2. RAW MATERIALS ACQUISITION AND MANUFACTURING

The GHG emissions associated with raw materials acquisition and manufacturing are a key element of a life-cycle GHG analysis. This chapter describes how EPA estimated these emissions for 21 materials: aluminum cans, steel cans, copper wire, glass, three types of plastic (HDPE, LDPE, and PET), corrugated cardboard, magazines/third-class mail, newspaper, office paper, phonebooks, textbooks, dimensional lumber, medium-density fiberboard, carpet, personal computers, clay bricks, concrete, fly ash, and tires. This chapter also includes a similar analysis for three definitions of mixed paper (broad, residential, and office).

In manufacturing, substantial amounts of energy are used both in the acquisition of raw materials and in the manufacturing process itself. In general, the majority of energy used for these activities is derived from fossil fuels. Combustion of fossil fuels results in emissions of CO_2, a GHG. In addition, manufacturing of some materials also results in GHG emissions that are not associated with energy consumption. Section 2.1 addresses energy-related CO_2 emissions, and Section 2.2 covers nonenergy GHG emissions. Sections 2.3 and 2.4 discuss results and limitations of the analysis, respectively.

2.1 GHG EMISSIONS FROM ENERGY USE IN RAW MATERIALS ACQUISITION AND MANUFACTURING

To begin this analysis, EPA estimated the GHG emissions from fossil fuel combustion for both (1) raw materials acquisition and manufacturing (referred to here as "process energy"), and (2) transportation (referred to as "transportation energy").

In this analysis, process energy GHG emissions consist primarily of CO_2.[1] The majority of CO_2 emissions are from combustion of fuels used directly, e.g., to operate mining equipment or fuel a blast furnace. CO_2 emissions from fuels used to generate electricity during the manufacturing stage also are included in process energy emissions. In addition, process energy GHG emissions include indirect emissions from "precombustion" activities, such as oil exploration and extraction, coal mining and beneficiation, and natural gas production.

Transportation energy GHG emissions consist of CO_2 emissions from combustion of fuels used to transport raw materials and intermediate products to the final manufacturing or fabrication facility. For transportation of recycled inputs, this analysis considers transportation (1) from the curbside to the materials recovery facility (MRF), (2) from the MRF to a broker, and (3) from a broker to the plant or mill where the recycled inputs are used. The transportation values for recycled inputs generally include the energy used to process the inputs at a MRF. Transportation of finished manufactured goods to consumers is not included in the analysis; however, this edition of the report does include transportation emissions from the manufacturer to the retailer. EPA did not estimate transportation emissions of CH_4 or N_2O; these emissions are considerably less significant than CO_2 emissions from transportation activities.[2] This omission would tend to understate the GHG impacts from transportation slightly.

Emissions from raw materials acquisition and manufacturing also include CH_4 associated with producing, processing, and transporting coal, oil, and natural gas. CH_4 is emitted during the various stages of fossil fuel production because CH_4 is trapped within coal and oil deposits, and is released when they are mined. Natural gas, of course, consists largely of CH_4.

---

[1] Note, however, that CO_2 emissions from combustion of biomass (e.g., in paper manufacturing) are not counted as GHG emissions (as described in Chapter 1).

[2] The *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004* estimates 2004 emissions from transportation to be 506.0 MMTCE for CO_2 and 12.1 MMTCE for CH_4 and N_2O combined.

EPA developed separate estimates for GHG emissions from process and transportation energy for virgin inputs and recycled inputs, generating a total of four separate GHG emission estimates for each material: (1) process energy with virgin inputs, (2) process energy with recycled inputs, (3) transportation energy for materials made from virgin inputs, and (4) transportation energy for materials made from recycled inputs.

2.1.1 Methodology

Virgin and recycled emission estimates for material processing and transportation were developed using two sets of data: (1) the amount of each type of fuel consumed per ton of the material, and (2) the "carbon coefficient" for each fuel (a factor that translates the energy value of fuel combusted into the mass of GHGs emitted).

EPA's methodology in using these two sets of data to estimate process and transportation energy GHG emissions is best illustrated by an example. To estimate process energy GHG emissions from the production of 1 ton of steel from virgin inputs, the EPA researchers multiplied the amount of each type of fuel consumed (as measured in million Btu) by the carbon coefficient for that type of fuel (as measured in metric tons of carbon equivalent, or MTCE, per million Btu). The result was an estimate of the GHG emissions (in MTCE) from the combustion of each type of fuel required to make 1 ton of steel. Total process energy GHG emissions from making 1 ton of steel are simply the sum of the GHG emissions across all of the fuel types. To estimate the GHG emissions when electricity is used, EPA used the national average mix of fuels used to generate electricity.

EPA estimated GHGs from the energy used to transport raw materials necessary for 1 ton of a given product (e.g., steel) to the retailer, and the energy used to transport the product from the manufacturer to the retail point, in the same way. The amount of each fuel used was multiplied by its carbon coefficient, and the resulting values for each of the fuels were summed to yield total transportation energy GHG emissions.

In this way, GHG estimates for raw materials acquisition and manufacturing were developed for each of the manufactured materials considered. As noted in Chapter 1, much of the energy information reflected in the analysis is drawn from an effort conducted by EPA's ORD to construct a Decision Support Tool for solid waste managers. The remaining energy data were developed by FAL as part of the original effort or subsequent updates.

