Falls WTE facility average (2020-2022)
Waste Composition	Statewide 2021 estimate, as disposed	NYS DEC (2023)
Waste Collection Frequency	1 time per week	
Transportation Distances		
Collection to Transfer Station	10 miles one way	
Collection to WTE plant	15 miles one way	
Collection to landfill	15 miles one way	
Truck Transfer to WTE plant	85 miles one way	Average distance to transfer stations
Truck Transfer to Landfill	226 miles one way	Average distance to landfills
WTE to Ash Landfill	174 miles one way	Distance to Putnam, CT Monofil
WTE		
Basic Design	Power only	
Plant Heat Rate (net)	21,695 btu/kwh	Estimate per HHV
Net Generation (MWh)	68,519	Average 2020-2022
Waste Input Heating Value (HHV)	4,800 Btu/lb	Estimate per Net Generation
Metals Recovery Rate	1.3% of incoming MSW[a]	
Offset for Energy Recovery	Annual average per eGRID NYUP region	eGRID, US EPA (2023)
Landfill		
Basic Design	US EPA Subtitle D Type	MSW DST default
Time Period for Emissions	100 years	MSW DST default
Landfill Methane Generation	100 m^3/Mg	AP-42, US EPA (2008)
Landfill Gas Management	Energy recovery (via ICE)	Assumed best-case
Landfill Gas Collection Efficiency	Variable by year[b]	MSW DST default
Offset for Energy Recovery	Annual average per eGRID NYUP region	eGRID, US EPA (2023)

[a] Modeled as a 0.25 recovery efficiency for ferrous and aluminum based on statewide waste composition.

[b] 0% in years 0-2, 0% and increasing to 75% in year 5, 90% in year 18 and back to 0% in years 51-100.

Table 3. eGRID Resource Mix and Emission Rates

	NYUP Subregion
Resource Mix (percentage)	
Coal	0.0
Oil	0.04
Gas	25.93
Nuclear	33.16
Hydro	33.18
Biomass	1.57
Other	6.14
Emission Rates (lb/Mwh)	
CO_2	836.821
CH_4	0.055
CO2e	840.213

Source: EPA, 2023

3. Scenario Results

Summary level results, reported as net totals, for the WTE and landfill scenarios analyzed are provided in **Table 4**. In the proceeding sections, results for energy consumption and GHG emissions are presented and discussed.

3.1 Energy Consumption

Energy is consumed by all waste management activities (e.g., landfill operations), as well as by the processes to produce energy and material inputs (e.g., diesel fuel, landfill liner) that are included in the analysis. Energy can also be produced by some waste management activities (e.g., WTE) and can be offset or avoided by other activities (e.g., metals recovery and recycling from combustion ash). If the energy produced and/or offset by the waste management system is greater than the energy consumed, then a net energy savings is achieved. Energy use (or savings) is an important parameter in life-cycle studies because it often drives the results of the study due to the significant amounts of air and water-borne pollutants associated with energy production.

As shown in **Figure 3**, the base case WTE scenario results in a net energy savings of **541,767** MMBTU as compared to the alternative out-of-state landfill scenario. The net energy savings associated with the WTE scenario can be attributed to the following aspects:

- Electrical energy production at the WTE facility offsets the production of electricity in the utility sector including energy used in the mining or extraction and transportation of fossil fuels used in electricity generation.
- Ferrous metal recovery at the WTE facility and subsequent recycling offsets the extraction and processing of virgin resources to manufacture ferrous metal.

Table 4. Net Total MSW DST Results by Scenarios Analyzed and Total Savings of WTE

Parameter	Units	WTE	Landfill	Total Savings of WTE vs Landfill
Energy Consumption	MMBTU	-181,827	359,940	541,767
Air Emissions				
Carbon Dioxide Biogenic	lb	165,490,069	66,324,525	-99,165,543
Carbon Dioxide Fossil	lb	101,908,664	31,483,300	-70,425,364
Methane (CH4)	lb	-168,976	4,254,109	4,423,085
Carbon Equivalents	MTCO2e	39,986	173,840	133,854

