FINAL REPORT

LIFE CYCLE INVENTORY OF POLYMER COMPOSITES

SUBMITTED TO:

GREEN COMPOSITES COUNCIL
AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION (ACMA)

SUBMITTED BY:

FRANKLIN ASSOCIATES, A DIVISION OF
EASTERN RESEARCH GROUP, INC. (ERG)

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FRANKLIN Associates
A Division of ERG

Preface

This Life Cycle Inventory (LCI) study was conducted for the Green Composites Committee of the American Composites Manufacturers Association (ACMA). John Busel was the project coordinator for ACMA. The report was made possible through the cooperation of ACMA member companies and one non-member company who provided data on the production of fiber polymer composites, and five associated composites manufacturing process steps.

Eastern Research Group, Franklin Associates Division, carried out the work as an independent contractor for this project. Rebe Feraldi and Anne Marie Molen were the primary analysts collecting and compiling the LCI data and authoring the report. Melissa Huff, Senior Chemical Engineer was Project Manager and oversaw collection and compilation of the LCI data as well as providing technical and editorial review. Lori Snook contributed to research and report preparation tasks.

Franklin Associates and the ACMA are grateful to all of the companies that participated in the LCI data collection process. These companies include Alaglass Pools; AOC, LLC; Ashland Performance Materials; Best Bath Systems; Bradley Corporation; Classic Cultured Marble; CCP Composites; Ershigs, Inc.; Fiber-Tech Industries, Inc.; Goldshield, Inc.; Hoffman Fixtures Company; International Marble Industries, Inc.; Interplastics Corporation; Johns Manville; Mar-Bal, Inc.; MFG Tray Company; Molded Fiber Glass Companies; Oasis Lifestyle, LLC.; Owens Corning; PCCR USA; PPG Industries; Premix, Inc.; Plasti-Fab, Inc.; Reichhold, Inc.; Stahlin Enclosures; and Xerxes Corporation.

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CHAPTER 1. STUDY GOAL & SCOPE/LCI METHODOLOGY

OVERVIEW

Franklin Associates developed a methodology for performing resource and environmental profile analyses (REPA), now known as life cycle inventories (LCI). This methodology has been documented for the United States Environmental Protection Agency and is incorporated in the EPA report "Product Life-Cycle Assessment Inventory Guidelines and Principles." The methodology is also consistent with the life cycle inventory methodology described in the ISO 14040 standards:

- ISO 14040: 2006, Environmental management – Life cycle assessment – Principles and framework
- ISO 14044: 2006, Environmental management – Life cycle assessment – Requirements and guidelines

This LCI quantifies the total energy requirements, energy sources, water consumption, atmospheric pollutants, waterborne pollutants, and solid waste resulting from the production of two input materials used in composite manufacturing, and five associated processing steps in the manufacture of polymer composites. The input materials studied are unsaturated polyester resin (UPR) and E-Glass fiber. The analysis also includes five representative processing steps that utilize UPR and/or E-Glass fiber to manufacture polymer composites—open molding, vacuum infusion, compression molding, open mold casting, and secondary bonding. The data collected for the input materials and polymer composites process are representative of the United States.

Figure 1 illustrates the basic approach to data development for each major process in an LCI analysis. This approach provides the essential building blocks of data used to construct a complete resource and environmental emissions inventory profile for the entire life cycle of a product. Using this approach, each individual process included in the study is examined as a closed system, or "black box", by fully accounting for all resource inputs and process outputs associated with that particular process. Resource inputs accounted for in the LCI include raw materials and energy and water use, while process outputs accounted for include products manufactured, water released and environmental emissions to land, air, and water.