Most of the materials included in this analysis are assumed to undergo closed-loop recycling (i.e., primary material type is remanufactured into the same material type). However, several materials are recycled in an open loop, where the primary material type is remanufactured into a different secondary material; these materials are mixed paper, corrugated cardboard, fly ash, carpet, and personal computers. The exhibits in this chapter show data not only for the 21 primary materials of interest, but also for secondary materials such as boxboard, carpet pad, carpet backing, molded auto parts, asphalt, CRT glass, lead bullion, and copper wire. Because recycling processes data are similar for HDPE, LDPE, and PET, EPA adopted the approach used by ORD of using a single energy profile (fuel mix and energy intensity) for all recycled plastics. For steel cans, EPA developed the GHG estimates for virgin production using the basic oxygen furnace process, and for recycled production, electric arc furnace process was used.[3]

[3] Two types of furnace are used in recycling steel: electric arc (EAF), which uses nearly 100 percent recovered inputs, and basic oxygen (BOF), which uses 25 to 35 percent recovered steel. Steel from EAFs is structurally unsuited to milling into thin sheets to make steel cans. Therefore, although EPA models steel can recycling as a closed-loop process (steel cans made into steel cans), this is not entirely accurate, statistically. By modeling recovery of steel cans as a closed-loop process, EPA implicitly assumed that 1 ton of steel produced from recovered steel cans in an electric arc furnace displaces 1 ton of steel produced from virgin inputs in a basic oxygen furnace. However, the EPA researchers feel that the values from the two furnaces are close enough to make closed-loop

Carbon coefficients from DOE's Energy Information Administration for all energy sources except electricity were used.[4] The carbon coefficient for electricity was based on the weighted average carbon coefficients for all fuels used to generate electricity in the United States.[5]

Because the carbon coefficients from these sources only account for the CO_2 emissions from combustion of each type of fuel, EPA added to these carbon coefficients (1) the average amount of CH_4 emitted during the production, processing, and transportation of fossil fuels, and (2) the average CO_2 emissions from oil production, due to the flaring of natural gas. EPA calculated the average fugitive GHG emissions associated with U.S. production of coal, oil, and natural gas. The resulting average estimates for fugitive GHG emissions from fossil fuel production were 0.92 kg of carbon equivalent per million Btu (kg CE/million Btu) for coal, 0.10 kg CE/million Btu for oil, and 0.70 kg CE/million Btu for natural gas.[6]

The carbon coefficients that reflect both CO_2 and CH_4 emissions are supplied in Exhibit 2-1. (All exhibits are provided at the end of this chapter.)

The fuel mixes used in these calculations reflect the average U.S. fuel mixes for each process. However, it is worth noting that U.S. consumer products (which eventually become MSW) increasingly come from overseas, where the fuel mixes may be different. For example, China relies heavily on coal and generally uses energy less efficiently than the United States. Consequently the GHG emissions associated with the manufacture of a given product in China may be higher than for the same product made in this country. However, such analysis is beyond the scope of this report, which focuses only on domestic production, transportation, consumption, and disposal.

The process and transportation GHG values are summarized in Exhibit 2-2. For each product and each type of input (virgin or recycled), EPA summed the estimates for process and transportation GHG emissions, as shown in columns "b" (for virgin inputs) and "c" (for recycled inputs) of Exhibit 2-2. EPA also estimated the energy-related GHG emissions from manufacturing each material from the current mix of virgin and recycled inputs.[7] These values are shown in column "e." (The remaining two columns of Exhibit 2-2 are discussed later in this chapter.)

The energy intensity and fuel mix data are provided in Exhibit 2-3 through Exhibit 2-6. For most materials, the data in the exhibits are for manufacturing processes that either use (1) 100 percent virgin inputs or (2) 100 percent recycled inputs.[8]

To estimate the types and amounts of fuels used for process and transportation energy, ORD and FAL relied on published data (such as engineering handbooks and published production data), contacts

---

recycling a reasonable assumption. (For the fabrication energy required to make steel cans from steel, EPA used the values for fabrication of steel cans from steel produced in a basic oxygen furnace.)

[4] DOE, Energy Information Administration. 2004. *Annual Energy Review: 2003.*

[5] FAL reported the Btu value for electricity in terms of the Btu of fuel combusted to generate the electricity used at the factory, rather than the (much lower) Btu value of the electricity that is delivered to the manufacturer. Thus, FAL had already accounted for the efficiency of converting fuels to electricity, and the losses in transmission and distribution of electricity. EPA therefore did not need to account for these factors in the carbon coefficient for electricity.

[6] ICF Consulting. 1995. Memorandum, "Fugitive Methane Emissions from Production of Coal, Natural Gas, and Oil," August 8, updated to use global warming potential for CH_4 of 21.

[7] The current mix of virgin and recycled inputs is derived from FAL data, and varies from material to material.

[8] In the FAL data set, the one exception is the data for steel cans made from virgin inputs, for which FAL provided data for manufacture from 80 percent virgin inputs and 20 percent recycled inputs. EPA (or ICF Consulting) extrapolated from this data (and the corresponding values for production using 100 percent recycled inputs) to obtain estimates of the energy inputs for manufacturing these materials from 100 percent virgin inputs. Similarly, for corrugated cardboard, ORD assumed that a virgin corrugated box contains a minimum of 14.7 percent total recycled content.

with industry experts, and review by stakeholders and trade organizations. ORD and FAL counted all energy, no matter where it was used. For example, much aluminum produced in the United States is made from bauxite that is mined and processed into alumina in other countries. The energy required for overseas bauxite mining and processing is included in the analysis.