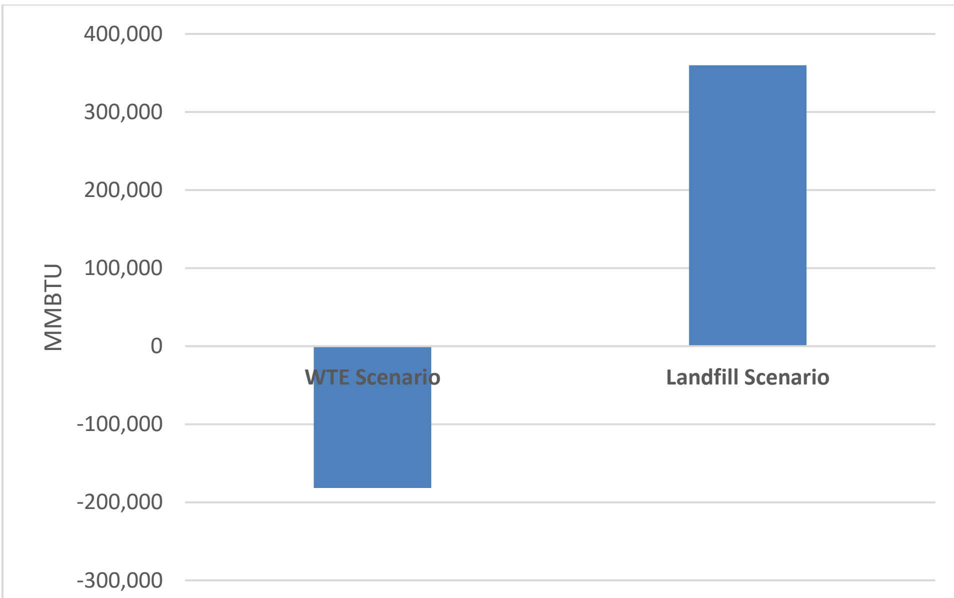

Figure 3. Net Total Energy Consumption by Scenario

3.2 GHG Emissions

The net total GHG emission results for each scenario are shown below in **Figure 4**. GHG emissions contribute to the greenhouse effect; thus, these emissions can lead to climate change and its associated impacts. From the waste sector, GHG emissions result from the combustion of fossil fuels from transportation of waste from curbside to final processing at a WTE facility or disposal at landfill, the biodegradation of organic wastes in a landfill (e.g., CH_4 emissions) and for WTE, combustion of wastes derived from fossil fuel such as plastics, rubbers and synthetic textiles. Offsets of carbon emissions result from the displacement of fossil fuels electricity generation, materials recycling such as paper, plastics, ferrous and non-ferrous metals recycling, and most importantly diversion of organic wastes from landfills and resulting release of methane emissions,

GHG emissions are reported in units of metric tons of CO_2 equivalent emissions ($MTCO_2$-eq), derived as follows:

$[(CO_2*1 + CH_4*82.5) / 2200$

The 20-year global warming potential of 82.5 was used for CH_4 based on IPCC (2021). As shown in Figure 4, the base case WTE scenario results in a GHG emissions savings of **133,854** $MTCO_2$-eq as compared to the alternative landfill scenario. The GHG reduction associated with the WTE scenario can be attributed to the following aspects:

- Avoiding methane emissions from biodegradation of organic wastes in landfills
- Materials recovery and recycling offsets GHG emissions by avoiding the consumption of energy that otherwise would be used in materials production processes.
- Energy recovery offsets GHG emissions by displacing electricity that otherwise would be produced by fossil fuel fired electric generators supplying electricity to the gird

Results are presented as net totals including the entire MSW management system from collection through to the ultimate disposition of materials.