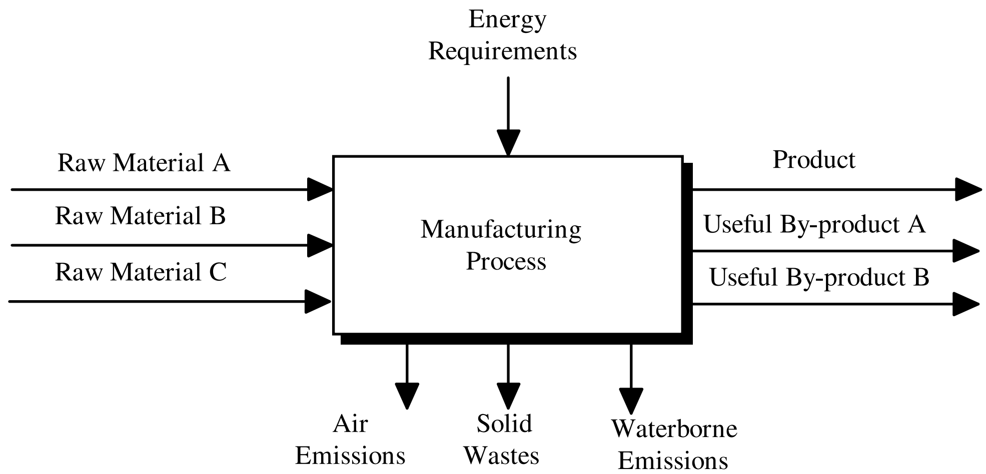

Figure 1. "Black Box" Concept for Developing LCI Data

For each process included in the study, resource requirements and environmental emissions are determined and expressed in terms of a standard unit of output. A standard unit of output is used as the basis for determining the total life cycle resource requirements and environmental emissions of a product.

The system boundaries for the LCI data provided to the U.S. LCI Database for the two polymer composites input materials and the five process data sets developed in this project are gate-to-gate; that is, the collected inventory data begins and ends with the fabrication step so that these datasets may be linked with the raw material data, use, and end-of-life data in order to create full life cycle inventories for a variety of composites material products. Within this report, cradle-to-gate LCI results for composites materials and the five processes are also provided, to illustrate the contributions of the material and converting steps to the total cradle-to-gate results for a composites product. The results for one LCA category, Global Warming Potential (GWP), are also included in the results of this report.

Overall, this analysis is not an impact assessment. It does not attempt to determine the fate of emissions, or the relative risk to humans or to the environment due to emissions from the systems. In addition, no judgments are made as to the merit of obtaining natural resources from various sources.

Study Goal and Intended Audience

The goal of this study is to conduct a transparent Life Cycle Inventory (LCI) for ACMA to:

1. Provide ACMA and its members with LCI data for the two polymer composites input materials and five associated processes that are specific to their operations for submission to the US LCI Database so that the LCI data may be used by public and private stakeholders, and

2. Provide the ACMA and their members with - LCI results representative of the cradle-to-gate production of the two polymer composites input materials and the five associated manufacturing processes for their use as an internal benchmarking and decision making resource.

ACMA members may use the information from this LCI as the basis for further study of any potential improvement of resource use and environmental emissions associated with the two polymer composites input materials and five associated processes.

The intent of the study was to develop unit process data sets for two composites material production steps and five composites converting processes using primary data from composites manufacturers. The data quality goal for this study was to use data that most accurately represents the U.S. for the composites input materials and associated manufacturing processes analyzed in this database. The quality of individual data sets vary in terms of representativeness, measured values or estimates, etc.; however, all process data sets used in this study were thoroughly reviewed for accuracy and currency and updated to the best of our capabilities for this analysis. Environmental profiles presented in this report for the material production and manufacturing processes were developed using the data provided by participating companies for this study.

This gate-to-gate LCI of has been conducted to provide both the members of the Green Composites Council of ACMA and the general public with primary LCI data for the composites input materials and associated manufacturing processes analyzed in this database. In due course, this fiber reinforced plastics (FRP) fabrication LCI database will be included in the U.S. Life Cycle Database, which is overseen by the National Renewable Energy Laboratory (NREL).

The materials production processes and manufacturing data sets developed in the project can be combined to model a wide variety of products. By making these data sets publicly available through the U.S. LCI Database, ACMA has provided valuable resources to support consistent, transparent modeling of composites products by any interested party.

Study Scope and System Boundaries

This project developed average unit process data for the following product systems:

Two input materials used in composites manufacturing:

- Unsaturated polyester resin (UPR) and
- E-Glass fiber

Five manufacturing processes typically used in the production of polymer composites:

- Compression molding
- Open molding of fiber reinforced composites
- Open mold casting of filled polymer composites

- Vacuum infusion
- Secondary bonding operations

Functional Unit

To provide a basis for comparison of different products, a common reference unit must be defined. The reference unit is based upon the function of the products, so that comparisons of different products are made on a uniform basis. This common basis, or functional unit, is used to normalize the inputs and outputs of the LCI. Results of the LCI are then expressed in terms of this functional unit. Three functional units are considered within this report:

- The functional unit of the LCI data of the input materials used in composites manufacturing (UPR and E-Glass) is ***1,000 pounds of output material.***
- The functional unit of the LCI data for four of the polymer composites manufacturing processes (compression molding, open molding, open mold casting, and vacuum infusion) is ***1,000 pounds of finished product.***
- The functional unit for secondary bonding is ***1,000 pounds of adhesive used***.

