7. ENERGY IMPACTS

The previous chapters of this report were focused on life-cycle GHG emissions associated with each of five management options for MSW. Materials have energy impacts at each life-cycle stage; the stages addressed in this report include the acquisition of raw materials, the manufacture of raw materials into products, and product disposal or recovery. Waste *reduction* practices (source reduction, recycling, and reuse) reduce the demand for raw material and energy inputs to the manufacturing stage of the life cycle, thereby conserving energy and reducing GHG emissions. Energy savings can also result from some waste *disposal* practices, including waste-to-energy combustors and landfill gas-to-energy systems.

To better understand the relationship between materials management and energy use, energy factors were developed for four waste management practices (source reduction, recycling, combustion, and landfilling), and this chapter includes a discussion on how to use these energy factors and the relationship between energy savings and GHG benefits.

7.1 METHODOLOGY FOR DEVELOPING ENERGY FACTORS

The methodology used to develop these emission factors is fundamentally the same as described in the preceding chapters, except that here the researchers view all life-cycle components through the lens of energy consumption or savings, rather than GHG emissions. Components such as forest carbon sequestration and landfill carbon storage are not a part of the energy life cycle; therefore they are not described here. The energy factors are based primarily on the amount of energy required to produce 1 ton of a given material. The total energy consumed is a result of direct fossil fuel and electricity consumption associated with raw material acquisition and manufacturing; fossil fuel consumption for transportation; and embedded energy. The total process and transportation energy for the production of both virgin and recycled materials is shown in Exhibits 2-3 to 2-7. Although the GHG emission factors are a product of fuel mix and the carbon coefficients of fuels, the energy factors are based only on the energy consumption (direct fossil fuel and electricity) component and are left in terms of Btu of energy consumption. Therefore, the total process energy required to make 1 ton of a particular material is the sum of energy consumed across all of the fuel types.

The total energy, or embodied energy, required to manufacture each material is made up of two components: (1) process and transportation energy, and (2) embedded energy (i.e., energy of the raw material). The process and transportation components are conceptually straightforward, but embedded energy is more complex. Embedded energy is the energy contained within the raw materials used to manufacture a product. For example, the embedded energy of plastics is due to their being made from petroleum. Because petroleum has an inherent energy value, the amount of energy that is saved through plastic recycling and source reduction is directly related to the energy that could have been produced if the petroleum had been used as an energy source rather than as a raw material input. Aluminum is the other material in this analysis that includes an embedded energy component. The aluminum smelting process requires a carbon anode, which is consumed during the electrolytic reduction process; carbon anodes are made from coal, itself an energy source. Total energy values contained in this report also include both nonrenewable and renewable sources. For example, the total energy savings estimate for recycling paper includes some renewable energy fuel sources that may have little or no associated GHG emissions.