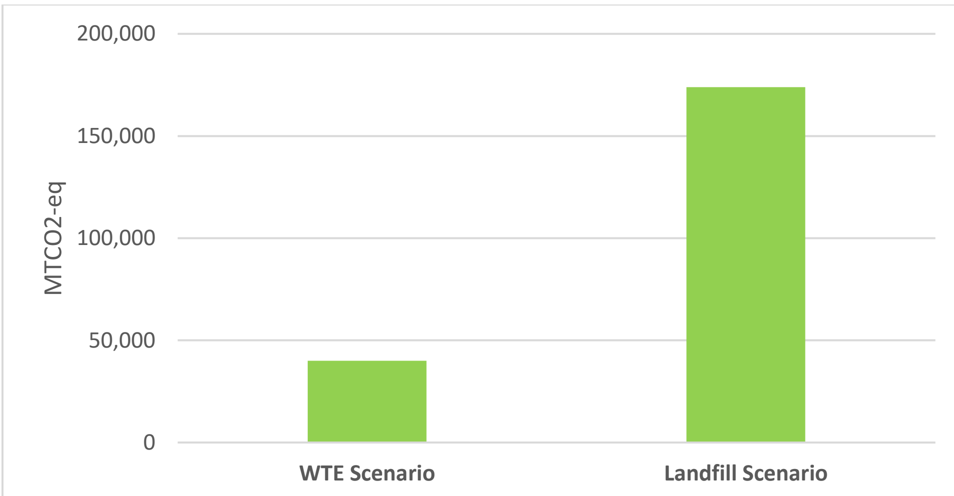

Figure 4. Net Total CO_2 Equivalent Emissions by Scenario

The GHG emissions savings associated with the WTE scenario can be attributed to the following aspects:

- Avoiding methane emissions from biodegradation of organic wastes in landfills
- Materials recovery and recycling offsets GHG emissions by avoiding the consumption of energy that otherwise would be used in materials production processes.
- Energy recovery offsets GHG emissions by displacing electricity that otherwise would be produced by fossil fuel fired electric generators supplying electricity to the gird

Results are presented as net totals including the entire MSW management system from collection through to the ultimate disposition of materials.

Figure 5 illustrates the contribution of each process to the net total GHG emissions for the WTE and landfill scenarios. A positive value represents the GHG emissions of each process; negative values for GHG emissions reflect emissions offset (or avoided) by way of energy and materials recovery displacing utility sector energy production and/or materials (ferrous metals) production from virgin resources respectively. The net GHG emissions for both scenarios are positive, as more GHG emissions are produced than are offset. As illustrated in **Figure 5**, landfill GHG emissions appear to dominate all other GHG sources and offsets.

