TOOL 9. ENERGY AND ENVIRONMENTAL ANALYSIS OF RECYCLING

INTRODUCTION

All human activity, including recycling, has some resource and environmental consequences. Recovery for recycling usually saves energy and reduces solid wastes landfilled. The most obvious benefit to recycling is diversion of recovered materials from conventional disposal, i.e., reduced dependence on landfills.

• Recovery for recycling usually saves energy and reduces solid wastes landfilled.

This analysis quantifies the energy and land disposal usage of four residential MSW scenarios: 1) 100 percent landfill disposal of residential MSW; 2) curbside recovery of recyclable materials with landfill disposal of the remaining MSW; 3) yard trimmings composting with landfill disposal of the remaining MSW; and 4) curbside recovery of recyclable materials plus yard trimmings composting with landfill disposal of the remaining MSW.

METHODOLOGY

In order to quantify energy and solid waste disposal requirements associated with each waste management scenario, a methodology known as life cycle inventory (LCI) serves as the basis for the analysis. LCI is a comprehensive technique that quantifies energy requirements and environmental emissions for a given product or system based upon the study boundaries established. The basic steps for which energy requirements and environmental effects are considered in this analysis of municipal solid waste management scenarios are:

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captured for composting represent 27 percent (by weight) of the total waste stream. The remaining household MSW discarded for disposal accounts for the other 54 percent (by weight) of the waste stream.

Energy requirements and solid waste disposal associated with each of the scenarios are summarized in the sections that follow. Energy required represents the energy used for collection vehicles and landfill equipment, recycling and compost processing, and transporting recovered materials to market. Energy credit represents energy savings due to recycling materials and the corresponding reduction in energy required for remanufacturing products (versus manufacturing with virgin raw materials). Solid waste includes processing residues from material recovery and compost facilities and any remaining municipal solid waste.

SCENARIO 1. LANDFILLING ONLY

For Wyoming, landfill disposal typically remains the primary method used to dispose of municipal solid waste (MSW). This scenario assumes no alternative solid waste management options are used and all MSW is collected and transported to landfill for disposal.

- **For Wyoming, landfill disposal typically remains the primary method used to dispose of MSW.**

Landfill disposal of MSW begins with the collection and transporting of MSW from the point of generation to the landfill through a collection vehicle, and includes moving the waste into landfill cells using earth moving equipment. Landfill disposal requires relatively little energy, about 0.5 million Btu (or 3 gallons of fuel) per ton of residential municipal solid waste landfilled. As a relative comparison, the average annual residential energy consumption per household is about 100 million Btu (U.S. Energy Information, 1990). Therefore the energy required to landfill

Table 9-1

RESIDENTIAL MUNICIPAL SOLID WASTE STREAM FROM A PARTICIPATING HOUSEHOLD CONSIDERED FOR WASTE MANAGEMENT OPTIONS (1)

	Avg. Pounds per week Generated from a Participating Household	Percent of Total Generated from a Participating Household
Recyclables separated		
Newspapers	2.0	5.5%
Glass containers	3.3	8.8%
Steel cans	0.9	2.4%
HDPE natural and colored bottles	0.4	1.1%
Aluminum cans	0.4	0.9%
PET soft drink bottles	0.2	0.5%
Total Recyclables	7.1	19%
Yard trimmings separated	10	27%
Other MSW discarded	20	54%
Total Residential MSW Generated	37	100.0%

(1) Represents a typical waste stream from a single family household participating in a curbside recycling program located in a rural area. Typical yard trimmings generation assumed. Bulky waste items excluded.

Source: Franklin Associates, Ltd.

one ton of residential MSW represents less than one percent of the average annual household energy consumption. Once landfilled, however, the energy "investment" associated with the original manufacture and use of the product are lost.

- **The energy required to landfill one ton of residential MSW represents less than one percent of the average annual household energy consumption.**

Environmental costs of landfilling include land use loss, possible ground and surface water contamination, and methane and carbon dioxide air emissions. Land requirements are large during active landfilling and, after closure, the land use is limited. Recreational faciltities, such as parks, have been built on closed landfills. Use of the land surrounding an active landfill may be affected due to truck traffic, blowing debris, noise, and odors.