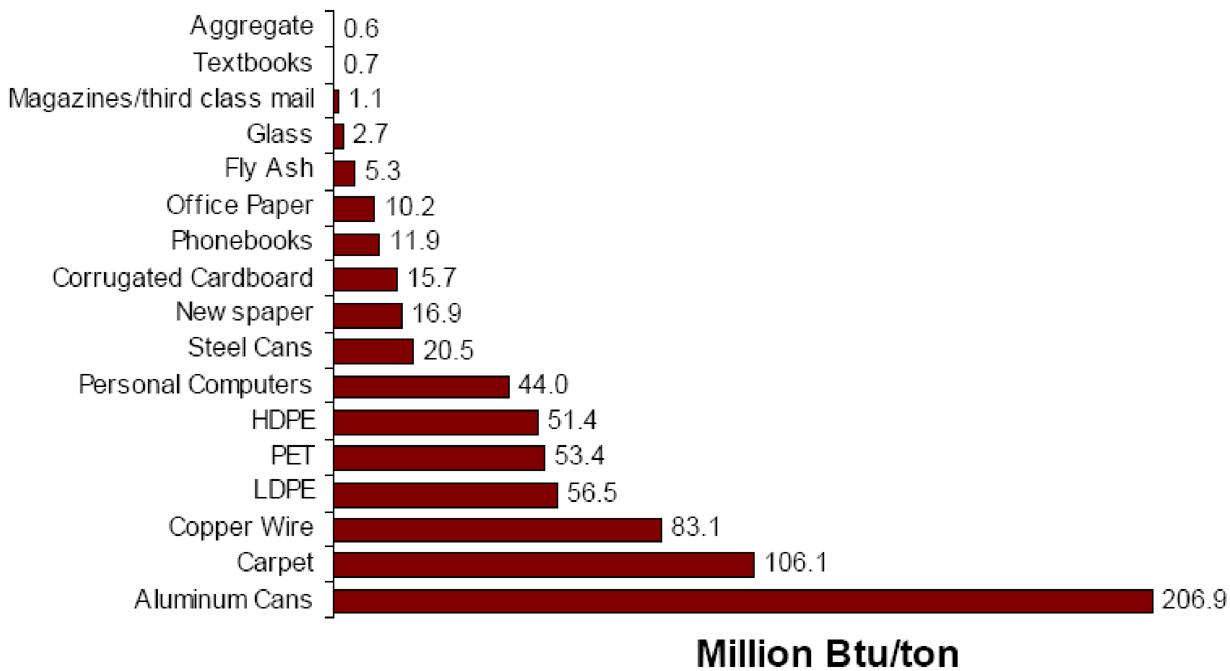
7.2 ENERGY IMPLICATIONS FOR WASTE MANAGEMENT OPTIONS

This chapter presents the life-cycle energy implications for four waste management practices. As with the GHG emission factors already presented, negative values indicate net energy savings.

Waste reduction efforts such as source reduction and recycling can result in significant energy savings. Source reduction techniques such as double-sided copying and light-weighting are in most cases more effective at reducing energy than recycling. This is because source reduction significantly reduces energy consumption associated with raw material extraction and manufacturing processes.

When comparing recycling to landfill disposal, aluminum cans give the greatest energy savings per ton, as shown in Exhibit 7-1. These savings reflect the nature of aluminum production; manufacturing aluminum cans from virgin inputs is very energy intensive, whereas relatively little energy is required to manufacture cans from recycled aluminum. Recycling carpet also results in significant energy savings, since the recycled material is turned into secondary products and the energy-intensive processes that would have been used to manufacture those secondary products are avoided.

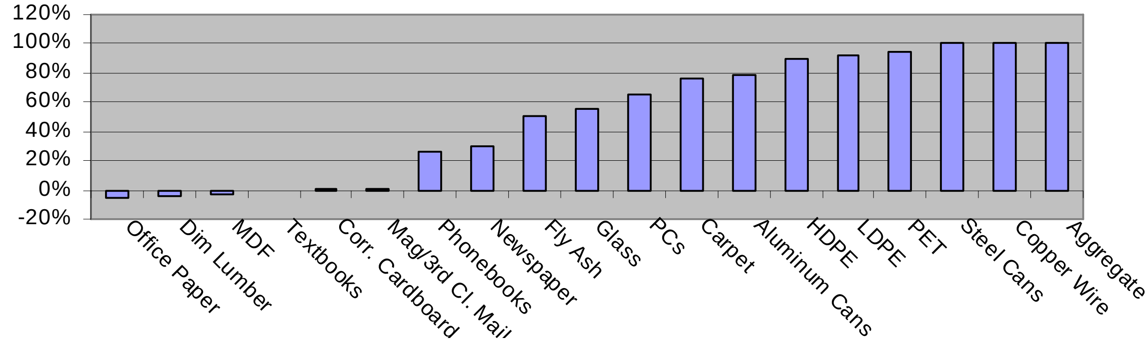
Exhibit 7-1 Energy Savings per Ton Recycled [a]



[a] Assumes recycled materials would otherwise have been landfilled. Aggregate refers to concrete recycled as aggregate.