The EPA methodology also accounts for GHG emissions associated with the transport of materials as commodities (i.e., manufactured products or materials) from the manufacturing point to the retail/distribution point. The U.S. Census Bureau along with the Bureau of Transportation Statistics recently conducted a Commodity Flow Survey that determined the average distance commodities were shipped in the United States and the percentage each of the various transportation modes was used in shipping these commodities.[9] The estimated transportation energy for each material type was estimated by applying the transportation fuel efficiency and fuel-specific heating value to the average miles that commodities were shipped within each mode. Although these factors may be small relative to the larger raw materials acquisition and manufacturing emissions for each material, their inclusion adds to the robustness of the life-cycle methodology. Because this adjustment was made to both the 100 percent virgin and 100 percent recycled material types, the change in transportation emissions will drop out when virgin and recycled materials are compared. Because source reduction emission factors reflect the benefit of not transporting the material in the first place, the adjustment will be more noticeable. For additional details on the methodology for estimating retail transportation for materials please see the *WARM Retail Transportation* background document.[10]

Finally, it should be noted that during EPA's extensive review of ORD and FAL data, the most critical assumptions and data elements that each model used were examined to ensure that they accurately reflect the energy requirements of the raw materials acquisition and manufacturing for the material types considered. Nevertheless, EPA recognizes that different manufacturers making the same product use somewhat different processes with different energy requirements and fuel mixes, and that there are limited data on the extent to which various processes are used. Thus, although the goal was to estimate as accurately as possible the national average GHG emissions for the manufacture of each material from virgin and recycled inputs, individual manufacturers will likely have GHG emissions that vary significantly from those estimated here.

2.2 NONENERGY GHG EMISSIONS FROM MANUFACTURING AND RAW MATERIALS ACQUISITION

In addition to GHG emissions from energy use, EPA researchers accounted for three additional sources of GHGs in manufacturing processes:

- When limestone ($CaCO_3$) is converted to lime (CaO), CO_2 is emitted. Significant quantities of lime are used in the production of cement,[11] steel, aluminum, and, to a much lesser extent, office paper.
- CH_4 emissions from natural gas pipelines and processing of natural gas are associated with the manufacture of plastic products.
- PFCs (CF_4 and C_2F_6) are emitted during aluminum smelting.

---

[9] U.S. Census Bureau, 2003. *Commodity Flow Survey*. United States Census Bureau. December 2003. Available online at: www.census.gov/prod/ec02/02tcf-usp.pdf.

[10] Available at EPA's Global Warming—Waste, "Background Documents for Solid Waste Management and GHG Report" website: http://www.epa.gov/mswclimate, then follow links to Publications → Reports, Papers, and Presentations → This report → Background Documents.

[11] For the category "concrete" the material being replaced is not the cement, but rather the aggregate (i.e. sand and rock) portion of concrete. However fly ash is used as a cement replacement in concrete, and the nonenergy emissions of the replaced virgin cement are accounted for in estimations for the "fly ash" category.

The process nonenergy GHGs for each material are shown in the second-to-last column of Exhibit 2-3 and Exhibit 2-5 (for manufacture from virgin inputs and recycled inputs, respectively), and are repeated in column "f" of Exhibit 2-2. ORD supplied the nonenergy CO_2 emissions for glass, corrugated cardboard, and newspaper. EPA based the calculation for PFC and CO_2 emissions from aluminum on the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*.[12]

Nonenergy CO_2 emissions for the other materials, as well as CH_4 emissions, are based on the original analysis supporting the first edition of this report.[13]

2.3 RESULTS

The estimates of the total GHG emissions from raw materials acquisition and manufacturing for each material are shown in Exhibit 2-2, column "g." In order to obtain these estimates, EPA summed the energy-related GHG emissions (column "e") and the nonenergy GHG emissions (column "f"). The estimates in column "g" correspond to the type of inputs that occur during the recycling process: virgin inputs, recycled inputs, or the current mix of virgin and recycled inputs.

The process energy and transportation GHG values for virgin and recycled production are shown in the third-to-last columns of Exhibit 2-3 and Exhibit 2-5, and in the last columns of Exhibit 2-4 and Exhibit 2-6 (the last columns of Exhibit 2-3 and Exhibit 2-5 show the total process energy GHG emissions). The retail transport energy and emission values are presented in Exhibit 2-7.

2.4 LIMITATIONS

There are several limitations to the analysis of the GHG emissions associated with raw materials acquisition and manufacturing, as described below.

The approach used in this analysis provides values for the average GHG emission rates per ton of material produced, not the marginal emission rates per incremental ton produced. In some cases, the marginal emission rates may be significantly different. For example, reducing the production of plastic products from virgin inputs may not result in a proportional decrease in CH_4 emissions from natural gas pipelines and natural gas processing. The operating pressure in natural gas pipelines and the number and size of leaks in the pipeline determine CH_4 emissions from natural gas pipelines. Consequently, the amount of natural gas consumed at one end of the pipeline (e.g., to make plastic) does not affect the level of pipeline CH_4 emissions in a direct, linear way. As another example, long-term reductions in electricity demand could selectively reduce demand for specific fuels, rather than reducing demand for all fuels in proportion to their representation in the current average fuel mix. This analysis estimates average carbon conversion rates largely because the marginal rates are much more difficult to estimate. Nevertheless, EPA believes the average values provide a reasonable approximation of the GHG emissions.

In addition, the analysis assumes that the GHG emissions from manufacturing a given product change in a linear fashion as the percentage of recycled inputs moves from 0 to 100 percent. In other words, the analysis assumes that both the energy intensity and the fuel mix change in linear paths over this range. However, it could be that GHG emissions from manufacturing move in a nonlinear path, (e.g., some form of step function) when the percentage of recycled inputs changes, due to capacity limits in manufacturing or due to the economics of manufacturing processes.

