

**Modern Waste-to-Energy
As An Energy and Environmental Management System**

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ABSTRACT

Recent international attention to renewable energy and climate change has focused on energy security with a key question being “how can a country achieve a greater degree of energy independence while also considering environmental consequences such as global climate change”. Alternative renewable technologies such as solar, wind, biofuels, and nuclear power have received increased media attention in the USA. The management of municipal solid waste for energy generation/recovery has received comparatively less attention in America. However the European Union has recognized the link between responsible management of MSW, renewable energy and the reduction of greenhouse gas emissions. The EU’s recently proposed Thematic Strategy on the Prevention and Recycling of Waste and the EU Land Directive both recognize that disposal of MSW in a landfill is a loss of valuable resource (s) while also being the source of greenhouse gas emissions. This paper uses the EPA’s life-cycle based Decision Support Tool (MSW-DST) to evaluate the existing MSW management infrastructure in America and the potential of waste-to-energy to be a larger source of renewable energy while also reducing greenhouse gas emissions, PM_{2.5} precursors and other emissions.

BACKGROUND

According to an April 2005 EPA report, the 2003 MSW pre-recycling inventory is 236 million tons (Mtons) with approximately 14 % being processed at municipal waste-to-energy facilities, 31 % being managed by materials recovery and 55 % being landfilled¹. Table 1 provides information from this report including both the total tonnage and the amount managed by each waste management option. The MSW inventory is relevant because it defines the problem and opportunities for improvement. The key question addressed in this analysis is “What are the energy and environmental consequences of landfilling MSW instead of using waste-to-energy?” The compatibility of waste-to-energy with recycling is also examined.

The different energy and environmental impacts of WTE and landfilling have been evaluated for two general conditions. The Existing Case evaluates and quantifies the energy and environmental benefits of processing 33 Mtons (EPA 2003 data) at WTE facilities instead of disposing this same MSW at landfills with their existing landfill gas collection efficiencies and treatment technologies. The Future Case scenario compares the different energy and environmental consequences of processing MSW at a WTE facility or a “best-case” landfill design with 75 % collection efficiency of LFG and energy recovery using an internal combustion engine (ICE).

A total of thirteen operating scenarios were evaluated via EPA’s MSW-DST that considers the multi-media life-cycle performance of MSW management options over an

extended time period. This type of long-term analysis is considered to be a better evaluation than a simple year-to-year comparison for several reasons. First, any MSW infrastructure such as a WTE facility or landfill must be operated for a significant period of time to be a cost-effective solution. Second, certain issues such as energy independence cannot be achieved overnight, a long-term plan is necessary. Third, it is the only way to accurately compare two different technologies such as WTE and landfilling because WTE processes MSW in a comparatively instantaneous manner whereas the decomposition of MSW in a landfill takes many years. Lifecycle assessments such as the MSW-DST are not limited to direct outputs of MSW management facilities themselves, but also consider the impacts of related actions such as transportation, energy production, and material production. Background information about the MSW-DST is provided as Attachment A.

While the technical aspects of renewable energy are the focus of this paper, it is important to note the current status of WTE as renewable energy according to State and Federal initiatives. The regulatory overview provided as Table 2 demonstrates that from a federal perspective, the consensus is that WTE is a proven renewable energy source.

ENERGY IMPACTS

The President's Energy Vision has identified a sound energy policy as being vital to national security and protecting the environment². While this policy is far reaching, in that it considers the way we fuel our vehicles to the way we power our homes and businesses, the following information focuses on the amount of fossil fuel (coal, oil or natural gas) that can be avoided due to the energy recovery of WTE and landfills that include Landfill Gas to Energy (LFGTE) systems.

The amount of renewable energy that can be generated by WTE or landfills is the first parameter evaluated for two reasons;

1. The amount of renewable energy generated by either option determines the amount of fossil fuel power that can be avoided.
2. The amount of fossil fuel avoided is critical in understanding the environmental impacts of each on a pound of pollutant per kilowatt-hour generated basis (lb/kwh).

The amount of fossil fuel that can be avoided will vary depending upon the scope of the mass and energy balance. Two approaches were used to establish a fossil fuel equivalence factor (1 ton of MSW is equivalent to a certain amount of coal, oil or gas) for WTE. The conventional approach is a direct comparison of the electrical output from one ton of MSW with different fossil fuels; coal, oil and natural gas. This approach only compares the heat content of the different fuels and the thermal conversion efficiency of a typical power plant. The life-cycle approach is more inclusive and appropriate because it considers the energy savings of WTE versus a landfill including a LFGTE system using an internal combustion engine for power production. Landfill options using vents and flares were not considered due to the absence of electrical energy recovery. Table 3 provides an overview of the variables used in the energy and environmental analysis.

Table 4 provides the results of the conventional and lifecycle approach. Table 3 and 4 understate WTE's likely benefit because of conservative assumptions including;

- The transportation component for both WTE and LFGTE was minimized in the model to keep the results oriented to the MSW management option – WTE or LFGTE.
- Transportation impacts of long hauling MSW via truck, barge or rail can be added as a separate factor.
- The thermal conversion factor of 19 % is low relative to the potential of a new WTE facility. Therefore a new WTE facility would actually have the same or better results than indicated.
- The 70 % ferrous recovery rate is a typical value that does not include the extra benefit of recovering non-ferrous materials or improvements in ferrous recovery.