Some materials, such as dimensional lumber and medium-density fiberboard, actually use more energy when they are made from recycled inputs. For these materials, the recovery and processing of recycled material is more energy intensive than making the material from virgin inputs. Although these materials may not provide an energy benefit from recycling, from a GHG emissions perspective, recycling these materials is still beneficial. Exhibit 7-2 presents the GHG benefits attributable to the energy savings achieved through recycling.

Exhibit 7-2 Recycling GHG Benefits Attributable to Energy Savings (Recycling vs. Landfilling)



7.3 APPLYING ENERGY FACTORS

Due to recent fuel shortages and increases in prices for fuel and energy, it is becoming increasingly important to examine the impacts of waste management practices on energy. The energy factors presented in Exhibit 7-3 through Exhibit 7-8 may be used by organizations interested in quantifying energy savings associated with waste management practices. With these exhibits, organizations can compare the energy benefits of switching from landfilling to one of the other waste management options. For example, using these factors, the researchers evaluated the progress of voluntary programs aimed at source reduction and recycling, such as EPA's WasteWise, Pay-as-You-Throw, and Coal Combustion Product Partnership (C^2P^2) programs.

In order to apply the energy factors presented in this report, one must first establish two scenarios: (1) a baseline scenario that represents current management practices (e.g., disposing of 1 ton of steel cans in a landfill); and (2) an alternative scenario that represents the alternative management practice (e.g., recycling the same ton of steel cans).[1] The energy factors developed in this report can then be used to calculate energy consumed or avoided under both the baseline and the alternative management practices. Once energy for the two scenarios has been determined, the next step is to calculate the difference between the alternative scenario and the baseline scenario. The result represents the energy consumed or avoided that is attributable to the alternative waste management practice.

Exhibit 7-8 illustrates the application of these factors where the baseline management scenario is disposal in a landfill with national average conditions. In the alternate scenario, the material is recycled. For example, recycling 1 ton of steel cans rather than landfilling them reduces the energy consumed by 20.5 million Btu. The calculations used to generate this result are shown below. Under the sign convention used in this report, the negative value indicates that energy consumption is avoided.

Energy Impacts of Waste Reduction

Baseline: landfill 1 ton of steel cans
1 ton x 0.53 million Btu/ton = 0.53 million Btu

Alternate: recycle 1 ton of steel cans
1 ton x -19.97 million Btu/ton = -19.97 million Btu

Energy Savings:
-19.97 million Btu – 0.53 million Btu =
- 20.5 million Btu

[1] The energy factors are expressed in terms of million Btu of energy per ton of material managed. In the case of recycling, EPA defines 1 ton of material managed as 1 ton *collected* for recycling.

In cases where parties have been source reducing or recycling materials not specifically analyzed in this report, it is possible to estimate the energy consumed or avoided by assigning surrogate materials. A list of materials not specifically analyzed and their corresponding surrogates is presented in the following chapter. Surrogates are based on similarities in characteristics likely to drive energy factors, such as similarities in energy consumption during the raw material acquisition and manufacturing life-cycle stages. Note that the use of these surrogates involves considerable uncertainty.

7.4 RELATING ENERGY SAVINGS TO GHG BENEFITS

It can be difficult to conceptualize energy savings in Btu and GHG emissions reductions in MTCE; therefore, these quantities are frequently converted to common equivalents such as barrels of crude oil or gallons of gasoline. There are important nuances to interpreting these equivalencies, particularly converting from savings in MTCE to equivalent energy savings. This is complicated for two reasons: (1) GHG reductions reflect both energy and nonenergy savings, and (2) the energy savings reflect savings across a range of fossil fuels. Thus, converting from total GHG reductions to an equivalency for "barrels of oil" must be done with caution.