Unit process data are also presented in metric units.

System Boundaries

This LCI focuses on two common input materials in composites manufacturing and five associated manufacturing processes used to fabricate polymer composites (Figure 2). The produced input materials and the associated composites manufacturing process steps are modeled as gate-to-gate unit processes. These datasets will be provided to the US LCI Database in this format. Each unit process LCI module includes incoming transportation steps. Recycling potential of the fabricated products is not included, because these benefits are outside of the scope of the gate-to-gate process modules intended for the public LCI database. Each LCI data module includes the following information:

Elementary inputs and outputs (to and from nature)
- Water inputs required
- Raw material inputs required
- Air emission outputs
- Waterborne emission outputs
- Water output

Intermediate inputs and outputs (to and from the technosphere)
- Energy product inputs required
- Economic goods (material) input required
- Solid waste outputs to be managed
- Wastewater outputs to be treated
- Economic goods (material) output

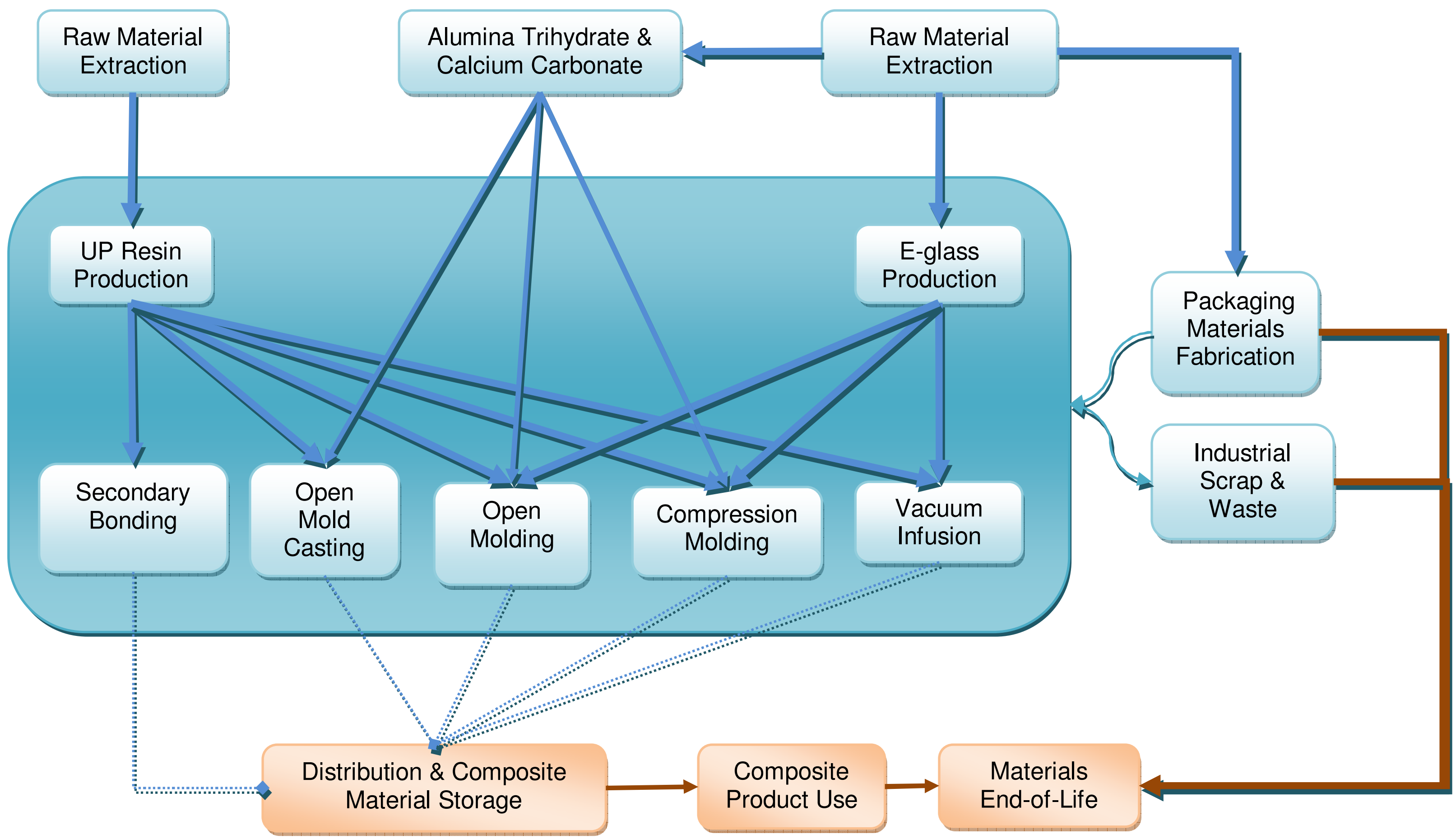

Figure 2. System Boundaries for Composites Product Systems LCI
(Processes and transport steps included in system boundaries highlighted in blue)

Each converting data set includes incoming transportation steps. The energy used to heat, cool, and/or light non-manufacturing space is included in the system boundaries of this LCI, as not all processors were able to separate out this energy. The amount of energy used to heat, cool, and/or light the non-manufacturing space of the processing facilities is expected to vary widely depending on the location (i.e., surrounding climate) and configuration of the plant.

Transportation of the finished product to a retailer, use of that product by consumers, and disposal of the product are not included in the study. Cradle-to-gate data for the composites products are provided to illustrate the contribution of the processes to the LCI results for production of the composites products.

Process flow diagrams and LCI results, along with brief descriptions of processes are found in the concurrent Chapters in this report.

System Components Not Included

The following components of each system are not included in this LCI study:

Capital Equipment: The materials and energy inputs as well as waste outputs associated with the manufacture of capital equipment are excluded from this analysis. This includes equipment to manufacture buildings, motor vehicles, and industrial machinery. In general, these types of capital equipment are used to produce large quantities of product output over a useful life of many years. Thus, energy and emissions associated with the production of these facilities and equipment generally become negligible.

Support Personnel Requirements: The energy and wastes associated with research and development, sales, and administrative personnel or related activities have not been included in this study. Energy requirements and related emissions are assumed to be quite small for support personnel activities.