A landfill with an inadequate liner and/or leachate collection system may contaminate groundwater by migration of liquid through the soil. Improper control of surface water run-off at the landfill may impact surrounding surface water sources.

Microorganisms present in landfills produce gaseous byproducts. The gases of most environmental concern are methane (CH_4) and carbon dioxide (CO_2). Both gases have been identified as contributing to the "greenhouse effect". Methane, produced by anaerobic microorganisms, can be captured and used as an energy source. If not recovered for energy use, the gas must be vented to reduce the possiblity of explosion. Both aerobic and anaerobic microorganisms produce CO_2 as a byproduct. Although not a safety hazard, CO_2 has been identified as a greenhouse gas and therefore results in some environmental costs.

- **Microorganisms present in landfills produce methane and carbon dioxide gases.**

SCENARIO 2. CURBSIDE RECYCLING AND LANDFILLING

For a conventional curbside program, recyclables are collected separately and processed at a materials recovery facility (MRF). Processed recyclables are shipped to market, where the materials are substituted for virgin raw materials and used to remanufacture new products. Average, or typical, shipping distances for an area similar to Wyoming are assumed for this analysis. The remaining MSW and residue from the recovery facility are transported to the landfill for final disposal.

- **For a conventional curbside program, recyclables are collected separately and processed at a MRF.**

Energy requirements and solid waste generated assuming curbside recycling and landfill disposal are summarized in Table 9-2. Based on a mix of recyclables materials commonly found in a curbside collection program, compared to landfill only disposal, recycling results in less solid waste landfilled, and a net energy savings (due to increased use of recyclable materials in place of virgin raw materials in remanufacturing). Accounting for MRF residue, total residential municipal solid waste landfilled (from a participating single-family household) is reduced by approximately 18 percent (versus landfill disposal only).

Because the primary emphasis of this manual is residential municipal solid waste management, changes in industrial process waste due to increased use of recyclable materials in remanufacturing are not included in the tables in this tool. Generally industrial process wastes are reduced when recyclable materials are substituted for virgin raw materials. Based on the mix of recovered recyclables assumed for this study, approximately one pound of process wastes are avoided for every two pounds of recyclable material used in place of virgin raw materials. Thus for this analysis approximately 190 pounds of process wastes are avoided due to the use of over 380 pounds of recyclable materials in the remanufacturing process.

- **Generally industrial process wastes are reduced when recyclable materials are substituted for virgin raw materials.**

Gross energy requirements of approximately 0.8 million Btu per ton of residential municipal solid waste generated account for collecting MSW and recyclables, sorting and preparing recyclables for market, transporting recyclables to market, and landfilling remaining municipal solid waste and MRF residues. This assumes that recyclables are collected through a curbside program. If recyclables are collected through buy-back or drop-off sites, collection energy requirements are slightly higher than through curbside programs.

• Collection energy requirements are slightly higher for a buy-back or drop-off recycling program compared to a curbside collection program.

The most significant energy and environmental effects are not from the collection, processing, and shipment of recovered materials. Rather, the most significant effects are realized due to the increased use of recovered materials in the manufacturing step. Recycling recovered materials into new products often involves different processes than those using virgin raw materials. The most notable difference is replacement of processes associated with virgin raw material extraction and processing by the processes of collecting, sorting and preparation, and shipping recovered materials to market. Differences in manufacturing with recovered materials versus virgin raw materials also occur. The different steps involved when manufacturing with recovered materials versus virgin raw materials result in different energy demands and environmental emissions.

• The most significant energy and environmental savings are realized due to the increased use of recovered materials in the manufacturing step.