Common Energy Conversion Factors

Fuel:	Million Btu per Barrel of Oil: 5.8 Gallons Oil per Barrel of Oil: 42 Million Btu per Gallon of Gas: 0.125
Cars ("average" passenger car over one year):	Fuel Consumption (gallons of gas): 502 CO_2 Emissions (tons): 4.6

Although energy savings are often the driving force behind GHG emissions savings, it would not be accurate to directly convert overall GHG emission benefits into energy savings equivalents. Equivalencies must remain consistent within the energy or GHG emission context in which they were originally created. As shown in Exhibit 7-2, energy consumption can account for only a fraction of the emission benefits associated with some material types. For example, only about 55 percent of the emission benefits for recycling glass are due to energy consumption. Because the GHG benefits of glass recycling consist of some energy and some nonenergy-related savings, this material type demonstrates the difficulties of converting GHG savings to energy equivalents. When the total GHG benefits of recycling glass are converted to barrels of oil using the common equivalency factors, the *GHG emission benefits* are equivalent to GHG emissions from the combustion of 68 barrels of oil. In contrast, the *energy savings* associated with recycling glass are equivalent to the energy content of 46 barrels of oil.

Recycling 100 tons of Glass Compared to Landfilling

GHG Emission Benefits: 9 MTCE

Equivalent to the combustion emissions from *68* barrels of oil.

Energy Savings: 265 Million Btu

Equivalent to the energy contained within *46* barrels of oil.

Understanding the differences between these values is very important. Similarly, because energy savings estimates are based on a diverse fuel mix of fuels (electricity, natural gas, petroleum, coal, etc.), the results do not mean that 46 barrels of oil will be avoided in the real world. The equivalency "barrels of oil" is simply utilized as a recognizable and understandable unit of energy. In the case of manufacturing glass, the primary energy sources are electricity, coal, and natural gas with only a small fraction of the total energy derived from petroleum products.

Exhibit 7-3
Energy Consumed/Avoided for Source Reduction (Million Btu/Ton of Material Source Reduced)

	(a) Raw Materials Acquisition and Manufacturing Process Energy		(b) Raw Materials Acquisition and Manufacturing Transport Energy		(d) Net Energy (d = a + b)	
Material	Source Reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs	Source Reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs	Source Reduction Displaces Current Mix of Virgin and Recycled Inputs	Source Reduction Displaces Virgin Inputs
Aluminum Cans	121.85	231.42	4.33	7.46	126.18	238.88
Steel Cans	26.04	31.58	4.75	4.91	30.79	36.49
Copper Wire	121.45	122.52	0.86	0.77	122.31	123.30
Glass	5.99	6.49	1.54	1.60	7.53	8.09
HDPE	63.19	69.75	0.49	0.48	63.68	70.23
LDPE	73.43	76.32	0.49	0.48	73.92	76.80
PET	70.19	72.23	0.49	0.48	70.67	72.71
Corrugated Cardboard	20.45	25.13	1.45	1.63	21.91	26.76
Magazines/Third-class Mail	32.95	32.99	0.26	0.26	33.21	33.25
Newspaper	35.80	39.92	0.65	0.76	36.45	40.68
Office Paper	36.32	37.01	0.26	0.26	36.58	37.27
Phonebooks	39.61	39.61	0.26	0.26	39.87	39.87
Textbooks	35.01	35.07	0.29	0.26	35.30	35.33
Dimensional Lumber	2.53	2.53	1.00	1.00	3.53	3.53
Medium-density Fiberboard	10.18	10.18	1.33	1.33	11.51	11.51
Food Discards	NA	NA	NA	NA	NA	NA
Yard Trimmings	NA	NA	NA	NA	NA	NA
Mixed Paper						
Broad Definition	27.16	32.26	1.42	1.79	27.16	32.26
Residential Definition	26.86	32.26	1.40	1.79	26.86	32.26
Office Paper Definition	71.35	73.44	1.91	2.07	71.35	73.44
Mixed Metals	NA	NA	NA	NA	NA	NA
Mixed Plastics	NA	NA	NA	NA	NA	NA
Mixed Recyclables	NA	NA	NA	NA	NA	NA
Mixed Organics	NA	NA	NA	NA	NA	NA
Mixed MSW (as disposed)	NA	NA	NA	NA	NA	NA
Carpet	89.70	89.70	1.36	1.36	91.06	91.06
Personal Computers	951.71	951.71	5.03	5.03	956.74	956.74
Clay Bricks	5.10	5.10	0.03	0.03	5.13	5.13
Concrete	NA	0.05	NA	0.19	NA	0.05
Fly Ash	4.77	4.77	0.10	0.10	4.77	4.77
Tires	88.17	88.17	NA	NA	88.17	88.17