A review of the energy information provided in Table 4 demonstrates the following;

- The conventional analysis yields an energy equivalence of; One ton of MSW is equivalent to one barrel of distillate oil, 0.27 tons of coal or 60 therms of natural gas.
- The life-cycle inventory demonstrates a larger fossil fuel equivalence factor for one ton of MSW. One ton of MSW is equivalent to 2.2 barrels of distillate oil, 0.5 tons of coal or 130 therms of natural gas (1 therm = 100 cubic feet of natural gas).
- The energy difference between the conventional and life-cycle approach provides an estimate of how much energy is being wasted when MSW is buried in a landfill.
- Additional savings would be realized if MSW is being long hauled to the landfill due to the avoidance of fuel for transportation.

The clear conclusion is that WTE provides greater energy recovery than existing or future landfill options.

EMISSION FACTORS – Criteria Pollutants and Greenhouse Gases

General Approach

The MSW-DST has been used by the EPA, state agencies, communities and companies to evaluate many site specific situations with the result being numerous reports and papers available in the public domain. One recent EPA paper³ is a source of reference material for interested parties.

The general approach adopted for this analysis was to isolate the operating characteristics of WTE and various LFG systems by using the same nationwide average values for waste composition, transportation, manufacturing, etc. The only true variables in the evaluation were the energy and emission characteristics of the different technologies. A summary of the input factors to the MSW-DST are provided as Table 3.

Existing Case Results

The Existing Case addresses the question of “What are the energy and environmental consequences of processing 33 Mtons of MSW at WTE facilities instead of disposing this same waste at a landfill?” This question was addressed according to a 2-step process;

1. Identify unit emission factors for three different LFG collection efficiencies (20, 45 and 75 %) and four different LFG technologies including;
 - a. WTE vs. venting.
 - b. WTE vs. flare
 - c. WTE vs. internal combustion engine (ICE)
 - d. WTE vs. bioreactor and ICE

Table 5 identifies the matrix of technology comparisons (13 scenarios) considered in the analysis.

The amount of landfill gas (LFG) per ton of MSW is 4980 standard cubic feet (132 NM³) which is consistent with typical actual field data as summarized in several EPA references^{4,5}. The 20 to 75 % range of landfill gas collection was selected to represent the wide range of industry opinions^{6,7} and the general uncertainty of this process parameter as a long-term operating value. Landfill gas not collected by the LFG collection system is treated as a fugitive emission that escapes to the atmosphere through cover soil, which offers some attenuation. In reality, LFG may escape through routes other than soil.

2. Identify the nationwide blend of current landfill disposal practices and apply these to the unit emission factors from Step 1. Prior publications⁸ estimated a nationwide landfill blend of venting (50 %), flaring, (25 %) and energy recovery by ICE (25 %). A weighted average of these disposal options was used to estimate the energy and environmental consequences of landfilling 33 Mtons. Bioreactors were not included in this weighted average due to the relatively small amount of MSW managed by this technology.

Table 6 provides the energy and environmental consequences of processing 33 million tons of MSW at a WTE facility instead of having this same waste disposed of at landfills. Observations are provided relative to energy and environmental parameters;

WTE Energy Benefit

- There is a significant energy savings with WTE due to two factors; 1) WTE recovers approximately 99 % of the inherent chemical energy whereas the amount recovered by vents and flares is zero and IC ranges between 10 to 40 % of the total potential chemical energy, and 2) WTE recovers ferrous materials for recycling. This process is inherently more energy efficient than creating ferrous from virgin ore.
- The life-cycle energy equivalence factors convert to a fossil fuel avoidance of approximately 77 million barrels of oil, 19 million tons of coal or 4540 million therms of natural gas.

- This energy savings does not consider additional savings that would result if MSW is being long hauled by rail, truck or barge.

WTE Environmental Benefit

- Combustion of 33 million tons of MSW avoids approximately 30 million tons of greenhouse gas emissions as carbon dioxide. The weighted average for this national blend is approximately 0.9 tons of CO₂ avoided per ton of MSW processed.
- The controlled combustion of MSW also helps to avoid a significant amount of criteria pollutants including particulate (30,000 TPY), carbon monoxide (33,000 TPY), SO₂ (152,000 TPY) and NO_x (52,000 TPY).
- A significant amount of ambient PM_{2.5} (263,000 TPY) is also avoided when considering SO₂ emissions that would have converted to ammonium sulfate (75 % conversion) and NO_x that would have converted to ammonium nitrate (30 % conversion).

These results support a general conclusion that the existing WTE industry is a safe and reliable process for the disposal of solid waste that also provides significant energy and environmental advantages.

Future Case Results

The Future Case results assumes that an additional 33 Mtons of MSW is processed at either a WTE facility or a modern landfill with 75 % landfill gas collection and energy recovery by ICE. Table 7 presents these results. EPA's 2003 inventory identified that the 33 Mtons being processed by WTE is 14 % of the total MSW generated (20 % post-recycling). For the purpose of projecting future energy and environmental impacts, an additional 33 million tons per year was selected because it would essentially double the 2003 WTE inventory. This would increase the WTE allotment from 14 % to 28 % of the pre-recycling MSW generated assuming that there is not an increase in the total amount of MSW generated. This would increase the post-recycling rate from approximately 20 to 40 %. This example would increase the fraction of MSW being processed by WTE to be in the range of many European countries and far less than the rate in Japan and Taiwan. The 131 Mtons that was landfilled in 2003 demonstrates that there is an abundant amount of MSW available for this scenario. The compatibility of WTE and recycling is discussed later however it is important to note at this point that WTE and recycling are compatible and that processing an additional 33 Mtons of MSW at WTE would not translate into diminished recycling. The majority of post-recycled MSW would continue to be disposed of at landfills.