Miscellaneous Materials and Additives: Miscellaneous materials that comprise less than one percent by weight of the net process inputs are typically not included in the assessment unless inventory data for their production are readily available or there is reason to believe the materials would make significant contributions to energy use or environmental impacts. For example, in this study, the weight of some additives are less than 1 percent of material inputs and are not included in the analysis. Omitting miscellaneous materials and additives helps keep the scope of the study focused and manageable within budget and time constraints. While there are energy and emissions associated with production of materials that are used in very low quantities, the amounts would have to be disproportionately high per pound of material for such small additives to have a significant effect on overall life cycle results for the systems studied. This cut-off assumption is based on past LCA studies that demonstrate that materials which comprise less than one percent of system weight have a negligible effect on total LCA results. The intent of this project was to develop processing data sets that are applicable to a broad range of products. Average material inputs based on the LCI surveys are reported in the tables, but modeling of specific composites product systems should use product-specific input data whenever possible.

Cut-Off Criteria. This LCI elects to use the one percent by mass cut-off criteria. In other words, any material flow comprising less than one percent by weight of the system is excluded. This cut-off assumption is based on past LCI studies that demonstrate that materials which comprise less than one percent of system weight have a negligible effect on total LCI results. The exception to this criterion is that if a material less than one percent by mass of the system is hazardous, toxic, and/or produces environmental burdens in excess of its weight fraction of the finished product; in this case, the material should be included in the LCI. This is true of a number of additives within this inventory. It should be noted that if data has been compiled for components that comprise less than one percent of a system's weight, these components are included in the analysis.

Data Sources and Data Quality

Overview

Data necessary for conducting the inventory and for presenting the gate-to-gate environmental profiles for the two materials and five polymer composites processes are separated into two categories: foreground process-related data and the background data required for material and energy inputs to the foreground processes. The accuracy of the study is directly related to the quality of input data. Quality of input data is dependent on both data sources and methodological considerations. This section discusses the data sources used and data quality considerations given to both the foreground and background process data compiled for this analysis.

Data Sources

Foreground inventory data is primary data compiled specifically for this analysis. Survey participants are members of the ACMA, with one non-member participating. For background data used to develop cradle-to-gate environmental profiles of UPR, E-Glass, and polymer composites production processes, data from a number of published sources were utilized for this report. The data sources used to characterize upstream processes associated with composites materials and processes are listed under the relevant sections. A summary of the primary data modules and their data source(s) is presented in Table 1.