Exhibit 7-4
Energy Consumed/Avoided for Recycling (Million Btu/Ton of Material Recycled)

Material	(a) Recycled Input Credit Process Energy	(b) Recycled Input Credit Transportation Energy	(c) Net Consumption/Savings (Postconsumer)
Aluminum Cans	-200.68	-5.74	-206.42
Steel Cans	-19.40	-0.56	-19.97
Copper Wire	-81.64	-0.95	-82.59
Glass	-1.91	-0.21	-2.13
HDPE	-50.97	0.06	-50.90
LDPE	-56.07	0.06	-56.01
PET	-52.90	0.06	-52.83
Corrugated Cardboard	-14.67	-0.74	-15.42
Magazines/Third-class Mail	-0.69	0.00	-0.69
Newspaper	-16.07	-0.42	-16.49
Office Paper	-10.08	0.00	-10.08
Phonebooks	-11.93	0.51	-11.42
Textbooks	-1.03	0.50	-0.53
Dimensional Lumber	0.52	0.07	0.59
Medium-density Fiberboard	0.65	0.21	0.86
Food Discards	NA	0.58	0.58
Yard Trimmings	NA	0.58	0.58
Mixed Paper			
Broad Definition	-21.38	-1.57	-22.94
Residential Definition	-21.38	-1.57	-22.94
Office Paper Definition	-12.98	-0.97	-13.95
Mixed Metal	-72.72	-2.08	-74.81
Mixed Plastics	-52.48	0.06	-52.42
Mixed Recyclables	-16.36	-0.55	-16.91
Mixed Organics	NA	0.58	0.58
Mixed MSW (as disposed)	NA	NA	NA
Carpet	-103.67	-1.90	-105.58
Personal Computers	-41.95	-1.48	-43.44
Clay Bricks	NA	NA	NA
Concrete	-0.01	-0.09	-0.11
Fly Ash	-4.77	0.00	-4.77
Tires[a]	-51.96	0.00	-51.96

[a] Recycling of tires, as modeled in this analysis, consists only of retreading the tires.

Exhibit 7-5
Energy Consumed/Avoided for Combustion (Million Btu/Ton of Material Combusted)