WTE Energy Benefit

- The life-cycle energy equivalence factors convert to a fossil fuel avoidance of approximately 71 million barrels of oil, 18 million tons of coal or 4190 million therms of natural gas. This is slightly less than the amount avoided by the Existing Case which makes sense due to the greater energy recovery (75 % vs. 45 % landfill gas collection) in the Future Case.

- Consistent with the Existing Case, this energy savings does not consider additional savings that would result if MSW is being long hauled by rail, truck or barge.

WTE Environmental Benefit

- Combustion of an additional 33 million tons of MSW would avoid an additional 14 million tons of greenhouse gas emissions as carbon dioxide. The weighted average for this scenario is approximately 0.45 tons of CO₂ avoided per ton of MSW processed.
- The controlled combustion of MSW would also avoid an additional amount of criteria pollutants including particulate (28,000 TPY), carbon monoxide (43, 000 TPY), SO₂ (129,000 TPY) and NOX (48,000 TPY).
- A significant amount of ambient PM_{2.5} (224,000 TPY) would also be avoided when considering the SO₂ emissions that would have converted to ammonium sulfate (75 % conversion) and the NOx emissions that would have converted to ammonium nitrate (30 % conversion).

The LFGTE option where 75 % of LFG is collected and processed through an internal combustion engine provides better energy and environmental performance than the nationwide average on a “per ton basis” however a typical WTE facility continues to provide far superior performance in regards to both energy recovery and avoidance of criteria pollutants and greenhouse gas emissions.

EMISSION FACTORS – Air Toxics

General Reference

Landfill gas contains nonmethane organic compounds (NMOC) and other trace contaminants, many of which are Hazardous Air Pollutants (HAP) listed in Title III of the 1990 Clean Air Act Amendments. The emission analysis of air toxics from landfill gas management options presented herein is based entirely on EPA’s AP 42⁹ and a landfill gas generation rate of 4980 standard cubic foot per ton of MSW from the EPAs MSW-DST. AP 42 information includes a list of forty-six (46) specific pollutants, their default values and destruction efficiencies. This data is currently used in EPAs Landfill Gas Emissions Model (Landgem) Version 3.02 and is understood to be the most current and complete summary of available emission data from landfills with various landfill gas management options.

Table 8 identifies the LFG constituents and default values from AP 42 for Landfills. The EPA default values were used to determine the uncontrolled emission factor as “pound of pollutant per ton of MSW” with a weighted average being used to proportionally consider both fugitive and point sources. The LFG collection efficiency was used to determine the amount of gas subject to direct treatment whereas the amount not collected was not treated except for oxidation of organic compounds. A weighted average was constructed for each LFG mode (20, 45 and 75 % collection). The Existing Case for air toxics used the same landfill distribution as the criteria and GHG calculations (50 % vent, 25 % flare and 25 % ICE) while the Future Case considered a landfill with 75 % collection and ICE.

Table 9 presents the annualized mass emission rate for three different constituent groups for both the Existing Case and Future Case scenario and disposal of 33 Mtons per year of MSW. These values reflect the MSW-DST life-cycle LFG emission flow rate however the results do not represent a complete lifecycle analysis because there was not sufficient data from all other operating parameters associated with a complete life-cycle assessment. As a point of contrast, the EPA LFG constituents are not considered by EPA to be characteristic of the combustion of MSW at a modern municipal waste combustor due to the controlled automatic combustion process and extensive flue gas temperature, residence time and air pollution control processes when compared to a flare or ICE.

Dioxin emissions are discussed separately because they are not included in AP 42 however EPA's Year 2000 Update¹⁰ does identify two sources of dioxins/furans from landfills – the exhaust of LFG treatment and landfill fires. A direct comparison of WTE and landfills is not readily available for several reasons including 1) WTE has a very robust data base due to the extensive test requirements whereas landfills do not have a test requirement for dioxin, and 2) WTE have an extensive set of monitoring and reporting requirements whereas landfills do not. The importance of long-term monitoring is evident when considering that an independent survey by the NJDEP of LFGTE operating systems¹¹ identified a range of NMOC destruction between 80 and 98 %. NMOC have a relatively low threshold for thermal destruction relative to PCDD/DF emissions therefore it is reasonable to expect significant variability in PCDD/F and other trace pollutants with more difficult thermal destruction requirements¹².

A direct comparison of NMOC emissions between WTE and LFGTE is also difficult due to limited data in AP 42 and the noted variability in actual operations. However, a direct application of AP 42 factors to the existing landfill inventory would yield a LFGTE emission factor range of 0.4 to 0.5 lb/ton of MSW whereas WTE is estimated at approximately 0.03 lb/T. These are general estimates however it is important to note that EPA's Good Combustion Practices for WTE is a federal set of enforceable operating requirements that promotes consistent and continuous low NMOC values. Landfills have a requirement for 98 % destruction of 20 ppm_{dv} at 3 % O₂ as hexane however as noted above by the NJDEP investigation – there are problems with continuous compliance of this standard.

COMPATABILITY OF WTE WITH RECYCLING

The compatibility of WTE and recycling has been challenged on several hypothetical grounds with the most common one being that recycling rates will go down if WTE capacity increases. This hypothesis is based on the idea that communities that commit to a long-term plan with capital investment will forego recycling to assure that there is adequate MSW for the WTE facility. This hypothesis has never been demonstrated in reality however the idea seems to persist.