In general, mining and manufacturing energy requirements are less with recovered materials than with virgin raw materials. For example, when producing aluminum cans from virgin raw materials, the energy requirements are quite large, over 200 million Btu per ton of cans produced. Using recovered aluminum in place of virgin aluminum reduces energy demand to about 50 million Btu per ton of cans produced, saving about 150 million Btu per ton. In contrast, when virgin raw materials are used to produce glass containers, the energy requirements are about 15 million Btu per ton of glass containers. Using post-consumer cullet in place of virgin raw

• In general, energy requirements are less with recovered materials than with virgin raw materials.

material reduces energy demand to approximately 13 million Btu per ton of glass containers produced, saving about 2 million Btu per ton.

In reality, most products are made using a combination of virgin and recovered raw materials. In fact, because of inherent yield losses in the manufacturing process, even a process striving to use 100 percent recovered materials will require some virgin raw materials to replace the losses. It should also be noted that in some industries, such as the paper industry, energy is generated from the use of residual wastes from virgin production.

• In some industries, such as the paper industry, energy is generated from the use of residual wastes from virgin production.

Table 9-2 includes energy savings associated with reusing a mix of over 380 pounds of recyclable materials in manufacturing, and totals over 3 million Btu. Net energy savings assuming recycling and landfill disposal are approximately 2.6 million Btu per ton of residential MSW generated from a participating household. This energy savings represents approximately 3 percent of the annual energy consumption experienced by a typical household in the U.S. Aluminum cans and plastic containers account for approximately 75 percent of the energy savings realized through the increased use of this assumed mix of recyclable materials in remanufacturing.

It should be noted that the energy savings associated with increased recycling are based on a mix of materials normally collected in a residential curbside collection program. Also system variables, such as shipping distances to end markets and manufacturing efficiencies, are assumed to be normal, or typical, for this analysis. Therefore, in some circumstances the energy savings associated with an individual material could be less than the savings determined in this analysis.

• System variables, such as shipping distances to end markets and manufacturing efficiencies will affect the energy savings associated with an individual material.

Table 9-2

ENERGY AND SOLID WASTE SUMMARY PER TON OF SINGLE-FAMILY RESIDENTIAL MSW GENERATED *
SCENARIO 2 CURBSIDE RECYCLING AND LANDFILL DISPOSAL
(In thousand Btu and pounds of solid waste landfilled)

Energy Requirements	(thousand Btu)
Recycling	
Curbside collection of recyclables	254
Materials recovery facility processing	55
Residue landfill disposal	8
Transportation of recyclables to market	
Newspaper	56
Glass	24
All others	16
Collection and landfill disposal of MSW remaining after curbside collection of recyclables	426
Gross Energy Requirements	838
Manufacturing energy savings realized	
Aluminum cans	(1,305)
Newspaper	(507)
Plastic containers	(1,261)
Steel cans	(216)
Glass containers	(162)
Total Energy Savings Realized	(3,452)
Net Energy Requirements	(2,614)
Solid Waste Landfilled (1)	**(pounds)**
MSW landfilled	1,615
Residue from MRF	31
Total Solid Waste Landfilled	1,646

* Assuming household participation in curbside recycling program.

(1) Solid waste landfilled includes residential MSW and residue from MRF. Industrial solid process waste avoided due to increased use of recyclables in remanufacturing is not included.

Source: Franklin Associates, Ltd.

SCENARIO 3. YARD TRIMMINGS COMPOSTING AND LANDFILLING

Composting is a municipal solid waste management technique involving the biological degradation of organic wastes. Yard trimmings account for the majority of composting activity in the United States. Composting is increasing primarily due to state-wide bans of yard trimmings in landfills. For this analysis, the windrow process is assumed for yard trimmings composting. In windrow composting, processed materials are formed into elongated piles with sloped sides placed on a flat surface. The piles are turned periodically, providing active aeration and mixing of surface material into the windrow. For this scenario, yard trimmings are curbside collected separately from MSW and composted at a windrow facility. Remaining MSW and compost residues are transported to a landfill for disposal.

•Composting is a MSW management technique involving the biological degradation of organic wastes.