[12] To estimate aluminum PFC emissions on a per-ton basis, EPA divided the inventory estimates for CF_4 and C_2F_6 emissions from aluminum by total primary aluminum production, yielding units in MTCE/ton.

[13] ICF Consulting. 1994. Memorandum, "Detailed Analysis of Greenhouse Gas Emissions Reductions from Increased Recycling and Source Reduction of Municipal Solid Waste," July 29, p. 48 of the Appendix prepared by FAL, dated July 14, 1994.

The information used in this analysis represents the best available data from published and unpublished industry sources, some of it quite dated. Therefore, the data may not necessarily reflect recent trends in industrial energy efficiency or changes in the fuel mix.

Finally, this static analysis does not consider potential future changes in energy usage per unit of output or alternative energy (e.g., nonfossil) sources. Reductions in energy inputs due to efficiency improvements could occur in either virgin input processes or recycled input processes. Efficiency improvements and switching to alternative energy sources will result directly in GHG emissions reductions and may change the reductions possible through increased recycling or source reduction.

Exhibit 2-1
Carbon Coefficients For Selected Fuels (Per Million Btu)

Fuel Type	Metric Tons of CO_2 from Combustion	kg Carbon Equivalent (CE) from Combustion	Metric Tons of Fugitive CH_4 Emissions	kg CE from Fugitive Methane Emissions	kg CE Emitted
Gasoline	0.07	19.05	0.00002	0.10	19.15
LPG	0.06	16.81	0.00002	0.10	16.91
Distillate Fuel	0.07	19.65	0.00002	0.10	19.75
Residual Fuel	0.08	21.18	0.00002	0.10	21.28
Diesel	0.07	19.65	0.00002	0.10	19.75
Oil/Lubricants	0.07	19.94	0.00002	0.10	20.04
Steam (nonpaper products)	0.07	18.07	0.00011	0.61	18.81
Steam (paper products)	0.05	12.80	0.00004	0.25	13.17
National Average Fuel Mix for Electricity	0.06	15.26	0.00010	0.57	15.83
National Average Fossil Fuel Mix for Electricity	0.08	22.17	0.00015	0.83	23.01
Coal Used for Electricity	0.09	24.80	0.00016	0.92	25.72
Coal Used by Industry (Noncoking Coal)	0.09	25.10	0.00016	0.92	26.02
Petroleum Coke	0.10	27.57	-	-	27.57
Metallurgical Coke	0.11	30.69	-	-	30.69
Natural Gas	0.05	13.62	0.00012	0.70	14.33
Nuclear	0.00	0.84	-	-	0.84
Wastes	0.07	19.42	0.00000	0.01	19.61

Exhibit 2-2
GHG Emissions from the Manufacture of Selected Materials
(MTCE per Ton of Product)

(a)	(b)	(c)	(d)	(e)	(f)			(g)		
			Current Mix[a]		Process Nonenergy Emissions			Average Combined Process and Transportation Energy and Process Nonenergy Emissions		
Type of Product	Virgin Input Combined Process and Transportation Energy Emissions	Recycled Input Combined Process and Transportation Energy Emissions	Percent Recycled Inputs	Combined Process and Transportation Energy Emissions	Virgin Inputs	Recycled Inputs	Current Mix	Virgin Inputs	Recycled Inputs	Current Mix
Aluminum Cans	3.53	0.28	51%	1.87	0.73	0.02	0.37	4.27	0.30	2.24
Steel Cans	0.77	0.27	28%	0.63	0.24	0.24	0.24	1.01	0.51	0.87
Copper Wire	2.02	1.66	5%	2.00	0.00	0.00	0.00	2.02	1.66	2.00
Glass	0.13	0.09	23%	0.12	0.04	0.00	0.03	0.18	0.09	0.16
HDPE	0.48	0.05	10%	0.44	0.05	0.00	0.05	0.54	0.05	0.49
LDPE	0.59	0.05	4%	0.57	0.05	0.00	0.05	0.64	0.05	0.62
PET	0.56	0.05	3%	0.54	0.03	0.00	0.03	0.59	0.05	0.57
Corrugated Cardboard	0.23	0.25	35%	0.23	0.00	0.00	0.00	0.23	0.25	0.24
Magazines/Third-class Mail	0.46	0.46	4%	0.46	0.00	0.00	0.00	0.46	0.46	0.46
Newspaper	0.58	0.34	23%	0.52	0.00	0.00	0.00	0.58	0.34	0.52
Office Paper	0.27	0.37	4%	0.28	0.01	0.00	0.01	0.28	0.37	0.28
Phonebooks	0.68	0.42	0%	0.68	0.00	0.00	0.00	0.68	0.42	0.68
Textbooks	0.60	0.58	4%	0.60	0.00	0.00	0.00	0.60	0.58	0.60
Dimensional Lumber	0.05	0.07	0%	0.05	0.00	0.00	0.00	0.05	0.07	0.05
Medium-density Fiberboard	0.10	0.12	0%	0.10	0.00	0.00	0.00	0.10	0.12	0.10
Mixed Paper[b]										
Broad Def'n (Boxboard "A")	0.32	0.18	23%	0.29	0.00	0.00	0.00	0.32	0.18	0.29
Residential Def'n (Boxboard "B")	0.32	0.18	25%	0.29	0.00	0.00	0.00	0.32	0.18	0.29
Office Def'n (Paper Towels)	0.90	0.00	10%	0.81	0.00	0.00	0.00	0.90	0.00	0.81
Carpet	0.95	NA	0%	0.95	0.14	0.00	0.14	1.09	NA	1.09
Personal Computers	15.10	NA	0%	15.10	0.03	0.00	0.03	15.13	NA	15.13
Clay Bricks	0.08	NA	0%	0.08	0.00	0.00	0.00	0.08	0.00	0.08
Concrete	0.00	0.00	0%	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fly Ash	NA	NA	0%	NA	NA	NA	NA	NA	NA	NA
Tires	1.09	0.45	0%	1.09	NA	NA	0.00	1.09	0.45	1.09