The compatibility issue was independently evaluated in 1993¹³ and again in 2003¹⁴ with both reports yielding the same general conclusions; WTE and recycling are compatible. Table 10 provides a list of the reasons provided by waste management professionals interviewed for these surveys. At the time of the 2003 survey – the recycle rate for

communities with WTE was 33 % whereas the national average was 28 %. An evaluation of Table 1 shows that the recycle (23 %) and compost (7 %) recycle rate has been consistent from 2000 to 2003 at 30 %. WTE facilities have not been placed into operation since 1995 so there does not appear to be any relationship between the reasonably consistent recycle rates from the referenced surveys and more recent data.

The concept of compatibility was evaluated herein by examining the MSW plan ¹⁵ issued by the New Jersey Department of Environmental Protection. While the NJDEP plan report was not developed or designed to analyze this compatibility issue, the results of the study are informative as a stand alone set of facts because the State of New Jersey has one of the highest recycling rates in the USA while also having one of the largest fractions of MSW going to WTE facilities. Figure 1 presents the recycling rate for each of the twenty-one counties. The five counties that have a WTE facility are highlighted in this figure. It is apparent that the recycling rate is independent of the fact that there was a WTE facility in the same county. It is also important to note that the 2003 New Jersey MSW inventory had the following values; total generation (19.8 Mtons), recycling (10.3 Mtons), WTE (1.5 Mtons), out-of-state landfilling (3.9 Mtons) and in-state landfills (3.8 Mtons). This state-specific information is an independent demonstration that there is a WTE and recycling are compatible and that landfills are the predominant means of disposal.

Additional evidence of the compatibility of WTE with recycling, or that it is not draining MSW from recycle operations, is found in EPA 2005 MSW inventory ¹. Table 3 of this report was adjusted to provide the percent of MSW managed by WTE and landfilling on both a pre and post recycling basis. Figure 2 illustrates both sets of values. The pre-recycle percent for landfills has leveled off at an approximate 56 % factor whereas WTE is at 14 %. Conversely, the post-recycle percent for landfills is 80 % and WTE is 20 %.

The dependence on landfills as the primary post-recycle MSW management option can be due to a variety of factors however it cannot be because it is a superior energy or environmentally management system. Information presented in this analysis and others has identified that even the most effective LFGTE system has a detrimental impact to our energy economy and that the emission rate of greenhouse gases, PM 2.5 precursors and air toxics is significantly greater.

CONCLUSIONS

The objective of this analysis was to consider two key questions confronting our countries concern about energy and the environment;

“How can a country achieve a greater degree of energy independence while also considering environmental consequences such as global climate change?”, and;

“What are the energy and environmental consequences of landfilling MSW instead of using waste-to-energy?”

Analysis of modern waste-to-energy as an energy and environmental management system demonstrates that it provides significant advantages when considering both of these questions. Waste. The remaining question is “what is the best option when deciding how to manage post-recycled MSW?” The advantages of WTE exist are;

- Superior energy generation per ton of MSW that offsets more fossil fuel power,
- Recovery of ferrous and / or nonferrous materials
- Waste -to-energy has been demonstrated to be compatible with recycling
- Reduction of greenhouse gases
- Avoidance of PM_{2.5} precursors
- Avoidance of LFG constituents identified by EPA including 25 that are Hazardous Air Pollutants listed in Title III of the 1990 Clean Air Act Amendments.

The energy savings provided by WTE are significant. The lifecycle analysis identified the savings in energy when MSW is processed in the existing landfill system (Existing Case) and the Future Case. The MSW processed by WTE is 33 Mtons per year for each situation.

Fuel Offset	Units per Year	Existing Case	Future Case	Total
Oil	Million barrels	77	71	148
Coal	Million Tons	19	18	37
Natural Gas	Million Therms	4540	4190	8730

The associated reductions of GHG and criteria pollutants are also significant:

Avoided Emission	Units per Year	Existing Case	Future Case	Total
GHG				
As MTCE	Million metric tons	7.4	3.4	10.8
As CO2	Million tons	30	14	44
Criteria				
CO	Tons	32, 800	42, 700	75, 500
PM	Tons	29, 900	27, 700	57, 600
SO2	Tons	152, 300	128, 900	281, 200
NOx	Tons	51, 800	47, 900	99, 700
PM _{2.5}	Tons	262, 600	224, 400	486, 900

The amount of air toxics avoided by processing MSW with WTE is a smaller in magnitude than the GHG and criteria pollutants number but given their toxicological properties, the value is significant;

Group	Units per Year	Existing Case	Future Case	Total
Total	Tons	7410	3240	10, 650
HAPs	Tons	1650	700	2, 350

The total group includes all 46 of EPA's LFG constituents whereas the HAPs are the 25 pollutants listed as Hazardous Air Pollutants by Title III of the CAAA of 1990. The emission factor of NMOC from WTE is less than 10% of NMOC from landfills.

The information used to arrive at these conclusions is primarily from EPA or other independent sources. A certain degree of uncertainty is associated with the exact emission offsets due to the difference in data quality. The WTE data base is very robust due to the federally enforceable testing, monitoring and reporting requirements, whereas by contrast, the landfill data base is comparative small, largely because federal regulations do not require testing, monitoring or reporting of these constituents with the exception of an annual test for NMOC.