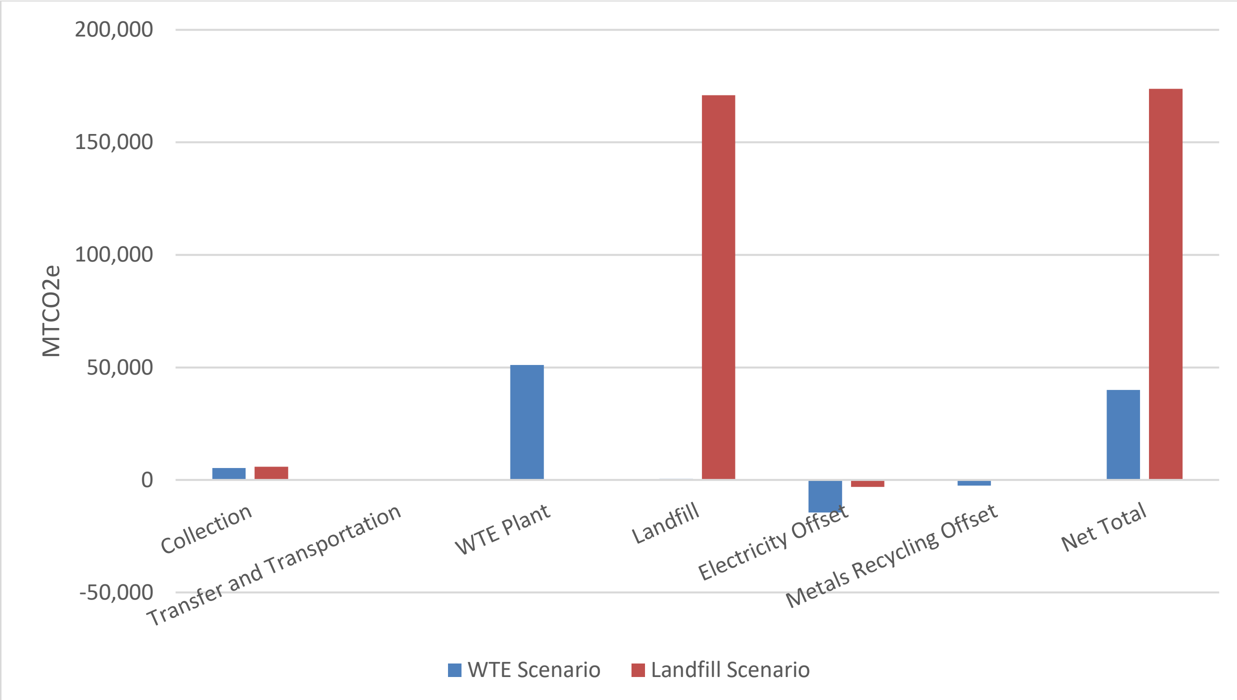

Figure 5. $MTCO_2$ Equivalent Emissions by Process for Each Scenario

4. Key Findings and Conclusions

The results of this analysis are useful for identifying the life cycle impacts and tradeoffs associated with operation of the Wheelabrator Hudson Falls WTE facility as compared to the alternative of long-haul transfer and disposal at a landfill. Results highlight the benefit of WTE as compared to landfill disposal. Processing post-recycled MSW at the Hudson Falls WTE facility results in large savings/reductions of energy, GHG emissions and most criteria air pollutant emissions as compared to the alternative case of out-of-region landfill disposal.

Key factors and assumption that influence these results include:

- transportation distances from the point of collection to WTE and landfill facilities,
- amount of energy recovery via WTE that displaces of utility electricity,
- amount of recovery and recycling of metals from WTE,
- assumed landfill gas collection efficiency and utilization (energy recovery), and
- assumed utility grid mix offset by electricity production.

The results of this analysis are not intended to be absolute but rather estimates that are useful for understanding the potential impacts and tradeoffs among the management scenarios.

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Attachment A: Background Information about the MSW DST

The MSW DST was developed through a cooperative agreement between the U.S. EPA's Office of Research and Development and RTI to assist communities and other waste planners in conducting cost and environmental modeling of MSW management systems. Users can evaluate the numerous MSW management scenarios that are feasible within a community or region and identify the alternatives that are economically and environmentally efficient, making tradeoffs if necessary.

The MSW DST allows users to analyze existing waste management systems and proposed future systems based on user-specified information (e.g., waste generation levels, waste composition, diversion rates, and infrastructure). The current components included in the MSW DST are waste collection, transfer stations, material recovery facilities (MRFs), mixed MSW and yard waste composting, combustion and refuse-derived fuel production, and conventional or bioreactor landfills. 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 A-1**,** the MSW DST consists of several components, including process models, waste flow equations, an optimization module, and a graphic user interface (GUI). 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 basis for each of the 39 MSW components being modeled for each solid waste management unit process (collection, transfer, etc.). Each process model describes and represents the essential activities that take place during the processing of waste items. For example, the collection model includes parameters for waste collection frequency, collection vehicle type and capacity, number of crew members, and number of houses served at each stop. Although national average default values are included in the MSW DST for such parameters, users can override the default values with site-specific information. These operational details, which are input by the user to represent an MSW management system, are then synthesized in the process model to estimate the cost of processing as a function of the quantity and composition of the waste entering that process. The resulting cost coefficients from each waste management process model are then used to estimate the cost of that option.

The MSW DST also contains models for ancillary processes that may be used by different waste management processes. These models calculate emissions for fuels and electrical energy production, materials production, and transportation. Electricity, for example, is used in every waste management process. Based on the user-specified design information and the emissions associated with generating electricity from each fuel type, the MSW DST calculates coefficients for emissions related to the use of a kilowatt hour 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 and facility lighting. The emissions associated with electricity generation would be assigned to the mass that flowed through that facility. Users can specify whether the emissions associated with generating electrical energy are based on a national, regional, or user-defined mix of fuel.

The optimization module is implemented using an open-source linear programming solver called COIN-LP. The model is constrained 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, recycling, treatment, and disposal options). These mass flow constraints preclude impossible or nonsensical model solutions. For example, these mass flow constraints will exclude the possibility of removing aluminum from the waste stream via a mixed waste MRF and then sending the recovered aluminum to a landfill. 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 are the use of existing equipment/facilities and a minimum recycling percentage requirement.