Note that totals may not add due to rounding, and more digits may be displayed than are significant. NA: Not applicable, or in the case of composting of paper, not analyzed.
[a] The current mix of recycled and virgin inputs varies by material type and is based on data from FAL.
[b] For recycled Boxboard, different sets of manufacturing and transportation data. Boxboard "A" and Boxboard "B" differ with respect to their recycled material inputs only (i.e., the proportion of newsprint, corrugated boxes, office paper, and different sets of manufacturing and transportation data).

Explanatory notes: To estimate the GHG emissions from manufacturing, EPA first estimated the process and transportation GHG emissions when 100 percent virgin inputs, or 100 percent recycled inputs, are used. For each product and each type of input (virgin or recycled), EPA summed the estimates for process and transportation GHG emissions. Next the EPA researchers estimated the GHG emissions from manufacturing each material from the current mix of virgin and recycled inputs. The researchers began with estimates of the percentage of recycled inputs currently used in the manufacture of each material, as shown in column "d." The team used these percentages to develop a weighted average value for the GHG emissions associated with the manufacture of each material from the current mix of virgin and recycled inputs. Specifically, the researchers used the estimate of the percentage of recycled inputs in the current mix, together with the estimates for GHG emissions from manufacture using virgin or recycled inputs, to develop estimates of GHG emissions from manufacture using the current mix of virgin and recycled inputs (column "e").

Column "f" shows estimates of the process nonenergy GHG emissions from manufacturing. First, this column shows the process nonenergy GHG emissions when virgin inputs are used. Then it shows the emissions when recycled inputs are used (these values are simply copied from the final columns of Exhibit 2-3 and Exhibit 2-5). Finally, column "f" shows the process nonenergy GHG emissions from manufacturing each product from the current mix of virgin and recycled inputs. The values for the current mix are the weighted averages of the values for virgin and recycled inputs, based on the percentage of recycled inputs used in the current mix (as shown in column "d").

The total GHG emissions from manufacturing are shown in column "g." This column shows total GHG emissions when a product is manufactured from virgin or recycled inputs, or from the current mix of virgin and recycled inputs.

Exhibit 2-3
Process GHG Emissions Per Ton of Product Manufactured from Virgin Inputs