The disposal of MSW in landfills (80 % of post-recycled MSW) is a waste of sustainable energy while also creating an adverse environmental impact relative to WTE. State and Federal governments should consider these issues when evaluating MSW waste management hierarchies and decisions on how to manage MSW.

Table 1
MSW Facts and Figures for 2003 (a)

Table 1A
Total Amount of MSW According to EPA 2003 report
As Millions of Tons

	1960	1970	1980	1990	1995	2000	2001	2002	2003
Total	88.1	121.1	151.6	205.2	213.7	234	231.2	235.5	236.2
Materials Separation									
Recycling	5.6	8	14.5	29	46.2	52.4	52.8	53.8	55.4
Composting	0	0	0	4.2	9.6	16.5	16.6	16.7	16.9
Total Materials Recovery (a)	5.6	8	14.5	33.2	55.8	68.9	69.4	70.5	72.3
Post Recycling Options									
Combustion	27.0	25.1	13.7	31.9	35.5	33.7	33.6	33.4	33.1
Landfill	55.5	87.9	123.4	140.1	122.4	131.4	128.3	131.7	130.8

Table 1B
Distribution of MSW Management
As a Percent of Total

Recycling as % of Total	1960	1970	1980	1990	1995	2000	2001	2002	2003
Materials Separation									
Recycling	6.4	6.6	9.6	14.1	21.6	22.4	22.8	22.8	23.5
Composting	0.0	0.0	0.0	2.0	4.5	7.1	7.2	7.1	7.2
Total Materials Recovery (a)	6.4	6.6	9.6	16.2	26.1	29.4	30.0	29.9	30.6
Post Recycling Distribution									
Combustion	32.7	22.2	10.0	18.6	22.5	20.4	20.8	20.2	20.2
Landfill	67.3	77.7	90.0	81.5	77.5	79.6	79.2	79.8	79.8
Pre Recycling Distribution									
Combustion	30.6	20.7	9.0	15.5	16.6	14.4	14.5	14.2	14.0
Landfill	63.0	72.6	81.4	68.3	57.3	56.2	55.5	55.9	55.4

(a) EPA 2005 Report EPA530-F-05-003. An inventory of MSW values from 1960 through 2003 inclusive.

Table 2
Overview of WTE Status as a Source of Renewable Energy

Federal	State
<ul style="list-style-type: none">• Section 45 Production Tax Credits• Energy Policy Act of 2005 (federal renewable purchasing program)• Biomass Research and development Act of 2000• PURPA• Federal Power Act• Pacific Northwest power Planning and Conservation Act• FERC Regulations• DESC and GSA REC Solicitations	<ul style="list-style-type: none">• California• Connecticut• Hawaii• Iowa• Maine• Maryland• Massachusetts• Michigan• Minnesota• Nevada• New Hampshire• New Jersey• Pennsylvania• Virginia• Washington

**Table 3. Summary of Key Assumptions Used in This
EPA MSW-DST Lifecycle Assessment**

Parameter	Assumption
<i>General</i>	
Waste Composition	National Average – post recovery
Waste Collection Frequency	1 times per week
<i>Transportation Distances</i>	
Collection to WTE	10 miles one way
Collection to Landfill	10 miles one way
WTE Facility to Ash Landfill	10 miles one way
<i>WTE Facility</i>	
Basic Design	Mass Burn
Heat Rate	17,500 BTU/kWh
Waste Input Heating Value	Varies by waste constituent
Ferrous Metal Recovery Rate	70%
Utility Sector Offset	Offset is baseload coal, oil, and natural gas power production based on the National Power Grid mix.
<i>Landfill</i>	
Basic Design	Subtitle D
Time Period for Calculating Emissions	100 years
Landfill Gas Management	50% vent, 25% flare, 25% energy recovery
Landfill Gas Collection Efficiency	Varied, where applicable, at 20%, 45%, and 75%
Utility Sector Offset	Offset is baseload coal, oil, and natural gas power production based on the National Power Grid mix.

Table 4
Energy Equivalent Factors
Amount of Fossil Fuel Offset by One Ton of MSW
When Processed by WTE

Fossil Fuel	Coal as tons	Oil as barrels	Natural Gas as Therms
Conventional Equivalence	0.27	1	60
Life-cycle Equivalence (a)	0.57	2.3	140

(a) Based on existing MSW disposal practices and 45 % LFG collection.

Table 5
Matrix of MSW Management Scenarios
Considered in MSW-DST Analysis

	Landfill Gas (LFG) Collection Efficiency as % (a)			
	0	20	45	75
Vent	1	---	---	---
Flare	---	2a	2b	2c
ICE	---	3a	3b	3c
Flare/ICE Mix	---	4a	4b	4c
Bioreactor	---	5a	5b	5c

(a) The "percent value" indicates the amount collected by the LFG collection system for delivery to some form of LFG technology (flare or ICE).

Table 6
Existing Case – Current Annual
Energy and Environmental Benefits
Of Disposing of 33 Million Tons of MSW by WTE

Reference Information		Landfill Gas Collection Efficiency as %		
Emissions Avoided	Units per Year	20%	45	75
GHG				
as MTCE	Million metric Tons	8.2	7.4	6.4
as CO2	Million tons	33	30	26
Criteria				
CO	Tons	29,000	33,000	37,000
PM	Tons	30,000	30,000	30,000
SO2	Tons	155,000	152,000	150,000
NOX	Tons	52,000	52,000	52,000
PM 2.5				
(NH4)2SO4	Tons	239,000	237,000	231,000
NH4NO3	Tons	27,000	27,000	27,000
Sum	Tons	266,000	263,000	258,000
Energy saved				
Total Energy	Million MBTU	460	450	450
Oil Equivalence	Million Barrels	78	77	76
Coal Equivalence	Million tons	19	19	19
Natural Gas Equivalence	Million Therms	4570	4540	4500

(a) The emission impact determined by the life-cycle assessment is based on a comparison of MSW being processed by either a WTE facility or a landfill facility with the landfill having two variables – the amount of LFG being collected and the process for treating the LFG. LFG that is not collected is treated a fugitive emission. The results are “negative” or avoided emissions. From a practical perspective, there is less of an environmental impact when processing MSW by WTE than a landfill with any form of LFG process.