Energy requirements and solid waste generated assuming composting and landfill disposal are summarized in Table 9-3. Accounting for compost residue, total residential municipal solid waste landfilled is reduced by 24 percent (versus landfill disposal only). Total energy requirements, which are approximately 0.6 million Btu per ton of residential municipal solid waste generated, include separate collection of yard trimmings and the remaining MSW, composting the yard trimmings, and landfilling the remaining MSW and compost residues. Similar to the landfill disposal scenario, the energy requirements for this scenario are relative small compared to total household energy consumption.

•The energy requirements for this scenario are relatively small compared to total household energy consumption.

Table 9-3
ENERGY AND SOLID WASTE SUMMARY PER TON
OF SINGLE-FAMILY RESIDENTIAL MSW GENERATED
SCENARIO 3 YARD TRIMMINGS COMPOSTING AND LANDFILL DISPOSAL
(In thousand Btu and pounds of solid waste landfilled)

Energy Requirements	(thousand Btu)
Yard trimmings composting	
Curbside collection of yard trimmings	98
Windrow composting facility	60
Residue landfill disposal	14
Collection and landfill disposal of MSW remaining after curbside collection of yard trimmings	385
Total Energy Required	557
Solid Waste Landfilled	(pounds)
MSW landfilled	1,459
Residue from composting	54
Total Solid Waste Landfilled	1,513

Source: Franklin Associates, Ltd.

SCENARIO 4. CURBSIDE RECYCLING PLUS YARD TRIMMINGS COMPOSTING

In this scenario household recyclables and yard trimmings are curbside collected separately (i.e., two vehicles). Recyclables are processed at a MRF and yard trimmings are windrow composted. Processed recyclables are shipped to market, where they are substituted for virgin raw materials and remanufactured. Residue from recycling and composting is transported to landfill for disposal. The remaining MSW is collected separately and transported to a landfill for disposal.

- **Yard trimmings account for the majority of composting activity in the United States.**

Energy requirements and solid waste generated assuming recycling, composting, and landfill disposal are summarized in Table 9-4. Because yard trimmings composting and recycling are included as key components of residential municipal solid waste management, a reduction of 42 percent in residential municipal solid waste ultimately landfilled from a participating household is possible (versus landfill disposal only).

Gross energy requirements for this scenario are over 0.8 million Btu per ton of residential municipal solid waste generated. However, energy savings due to increased use of recovered materials in the remanufacturing process provide a total energy saving of over 3 million Btu, or a net energy saving of about 2.6 million Btu per ton of residential municipal solid waste generated.

Table 9-4

ENERGY AND SOLID WASTE SUMMARY PER TON
OF SINGLE-FAMILY RESIDENTIAL MSW GENERATED *
SCENARIO 4 CURBSIDE RECYCLING, YARD TRIMMINGS COMPOSTING,
AND LANDFILL DISPOSAL
(In thousand Btu and pounds of solid waste landfilled)

Energy Requirements	(thousand Btu)
Recycling	
Curbside collection of recyclables	254
Materials recovery facility processing	55
Residue landfill disposal	8
Transportation of recyclables to market	
Newspaper	56
Glass	24
All others	16
Yard trimmings composting	
Curbside collection of yard trimmings	98
Windrow composting facility	60
Residue landfill disposal	14
Collection and landfill disposal of MSW remaining after curbside collection of recyclables and yard trimmings	283
Gross Energy Requirements	867
Manufacturing energy savings realized	
Aluminum cans	(1,305)
Newspaper	(507)
Plastic containers	(1,261)
Steel cans	(216)
Glass containers	(162)
Total Energy Savings Realized	(3,452)
Net Energy Requirements	(2,585)
Solid Waste Landfilled (1)	(pounds)
MSW landfilled	1,074
Residue from MRF	31
Residue from compost	54
Total Solid Waste Landfilled	1,159

* Assuming household participation in curbside recycling program.

(1) Solid waste landfilled includes residential MSW and residue from MRF and composting facility. Industrial solid process waste avoided due to increased use of recyclables in remanufacturing is not included.

Source: Franklin Associates, Ltd.