Type of Product	Process Energy (Million Btu)	Average Fuel Mix (in Percent)											Process Energy Emissions (MTCE)	Process Nonenergy Emissions (MTCE)	Total Process Emissions (MTCE)
		Gasoline	LPG	Distillate Fuel	Residual Fuel	Biomass / Hydro	Diesel	Electricity	Coal	Natural Gas	Nuclear	Other			
Aluminum Cans	213.33	0.11	0.01	0.59	1.13	0.03	0.20	88.50	0.69	8.57	0.16	0.02	3.38	0.73	4.11
Steel Cans	31.58	0.21	0.00	5.06	0.35	0.00	0.00	21.02	53.90	19.45	0.00	0.00	0.67	0.24	0.91
Copper Wire	122.52	0.29	0.02	0.77	6.14	0.05	10.82	49.95	2.25	29.38	0.29	0.04	2.00	0.00	2.00
Copper Ingot	109.23	0.00	0.00	0.00	0.00	0.00	21.36	51.24	0.00	27.04	0.00	0.00	1.77	0.00	1.77
Glass	6.49	0.55	0.00	1.45	0.47	0.03	0.00	10.12	7.18	79.95	0.23	0.02	0.10	0.04	0.14
HDPE	28.69	0.00	0.00	0.00	33.14	1.16	0.00	5.64	4.59	51.35	4.00	0.13	0.47	0.05	0.53
LDPE	35.26	0.00	0.00	0.00	32.59	1.56	0.00	7.66	6.15	46.52	5.36	0.17	0.58	0.05	0.63
PET	32.82	0.00	0.00	0.00	36.67	1.62	0.00	7.10	6.42	42.41	5.59	0.18	0.55	0.03	0.58
Corrugated Cardboard	25.13	0.01	0.00	0.02	0.54	61.33	1.20	14.06	15.52	7.31	0.01	0.00	0.19	0.00	0.19
Magazines/Third-class Mail	32.99	0.15	0.01	0.32	8.30	24.27	0.00	25.40	17.11	24.33	0.11	0.01	0.46	0.00	0.46
Newspaper	39.92	0.25	0.00	0.52	0.75	9.09	0.68	54.21	1.75	32.43	0.27	0.04	0.56	0.00	0.56
Office Paper	37.01	0.08	0.00	0.17	4.33	60.53	0.00	13.24	8.92	12.68	0.06	0.01	0.27	0.01	0.27
Phonebooks	39.61	0.18	0.01	0.38	9.99	8.86	0.00	30.56	20.59	29.28	0.13	0.02	0.66	0.00	0.66
Textbooks	35.07	0.18	0.01	0.38	9.96	9.14	0.00	30.47	20.52	29.19	0.13	0.02	0.58	0.00	0.58
Dimensional Lumber	2.53	1.57	0.00	0.00	0.00	32.81	15.99	43.09	0.00	6.53	0.00	0.00	0.03	0.00	0.03
Medium-density Fiberboard	10.18	0.14	0.00	0.38	0.05	51.90	1.26	27.61	0.00	18.68	0.00	0.00	0.08	0.00	0.08
Boxboard	32.26	0.00	0.00	0.00	0.94	59.34	1.36	5.32	24.01	9.02	0.00	0.00	0.29	0.00	0.29
Paper Towels	73.44	0.00	0.00	0.01	1.80	24.89	0.45	28.15	2.93	41.78	0.00	0.00	0.86	0.00	0.86
Carpet	60.32	0.47	0.04	0.67	1.48	0.05	0.00	52.06	0.82	44.10	0.28	0.04	0.92	0.14	1.06
Carpet Padding	107.46	0.41	0.02	0.66	1.38	0.05	0.00	58.81	0.97	37.37	0.30	0.04	1.66	0.52	2.17
Carpet Backing	46.54	0.71	0.02	0.70	0.71	0.05	0.00	60.17	0.77	36.53	0.29	0.04	0.72	0.03	0.75
Personal Computers	945.13	0.14	0.00	0.72	0.38	0.06	0.10	92.42	0.97	5.00	0.35	0.05	15.00	0.03	15.03
Clay Bricks	5.10	0.00	0.00	0.00	0.00	0.00	1.89	39.38	0.00	58.73	0.00	0.00	0.08	0.00	0.08
Concrete	0.05	3.16	0.00	60.42	5.68	0.00	0.00	22.61	1.40	6.74	0.00	0.00	0.00	0.00	0.00
Cement	4.77	0.11	0.01	0.89	0.09	0.00	0.00	9.98	58.24	5.58	0.00	25.11	0.11	0.12	0.24
Injection Molded Auto Parts	113.75	0.40	0.02	0.68	1.13	0.05	0.00	61.19	0.79	35.41	0.30	0.04	1.75	0.51	2.27
Asphalt (Cold Patch)	0.50	1.09	0.74	4.84	10.56	0.04	0.00	22.17	1.05	59.24	0.25	0.04	0.01	0.00	0.01
Steel Sheet	14.60	0.67	0.01	9.42	0.82	0.04	0.00	44.67	1.44	42.61	0.27	0.04	0.23	0.40	0.63
Lead Bullion	19.46	0.16	0.00	0.74	0.92	0.05	0.02	86.11	0.91	10.69	0.34	0.05	0.31	0.01	0.32
CRT Glass	9.16	0.40	0.01	6.98	6.88	0.04	0.00	19.64	2.25	63.52	0.24	0.03	0.14	0.04	0.19
Tires	88.17	0.00	0.48	0.48	0.48	0.00	0.00	11.54	9.62	53.85	0.00	23.08	1.09	0.00	1.09

Exhibit 2-4
Transportation GHG Emissions Per Ton of Product Manufactured from Virgin Inputs

Type of Product	Transportation Energy (Million Btu)	Average Fuel Mix (in Percent)											Transportation Energy Emissions (MTCE)
		Gasoline	LPG	Distillate Fuel	Residual Oil	Biomass/ Hydro	Diesel	Electricity	Coal	Natural Gas	Nuclear	Other	
Aluminum Cans	7.15	0.10	0.08	0.39	80.26	0.05	10.82	0.34	0.87	6.71	0.34	0.05	0.15
Steel Cans	4.60	0.00	0.00	0.00	1.76	0.00	98.24	0.00	0.00	0.00	0.00	0.00	0.09
Copper Wire	0.46	0.09	0.08	0.39	4.16	0.06	87.04	0.02	0.86	6.92	0.34	0.05	0.01
Copper Ingot	3.06	0.00	0.00	0.00	0.00	0.00	72.25	27.75	0.00	0.00	0.00	0.00	0.06
Glass	0.58	0.10	0.08	0.40	2.64	0.04	88.95	0.00	0.89	6.51	0.36	0.03	0.01
HDPE	NA												NA
LDPE	NA												NA
PET	NA												NA
Corrugated Cardboard	1.31	0.05	0.00	0.05	0.27	0.01	98.51	0.00	0.00	1.07	0.04	0.01	0.03
Magazines/Third-class Mail	NA												NA
Newspaper	0.50	0.10	0.08	0.39	3.63	0.05	87.97	0.00	0.86	6.53	0.34	0.05	0.01
Office Paper	NA												NA
Phonebooks	NA												NA
Textbooks	NA												NA
Dimensional Lumber	0.88	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.02
Medium-density Fiberboard	1.01	0.00	0.00	0.00	0.06	0.00	98.10	0.00	0.00	1.84	0.00	0.00	0.02
Boxboard	1.79	0.00	0.00	0.00	0.05	0.00	99.93	0.00	0.00	0.01	0.00	0.00	0.04
Paper Towels	2.07	0.00	0.00	0.00	0.52	0.00	99.46	0.01	0.00	0.02	0.00	0.00	0.04
Carpet	1.36	0.15	0.07	0.40	28.61	0.05	51.89	1.76	0.88	15.83	0.32	0.05	0.03
Carpet Padding	2.15	0.35	0.07	0.16	30.60	0.05	51.59	1.77	0.83	14.22	0.32	0.05	0.04
Carpet Backing	1.36	0.19	0.06	0.38	23.75	0.05	47.13	1.27	0.77	26.07	0.29	0.04	0.03
Personal Computers	5.03	0.10	0.08	0.41	60.22	0.05	30.64	0.29	0.86	7.03	0.33	0.05	0.10
Clay Bricks	0.03	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Concrete	0.19	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Cement	0.10	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Injection Molded Auto Parts	1.51	0.16	0.07	0.38	43.15	0.05	35.19	2.51	0.81	17.33	0.30	0.04	0.03
Asphalt (Cold Patch)	0.20	0.11	0.08	0.40	41.98	0.05	47.26	2.34	0.86	6.54	0.33	0.05	0.00
Steel Sheet	1.41	0.10	0.08	0.39	13.18	0.05	78.30	0.04	0.85	6.64	0.32	0.05	0.03
Lead Bullion	0.63	0.10	0.08	0.41	5.10	0.05	86.35	0.01	0.86	6.66	0.32	0.05	0.01
CRT Glass	0.28	0.35	0.08	0.11	3.85	0.05	87.93	0.00	0.85	6.42	0.32	0.05	0.01
Tires	NA												