Material	Avoided Utility Fuel Consumption	Energy Savings Due to Steel Recovery	Transportation to Combustion Facility	Net Consumption/ Savings (Postconsumer)
Aluminum Cans	0.12	NA	0.30	0.42
Steel Cans	0.07	-17.61	0.30	-17.24
Copper Wire	0.10	NA	0.30	0.39
Glass	0.08	NA	0.30	0.38
HDPE	-6.66	NA	0.30	-6.37
LDPE	-6.66	NA	0.30	-6.37
PET	-3.46	NA	0.30	-3.16
Corrugated Cardboard	-2.51	NA	0.30	-2.21
Magazines/Third-class Mail	-1.87	NA	0.30	-1.58
Newspaper	-2.83	NA	0.30	-2.54
Office Paper	-2.42	NA	0.30	-2.13
Phonebooks	-2.83	NA	0.30	-2.54
Textbooks	-2.42	NA	0.30	-2.13
Dimensional Lumber	-2.96	NA	0.30	-2.66
Medium-density Fiberboard	-2.96	NA	0.30	-2.66
Food Discards	-0.85	NA	0.30	-0.55
Yard Trimmings	-1.00	NA	0.30	-0.70
Mixed Paper				
Broad Definition	-2.52	NA	0.30	-2.22
Residential Definition	-2.51	NA	0.30	-2.21
Office Paper Definition	-2.32	NA	0.30	-2.02
Mixed Metals	0.09	-12.43	0.30	-12.05
Mixed Plastics	-5.39	NA	0.30	-5.09
Mixed Recyclables	-2.36	-0.61	0.30	-2.67
Mixed Organics	-0.88	NA	0.30	-0.58
Mixed MSW (as disposed)	-1.78	NA	0.30	-1.49
Carpet	-4.78	NA	0.30	-4.78
Personal Computers	-0.55	-4.44	0.30	-4.69
Clay Bricks	NA	NA	NA	NA
Concrete	NA	NA	NA	NA
Fly Ash	NA	NA	NA	NA
Tires	-25.95	-1.06	0.30	-26.71

Exhibit 7-6
Energy Consumed/Avoided for Landfilling (Million Btu/Ton of Material Landfilled)

Material	Transportation to Landfill	Avoided Utility Energy	Net Consumption/ Savings (Postconsumer)
Aluminum Cans	0.53	NA	0.53
Steel Cans	0.53	NA	0.53
Copper Wire	0.53	NA	0.53
Glass	0.53	NA	0.53
HDPE	0.53	NA	0.53
LDPE	0.53	NA	0.53
PET	0.53	NA	0.53
Corrugated Cardboard	0.53	(0.30)	0.23
Magazines/Third-class Mail	0.53	(0.12)	0.41
Newspaper	0.53	(0.11)	0.42
Office Paper	0.53	(0.52)	0.01
Phonebooks	0.53	(0.11)	0.42
Textbooks	0.53	(0.52)	0.01
Dimensional Lumber	0.53	(0.15)	0.37
Medium-density Fiberboard	0.53	(0.15)	0.37
Food Discards	0.53	(0.19)	0.33
Yard Trimmings	0.53	(0.11)	0.41
Mixed Paper			
Broad Definition	0.53	(0.28)	0.24
Residential Definition	0.53	(0.27)	0.26
Office Paper Definition	0.53	(0.28)	0.25
Mixed Metals	0.53	NA	0.53
Mixed Plastics	0.53	NA	0.53
Mixed Recyclables	0.53	(0.22)	0.30
Mixed Organics	0.53	(0.15)	0.37
Mixed MSW (as disposed)	0.53	(0.25)	0.28
Carpet	0.53	NA	0.53
Personal Computers	0.53	NA	0.53
Clay Bricks	0.53	NA	0.53
Concrete	0.53	NA	0.53
Fly Ash	0.53	NA	0.53
Tires	0.53	NA	0.53

Exhibit 7-7
Net Energy Consumed/Avoided from Source Reduction and MSW Management Options
(Million Btu/Ton)