SUMMARY

The limited environmental analysis in this tool allows communities to begin to identify and understand the energy and environmental trade-off's associated with different solid waste management alternatives, and provide some perspective on the relative magnitude of net energy requirements and solid waste disposal requirements of each alternative.

From the standpoint of energy resources, the most significant effects are not from the collection, processing, and shipment of recovered materials. Rather, the most significant effects are realized due to the increased use of recovered materials in the manufacturing step. Approximately 2 million Btu of energy is required to collect, prepare for shipment, and transport to market, one ton of recyclable materials typically collected through a curbside collection program. However, the energy savings realized through the increased use of these materials in remanufacturing are approximately 18 million Btu.

Based on 5 million tons of recyclable materials collected through curbside programs in the U.S., and an average annual residential energy consumption per household of about 100 million Btu, the annual energy savings associated with curbside recycling in the U.S. is equivalent to the energy requirements of 840,000 residential households (U.S. Energy Information, 1990). Most of the energy conserved is derived from recycling aluminum, some plastics, and newspapers. Typically, the energy and/or environmental benefits occur outside the community from which the material is recovered for recycling (except for reduction of landfill requirements).

A summary of energy and landfill requirements for the four SWM scenarios reviewed is shown in Table 9-5 and Figures 9-1, 9-2.

Table 9-5

ENERGY AND SOLID WASTE SUMMARY FOR VARIOUS WASTE MANAGEMENT SCENARIOS: ONE TON BASIS*
(In thousand Btu and pounds)

	Scenarios Evaluated			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	Landfill	Curbside Recycling; Landfill	Compost; Landfill	Curbside Recycling; Compost; Landfill
Energy Requirements (1)				
Energy demand	527	838	557	867
Energy credit		(3,452)		(3,452)
Net energy required	527	(2,614)	557	(2,585)
MSW Disposed (pounds) (2)	2,000	1,646	1,513	1,159

* Based on one ton of solid waste generated from a participating single family household located in a rural area. Typical generation of yard trimmings assumed. Bulky waste items excluded.

(1) Values in parenthesis represent energy savings due to recycling materials and the corresponding reduction in energy required for remanufacturing products (versus manufacturing with virgin raw materials).

(2) Includes MSW landfilled, and residues from MRF and compost facility.

Source: Franklin Associates, Ltd.

Figure 9-1. Energy Summary For Solid Waste Management Scenarios

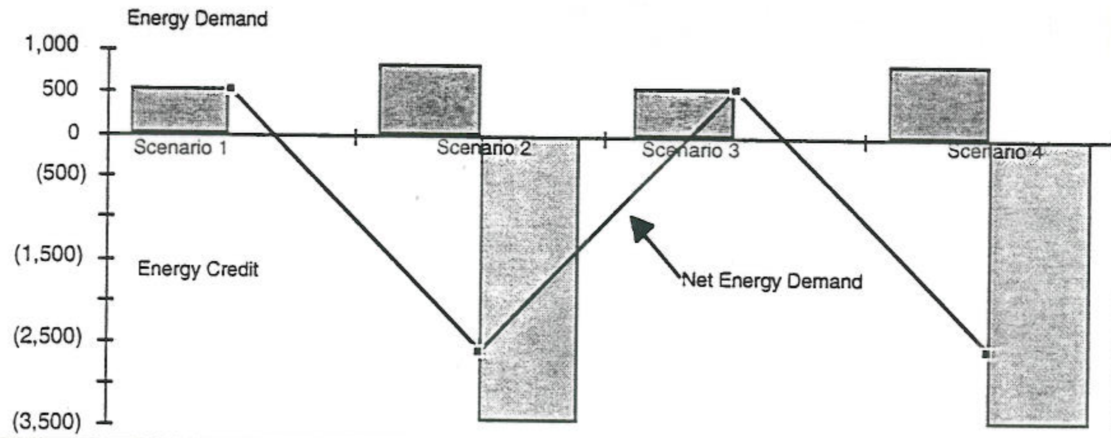

Figure 9-2. Solid Waste Summary For Solid Waste Management Scenarios