Note that for some materials, transportation data were included in the process energy estimates and not provided separately, denoted by "NA" in this table.

Exhibit 2-5
Process GHG Emissions Per Ton of Product Manufactured from Recycled Inputs

Type of Product	Process Energy (Million Btu)	Average Fuel Mix (in Percentage)											Process Energy Emissions (MTCE)	Process Nonenergy Emissions (MTCE)	Total Process Emissions (MTCE)
		Gasoline	LPG	Distillate Fuel	Residual Fuel	Biomass/ Hydro	Diesel	Electricity	Coal	Natural Gas	Nuclear	Other			
Aluminum Cans	16.59	0.34	0.01	0.49	4.28	0.04	0.00	45.10	0.72	48.71	0.27	0.04	0.26	0.02	0.28
Steel Cans	11.78	0.01	0.17	0.07	0.03	0.00	0.00	77.28	0.65	21.80	0.00	0.00	0.18	0.24	0.42
Copper Wire	101.05	0.33	0.01	0.81	6.87	0.05	0.00	52.65	2.53	36.42	0.30	0.04	1.61	0.00	1.61
Copper Ingot	8.90	0.00	0.00	18.98	0.00	0.00	0.00	27.70	0.09	51.23	0.00	2.00	0.14	0.00	0.14
Glass	4.32	0.55	0.00	0.39	0.26	0.03	0.00	5.10	0.54	92.91	0.21	0.02	0.06	0.24	0.30
HDPE	4.17	0.03	0.03	1.05	1.24	12.48	0.05	33.21	0.02	20.34	0.09	31.44	0.04	0.00	0.04
LDPE	4.17	0.03	0.03	1.05	1.24	12.48	0.05	33.21	0.02	20.34	0.09	31.44	0.04	0.00	0.04
PET	4.17	0.03	0.03	1.05	1.24	12.48	0.05	33.21	0.02	20.34	0.09	31.44	0.04	0.00	0.04
Corrugated Cardboard	11.73	0.01	0.05	0.05	0.66	0.00	0.31	51.11	38.40	9.40	0.01	0.00	0.23	0.00	0.23
Magazines/Third-class Mail	31.97	0.16	0.01	0.32	8.45	22.85	0.00	25.87	17.43	24.79	0.11	0.01	0.45	0.00	0.45
Newspaper	21.98	0.30	0.00	0.58	0.30	0.05	0.00	57.75	1.09	39.59	0.30	0.04	0.34	0.00	0.34
Office Paper	20.12	0.20	0.01	0.42	10.96	0.02	0.00	33.53	22.58	32.12	0.14	0.02	0.37	0.00	0.37
Phonebooks	22.02	0.20	0.01	0.42	10.96	0.02	0.00	33.53	22.58	32.12	0.14	0.02	0.40	0.00	0.40
Textbooks	33.51	0.21	0.01	0.60	10.02	8.38	0.00	30.40	20.61	29.57	0.17	0.02	0.56	0.00	0.56
Dimensional Lumber	3.17	0.00	0.00	0.00	0.00	0.00	23.61	76.39	0.00	0.00	0.00	0.00	0.05	0.00	0.05
Medium-density Fiberboard Made from Reused Dimensional Lumber	10.99	0.13	0.00	0.35	0.04	48.05	8.56	25.56	0.00	17.29	0.00	0.00	0.09	0.00	0.09
Boxboard Made from Broad Definition of Mixed Paper	10.45	0.00	0.00	13.57	0.00	0.00	0.00	13.78	15.38	57.27	0.00	0.00	0.18	0.00	0.18
Boxboard Made from Residential Definition of Mixed Paper	10.45	0.00	0.00	13.57	0.00	0.00	0.00	13.78	15.38	57.27	0.00	0.00	0.18	0.00	0.18
Paper Towels Made from Recovered File Stock	51.69	0.00	0.00	0.00	0.45	6.94	0.15	36.32	0.98	55.14	0.00	0.00	0.73	0.00	0.73
Carpet Padding	2.14	0.12	0.00	0.68	0.26	0.06	0.00	95.36	0.95	2.15	0.36	0.05	0.03	0.00	0.03
Carpet Backing	23.27	0.12	0.00	0.68	0.26	0.06	0.00	95.39	0.95	2.15	0.35	0.05	0.37	0.00	0.37
Concrete	0.04	0.00	0.00	0.00	0.00	0.00	54.23	45.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Injection Molded Auto Parts from Nylon Carpet	20.24	0.12	0.00	0.68	0.26	0.06	0.00	95.45	0.95	2.08	0.36	0.05	0.32	0.00	0.32
Asphalt (Cold Patch)	5.49	0.20	0.10	0.85	1.52	0.05	0.00	87.09	0.91	8.89	0.34	0.05	0.09	0.00	0.09
Steel Sheet	12.53	0.23	0.00	0.64	0.30	0.05	0.00	72.60	1.40	24.41	0.32	0.04	0.20	0.01	0.20
Lead Bullion	19.50	0.20	0.00	0.70	0.90	0.06	0.00	86.68	0.92	10.16	0.34	0.05	0.31	0.00	0.31
CRT Glass	7.29	0.36	0.01	6.48	6.50	0.04	0.00	29.64	0.69	55.99	0.26	0.04	0.11	0.00	0.11
Tires	36.21	0.00	0.48	0.48	0.48	0.00	0.00	11.54	9.62	53.85	0.00	23.08	0.45	0.00	0.45