(b) The energy impact determined by the life-cycle assessment is based on a comparison of MSW being processed by either a WTE facility or a landfill facility with the landfill having two variables – the amount of LFG being collected and the process for treating the LFG. LFG that is not collected is treated a fugitive emission. The results demonstrate that WTE saves energy and as a result, there is less need for the use of fossil fuels for generation of electrical power.

Table 7
Future Case – Potential Annual
Energy and Environmental Benefits
Of Disposing an Additional 33 Million Tons of MSW by WTE

Reference Information		Landfill Gas Collection Efficiency as %		
Emissions Avoided	Units per Year	20%	45	75
GHG				
as MTCE	Million metric Tons	---	---	3.4
as CO2	Million tons	---	---	14
Criteria				
CO	Tons	---	---	43, 000
PM	Tons	---	---	28, 000
SO2	Tons	---	---	129, 000
NOX	Tons	---	---	48, 000
PM 2.5				
(NH4)2SO4	Tons	---	---	199, 000
NH4NO3	Tons	---	---	25, 000
Sum	Tons	---	---	224, 000
Energy saved				
Total Energy	Million MBTU	---	---	420
Oil Equivalence	Million Barrels	---	---	71
Coal Equivalence	Million tons	---	---	18
Natural Gas Equivalence	Million therms	---	---	4190

(a) The emission impact determined by the life-cycle assessment is based on a comparison of MSW being processed by either a WTE facility or a landfill facility with the landfill having two variables – the amount of LFG being collected and the process for treating the LFG. LFG that is not collected is treated a fugitive emission. The results are “negative” or avoided emissions. From a practical perspective, there is less of an environmental impact when processing MSW by WTE than a landfill with any form of LFG process.

(b)The energy impact determined by the life-cycle assessment is based on a comparison of MSW being processed by either a WTE facility or a landfill facility with the landfill having two variables – the amount of LFG being collected and the process for treating the LFG. LFG that is not collected is treated a fugitive emission. The results demonstrate that WTE saves energy and as a result, there is less need for the use of fossil fuels for generation of electrical power.

Table 8 - Default Concentrations for Landfill Gas Constituents From EPAs AP-42

Item	Code	Pollutant	MW	Default ppmv	Rating
1	a	1,1,1-Trichloroethane (methylchloroform)	133.41	0.48	B
2	a,b	1,1,2,2 – Tetrachlorethane	167.85	1.11	C
3	a,b	1,1 – Dichloroethane (ethylidene dichloride)	98.97	2.35	B
4	a,b	1,1 – Dichloroethene (vinylidene chloride)	96.94	0.2	B
5	a,b	1,2 – Dichloroethane (ethylene dichloride)	98.96	0.41	B
6	a,b	1,2 – Dichloropropane (propylene dichloride)	112.99	0.18	D
7	b	2 – Propanol (isopropyl alcohol)	60.11	50.1	E
8		Acetone	58.08	7.01	B
9	a,b	Acrylnitrile	53.06	6.33	D
10	a,b	Benzene	78	1.91	B
11	b	Bromodichloromethane	163.83	3.13	C
12	b	Butane	58.12	5.03	C
13	a,b	Carbon disulfide	76.13	0.58	C
14		Carbon monoxide	28.01	141	E
15	a,b	Carbon tetrachloride	153.84	0.004	B
16	a,b	Carbonyl sulfide	60.07	0.49	D
17	a,b	Chlorobenzene	112.56	0.25	C
18		Chlorodifluoromethane	86.47	1.3	C
19	a,b	Chloroethane (ethylchloride)	64.52	1.25	B
20	a,b	Chloroform	119.39	0.03	B
21	b	Chloromethane	50.49	1.21	B
22	b	Dichlorobenzene	147	0.21	E
23		Dichlorodifluoromethane	120.91	15.7	A
24	b	Dichlorofluoromethane	102.92	2.62	D
25	a	Dichloromethane (methylene chloride)	84.94	14.3	A
26	b	Dimethyl sulfide (methyl sulfide)	62.13	7.82	C
27		Ethane	30.07	889	C
28	b	Ethanol	46.08	27.2	E
29	b	Ethyl mercaptan (ethanethiol)	62.13	2.28	D
30	a,b	Ethylbenzene	106.16	4.61	B
31	a,b	Ethylene dibromide	187.88	0.001	E
32	b	Fluorotrichloromethane	137.38	0.76	B
33	a,b	Hexane	86.18	6.57	B
34		Hydrogen sulfide	34.08	35.5	B
35	a	Mercury (total)	200.61	0.000292	E
36	a,b	Methyl Ethyl Ketone	72.11	7.09	A
37	a,b	Methyl isobutyl ketone	100.16	1.87	B
38	b	Methyl mercaptan	48.11	2.49	C
39	b	Pentane	72.15	3.29	C
40	a	Pechloroethylene (tetrachloroethylene)	165.83	3.73	B
41	b	Propane	44.09	11.1	B
42	b	t-i,2-dichloroethane	96.94	2.84	B
43	a,b	toluene	92.13	39.3	A
44	a,b	Trichloroethylene (trichloroethene)	131.4	2.82	B
45	a,b	Vinyl Chloride	62.5	7.34	B
46	a,b	Xylenes	106.16	12.1	B

(a) Hazardous Air Pollutant listed in Title III of 1990 Clean Air Act Amendments.