Material	Source Reduction	Recycling	Combustion	Landfilling
Aluminum Cans	-126.18	-206.42	0.42	0.53
Steel Cans	-30.79	-19.97	-17.24	0.53
Copper Wire	-122.31	-82.59	0.39	0.53
Glass	-7.53	-2.13	0.38	0.53
HDPE	-63.68	-50.90	-6.37	0.53
LDPE	-73.92	-56.01	-6.37	0.53
PET	-70.67	-52.83	-3.16	0.53
Corrugated Cardboard	-21.91	-15.42	-2.21	0.23
Magazines/Third-class Mail	-33.21	-0.69	-1.58	0.41
Newspaper	-36.45	-16.49	-2.54	0.42
Office Paper	-36.58	-10.08	-2.13	0.01
Phonebooks	-39.87	-11.42	-2.54	0.42
Textbooks	-35.30	-0.53	-2.13	0.01
Dimensional Lumber	-3.53	0.59	-2.66	0.37
Medium-density Fiberboard	-11.51	0.86	-2.66	0.37
Food Discards	NA	0.58	-0.55	0.33
Yard Trimmings	NA	0.58	-0.70	0.41
Mixed Paper				
Broad Definition	NA	-22.94	-2.22	0.24
Residential Definition	NA	-22.94	-2.21	0.26
Office Paper Definition	NA	-13.95	-2.02	0.25
Mixed Metals	NA	-74.81	-12.05	0.53
Mixed Plastics	NA	-52.42	-5.09	0.53
Mixed Recyclables	NA	-16.91	-2.67	0.30
Mixed Organics	NA	0.58	-0.58	0.37
Mixed MSW (as disposed)	NA	NA	-1.49	0.28
Carpet	-91.06	-105.58	-4.78	0.53
Personal Computers	-956.74	-43.44	-4.69	0.53
Clay Bricks	-5.13	NA	NA	0.53
Concrete	NA	-0.11	NA	0.53
Fly Ash	NA	-4.77	NA	0.53
Tires	-88.17	-51.96[a]	-26.71	0.53

[a] Recycling of tires, as modeled in this analysis, consists only of retreading the tires.

Exhibit 7-8
Energy Consumed/Avoided for MSW Management Options Compared to Landfilling
(Million Btu/Ton)

Material	Source Reduction Net Energy Minus Landfilling Net Energy (Current Mix)	Source Reduction Net Energy Minus Landfilling Net Energy (100% Virgin Inputs)	Recycling Net Energy Minus Landfilling Net Energy	Combustion Net Energy Minus Landfilling Net Energy
Aluminum Cans	-126.71	-239.41	-206.95	-0.11
Steel Cans	-31.32	-37.02	-20.49	-17.77
Copper Wire	-122.84	-123.82	-83.12	-0.13
Glass	-8.06	-8.62	-2.65	-0.15
HDPE	-64.21	-70.76	-51.43	-6.89
LDPE	-74.45	-77.33	-56.54	-6.89
PET	-71.20	-73.24	-53.36	-3.69
Corrugated Cardboard	-22.13	-26.99	-15.65	-2.44
Magazines/Third-class Mail	-33.62	-33.66	-1.09	-1.98
Newspaper	-36.87	-41.10	-16.91	-2.96
Office Paper	-36.59	-37.28	-10.09	-2.14
Phonebooks	-40.29	-40.29	-11.84	-2.96
Textbooks	-35.31	-35.34	-0.54	-2.14
Dimensional Lumber	-3.90	-3.90	0.21	-3.04
Medium-density Fiberboard	-11.88	-11.88	0.49	-3.04
Food Discards	NA	NA	0.25	-0.88
Yard Trimmings	NA	NA	0.17	-1.11
Mixed Paper				
Broad Definition	NA	NA	-23.19	-2.47
Residential Definition	NA	NA	-23.20	-2.47
Office Paper Definition	NA	NA	-14.20	-2.27
Mixed Metals	NA	NA	-75.33	-12.57
Mixed Plastics	NA	NA	-52.94	-5.62
Mixed Recyclables	NA	NA	-17.21	-2.97
Mixed Organics	NA	NA	0.21	-0.93
Mixed MSW (as disposed)	NA	NA	-0.28	-1.76
Carpet	-91.59	-91.59	-106.11	-5.31
Personal Computers	-957.27	-957.27	-43.96	-5.22
Clay Bricks	-5.66	-5.66	NA	NA
Concrete	NA	NA	-0.63	NA
Fly Ash	NA	NA	-5.29	NA
Tires	-88.70	-88.70	-52.49[a]	-27.23

[a] Recycling of tires, as modeled in this analysis, consists only of retreading the tires.