Exhibit 2-6
Transportation GHG Emissions Per Ton of Product Manufactured from Recycled Inputs

Type of Product	Transportation Energy (Million Btu)	Average Fuel Mix (in Percentage)											Transportation Energy Emissions (MTCE)
		Gasoline	LPG	Distillate Fuel	Residual Oil	Biomass/ Hydro	Diesel	Elec-tricity	Coal	Natural Gas	Nuclear	Other	
Aluminum Cans	1.01	0.10	0.08	0.40	3.76	0.05	87.87	0.00	0.85	6.53	0.32	0.05	0.02
Steel Cans	4.03	0.00	0.00	0.00	0.01	0.00	99.99	0.00	0.00	0.00	0.00	0.00	0.08
Copper Wire	2.17	0.10	0.08	0.39	3.84	0.05	87.67	0.00	0.86	6.63	0.33	0.05	0.04
Copper Ingot	1.89	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.04
Glass	0.34	0.10	0.08	0.41	2.59	0.04	89.01	0.00	0.89	6.51	0.35	0.03	0.01
HDPE	0.08	0.00	0.00	0.00	56.50	0.00	5.96	2.53	0.00	35.01	0.00	0.00	0.00
LDPE	0.08	0.00	0.00	0.00	56.50	0.00	5.96	2.53	0.00	35.01	0.00	0.00	0.00
PET	0.08	0.00	0.00	0.00	56.50	0.00	5.96	2.53	0.00	35.01	0.00	0.00	0.00
Corrugated Cardboard	0.80	0.05	0.00	0.05	0.22	0.01	98.55	0.00	0.00	1.07	0.04	0.00	0.02
Magazines/Third-class Mail	NA												
Newspaper	0.03	0.10	0.08	0.39	3.75	0.05	87.87	0.00	0.86	6.53	0.32	0.05	0.00
Office Paper	NA												
Phonebooks	NA												0.00
Textbooks	NA												0.00
Recycled Lumber from Dimensional Lumber	0.97	0.00	0.00	0.00	0.00	0.00	100.06	0.00	0.00	0.00	0.00	0.00	0.02
Medium-density Fiberboard Made from Reused Dimensional Lumber	1.27	0.00	0.00	0.00	0.05	0.00	98.46	0.00	0.00	1.47	0.00	0.00	0.02
Boxboard Using the "Broad Definition" for Mixed Paper	0.19	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Boxboard Using the "Single-Family Residential Definition" for Mixed Paper	0.19	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Paper Towels Using "Office Paper" for Mixed Paper	0.44	0.00	0.00	0.00	2.31	0.00	97.58	0.06	0.00	0.08	0.00	0.00	0.01
Carpet Padding	1.05	0.10	0.08	0.38	3.64	0.05	88.03	0.00	0.84	6.51	0.33	0.05	0.02
Carpet Backing	1.05	0.10	0.08	0.38	3.64	0.05	88.03	0.00	0.84	6.51	0.33	0.05	0.02
Concrete	0.09	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00
Injection Molded Auto Parts from Nylon Carpet	1.05	0.10	0.08	0.38	3.82	0.05	87.84	0.00	0.86	6.49	0.32	0.05	0.02
Asphalt (Cold Patch)	0.98	0.10	0.08	0.39	14.71	0.05	76.21	0.69	0.86	6.54	0.33	0.05	0.02
Steel Sheet	0.67	0.09	0.08	0.39	3.97	0.05	87.56	0.00	0.87	6.61	0.33	0.05	0.01
Lead Bullion	4.01	0.10	0.08	0.39	3.80	0.05	87.86	0.00	0.85	6.48	0.33	0.05	0.08
CRT Glass	5.28	0.05	0.04	0.20	1.89	0.03	93.85	0.00	0.42	3.33	0.17	0.02	0.10
Tires	NA												

Exhibit 2-7
Retail Transport Energy and Emissions

Material Type	Transportation Energy (Million Btu Per Ton of Product)	Transportation Emission Factors (MTCE per Ton of Product)
Aluminum Cans	0.31	0.01
Steel Cans	0.31	0.01
Glass	1.02	0.02
HDPE	0.48	0.01
LDPE	0.48	0.01
PET	0.48	0.01
Corrugated Cardboard	0.32	0.01
Magazines/Third-class Mail	0.26	0.01
Newspaper	0.26	0.01
Office Paper	0.26	0.01
Phonebooks	1.02	0.02
Textbooks	1.02	0.02
Dimensional Lumber	0.12	0.00
Medium-density Fiberboard	0.32	0.01