(b) Considered volatile organic compound (VOC) as defined by USEPA in 40 CFR 51.100(s).

Table 9
Annual Avoided LFG Emission Factor
for LFG Constituents When Disposing of
33 Million Tons of MSW by WTE

	Existing Case Annual Emissions as TPY			Future Case Annual Emissions as TPY
	20	45	75	75
LFG Collection %				
Pollutant Group				
Total (a) (c)	8270	7410	6370	3240
HAPs (b)	1860	1650	1410	700
NMOC	8580	7640	6520	2560

(a) All 46 pollutants listed in Table 8.

(b) The 25 pollutants from Table 8 that are identified as being Title III Hazardous Air Pollutants.

(c) Carbon monoxide is one of the listed 46 LFG constituents however its emissions have been removed from the total due to several EPA notes questioning the consistent presence of CO as a LFG constituent.

Table 10
Ways that WTE and Recycling Are Compatible (a)

- | |
|--|
| <ul style="list-style-type: none"> • Communities are more self-sufficient in terms of managing their own waste locally. • Fewer operation and maintenance problems at WTE when non-burnable recyclables are diverted • WTE provides a short-term management option when recycling markets are not available. • WTE promotes recycling by way of subsidies and incentives (e.g. tip fee surcharge) • The more materials are recycled locally – the more a WTE facility can tap the commercial and spot waste markets to yield better plant economics. • With aggressive recycling, the WTE plant can serve a larger surrounding area and meet the needs of a fast-growing location. • Recycling high btu fuels such as paper and plastic lowers the overall waste higher heating value. This results in more efficient plant operations and waste processing capabilities. • Waste to energy is a pure form of recycling since it converts waste into energy. |
|--|

(a) Comments by solid waste management professionals interviewed as part of the referenced surveys.

Figure 1
Recycling Rates of New Jersey Counties
With and Without Waste-to-Energy Facilities

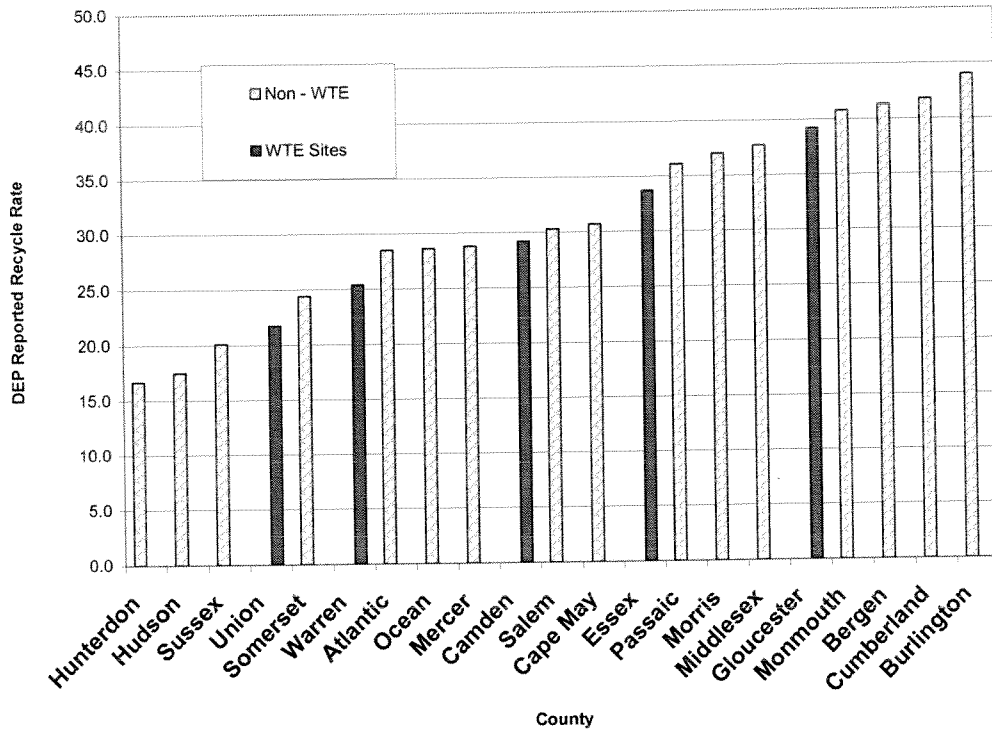
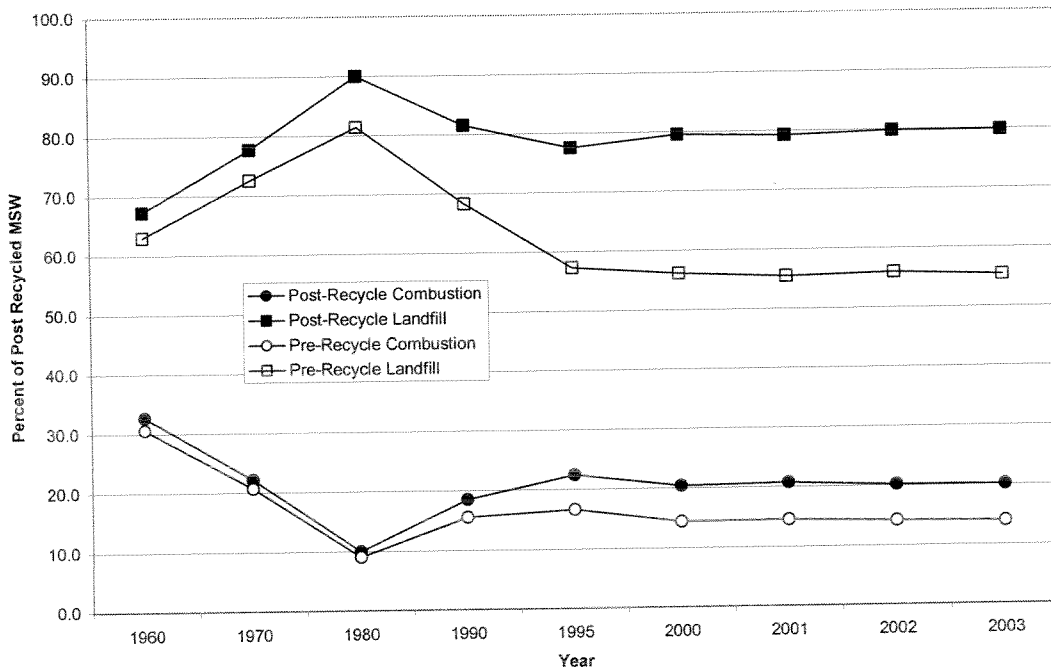