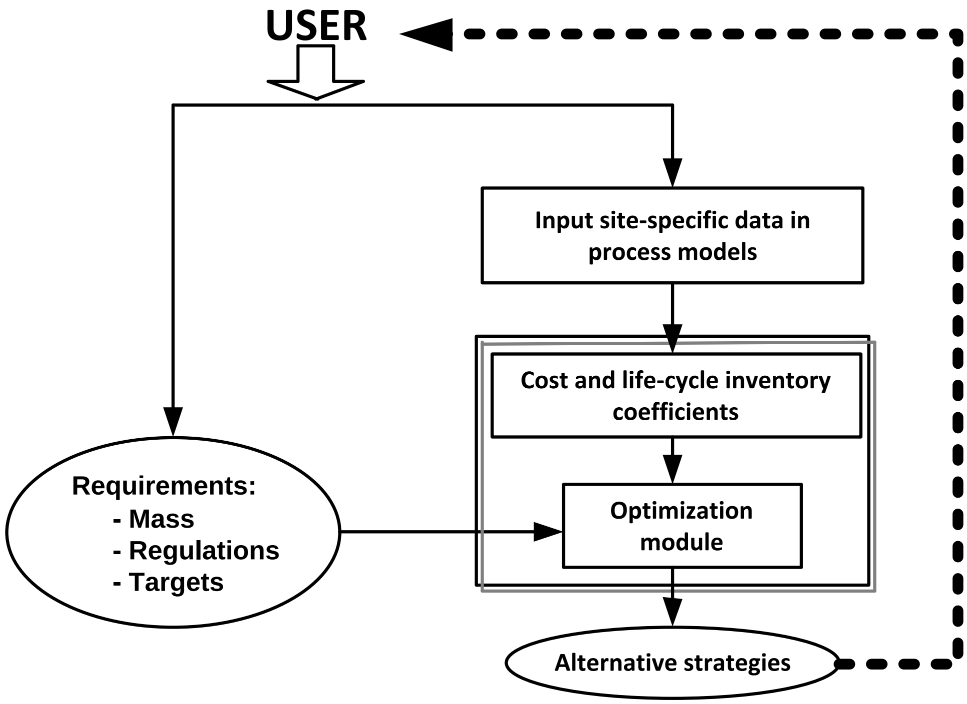

Figure A-1. Conceptual Framework for the MSW DST

The environmental aspects associated with a defined MSW management scenario are estimated in terms of annual net cost, energy consumption, and environmental releases (air, water, solid waste). For example, waste collection vehicles consume fuel and release several types of air pollutants in their exhaust. The collection process model of the MSW DST uses information about the quantity and composition of waste generated and a host of collection route parameters to estimate the amount of fuel consumed and air emissions by waste constituent collected. In addition, the environmental burdens associated with producing the fuel used in the collection vehicles are calculated and included in the collection results. All process modules in the MSW DST operate in a similar manner and express results as a function of the quantity and composition of the waste entering each process.

In some waste management processes, cost, energy, and emission offsets may occur. For example, diverting recycling materials from the waste stream results in a revenue stream and can displace energy consumption and emissions associated with virgin materials production. Similarly, waste management processes that recover energy (e.g., WTE, landfill gas utilization) will displace energy production in the utility sector and thereby avoid fossil fuel production- and combustion-related emissions. In applying the MSW DST, any materials or energy recovery-related benefits are netted out of the results for each process.

Attachment B:
Detailed MSW DST Results by Scenario Modelled

Table B-1. Base Case WTE

Parameter	Units	Collection	WTE Plant	Ash Disposal	Transfer Station and Transport	Electricity Offset	Recycling Offset	Net Total
Energy Consumption	MMBTU	80,589	381,159	5,937	3,522	-637,355	-15,678	-181,827
Air Emissions								
Carbon Dioxide Biogenic	lb	66,944	169,785,284	3,007	599	-4,214,860	-150,905	165,490,069
Carbon Dioxide Fossil	lb	10,205,615	117,221,523	846,934	525,239	-22,225,640	-4,665,007	101,908,664
Methane (CH4)	lb	16,696	-60,625	1,233	646	-117,830	-9,097	-168,976
Carbon Equivalents	MTCO2e	5,265	51,009	431	263	-14,521	-2,462	39,986

Table B-2. Alternative Case Landfill

Parameter	Units	Collection	Transfer Station and Transport	Landfill	Electricity Offset	Total
Energy Consumption	MMBTU	89,654	1,884	404,696	-136,294	359,940
Air Emissions						
Carbon Dioxide Biogenic	lb	74,352	310	67,151,178	-901,315	66,324,525
Carbon Dioxide Fossil	lb	11,353,551	281,111	24,601,420	-4,752,782	31,483,300
Methane (CH4)	lb	18,572	345	4,260,389	-25,197	4,254,109
Carbon Equivalents	MTCO2e	5,857	141	170,947	-3,105	173,840