Figure 2



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's Center for Environmental Analysis to assist communities and other waste planners in conducting cost and environmental modeling of MSW management systems. Users can evaluate the numerous MSW management strategies 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, 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 a commercial linear programming solver called CPLEX. 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.

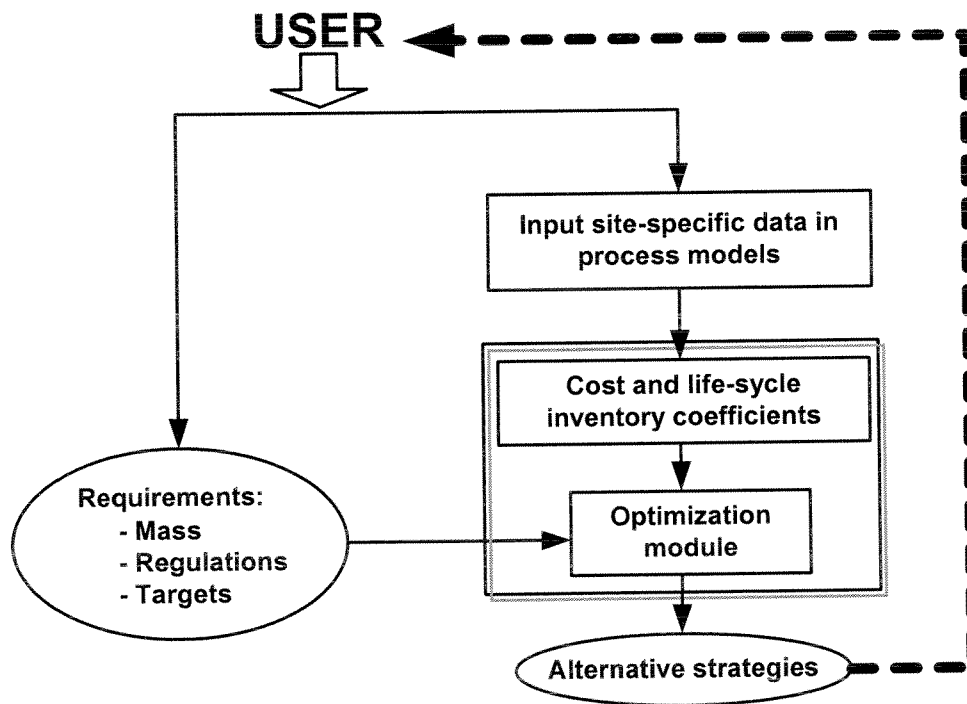


Figure A-1. Conceptual Framework for the MSW DST.

The environmental aspects associated with a defined MSW management strategy 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.

In terms of GHGs, the MSW DST accounts for CO₂ and methane emissions. Although there are other potential GHGs, CO₂ and methane are the main emissions associated with waste management. CO₂ emissions from fossil and nonfossil sources are tracked separately. This is because CO₂ emissions from nonfossil sources are typically given a “zero” weighting when converted to GHG equivalents. In addition to reporting emissions of CO₂ and methane, the MSW DST converts these emissions into an aggregate greenhouse gas equivalent (GHE) value using metric tons of carbon equivalent (MTCE) emitted per year as the reporting unit.

In addition to modeling GHG emissions for each scenario, we used a feature of the MSW DST that allows users to identify an objective (such as “minimize cost”) for each run of the model. Here, for each model run, we specified the objective of identifying waste management options that would minimize GHG emissions. We then conducted iterative runs of the model, at each pass seeking the waste management solution that minimizes GHG emissions within the constraints of the scenario.

Table A-1 includes a list of the various stakeholders that participated in the development of the MSW DST. Annual stakeholder workshops and smaller stakeholder working group meetings were held and stakeholders provided input to and review of the specific modules (e.g., combustion, landfill) of the MSW DST.

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