Table 1. Summary of Data Sources

	Temporal Information	Geographical Coverage	Technological Coverage	Data Sources
Domestic Electrical & Energy Sources	Energy source data from late 1990s to 2008; Electricity grid is 2005 U.S. average	Based on average U.S. grid	The most representative technologies	Energy sources are publicly available in the U.S. LCI database (From Franklin Associates). Electricity grid has been updated to E-Grid 2007 (2005 data). [1]
Raw Materials (Natural Gas and Oil)	Data from late 1990s to 2010	Natural gas and crude oil based on U.S. data; for average amount of domestic and foreign oil.	The most representative technologies.	Publicly available in the U.S. LCI database from Franklin Associates
Unsaturated Polyester Resin	Data from 2010	U.S. average	The most representative technologies.	ACMA
E-Glass	Data from 2000s	U.S. average	The most representative technologies.	ACMA
Composites Input Materials	Data from 2010	U.S. average	The most representative technologies.	ACMA
Composites Manufacturing	Data from 2010	U.S. average	The most representative technologies.	ACMA

[1] eGRID 2006 (Emissions and Generation Resource Integrated Database). U.S. EPA. at: www.epa.gov/cleanenergy/egrid.

(Table 1. cont.)	Temporal Information	Geographical Coverage	Technological Coverage	Data Sources
Virgin Plastic Resin Production	Data from 2003-2007, updated in 2011	U.S. average	The most representative technologies.	Virgin resin data compiled for the American Chemistry Council (ACC)[2] by Franklin Associates
Ancillary Components	Data from late 1990s to 2010	U.S. average	The most representative technologies.	Franklin Associates' Private Database, U.S. LCI Database, or adapted from ecoinvent
Transport Processes	Current data	U.S. average	The most representative technologies.	Primary data ACMA members; averages per mode from Franklin Associates' data compiled for the U.S. LCI Database[3]

2 American Chemistry Council. 2011. Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors. Franklin Associates, A Division of ERG. Available at: http://www.americanchemistry.com/plastics/sec_content.asp?CID=1593&DID=6056.

3 National Renewable Energy Lab (NREL). US LCI Database. See: http://www.nrel.gov/lci/database/default.asp.

Data Quality

ISO standard 14044:2006 states that "Data quality requirements shall be specified to enable the goal and scope of the LCA to be met." The data quality requirements listed include time-related representativeness, geographical coverage, technology coverage, completeness, and more.

The data quality goal for this study was to use data that most accurately represents the U.S. UPR, E-Glass, and composites manufacturing materials and processes analyzed in this study. The quality of individual data sets vary in terms of age, representativeness, measured values or estimates, etc.; however, all materials and process data sets used in this study were thoroughly reviewed for accuracy and currency and updated to the best of our capabilities for this analysis.

The data quality goal for this study was to use data that most accurately represents U.S. composites manufacturing processes. The development of methodology for the collection of data is essential to obtaining quality data. All process data sets used in this study were thoroughly reviewed for accuracy and currency for this analysis.

Geographic Scope

The geographic scope of this study is composites manufacturing processes in the U.S.; however, this does include raw material sourced from other regions of the world (this primarily applies to bauxite and crude oil imports). The main sources of data and information for geography-dependent process (e.g., energy production) are drawn from US specific reports and databases. Primary data specific to ACMA members operations are collected from an average of companies within the U.S. market.

Technology Coverage

Primary data is collected for the mix of technologies currently used by composites manufacturers in the US. In addition to process data, the LCI survey form also requested information for assessing the age and representativeness of the technology used by the facility/ies providing the process data.

Temporal Coverage

For the primary data collected, annual production data was collected for the most current full calendar year (2010). For data from shipping sources, the most current publically available data for the U.S. is utilized. A goal of this study is to use data with six or less years of difference to the reference year (2010). Six years is chosen as the goal because it meets the top two data scores for temporal correlation as identified in the pedigree matrix.[4] This goal was unable to be met as one E-Glass producer provided data from 2001.

4 Weidema, B. and Wesnaes. MS. 1996. Data quality management for life cycle inventories - an example of using data quality indicators. *International Journal of Cleaner Production,* 4: 167-74.

Fuel Data

When fuels are used for process or transportation energy, there are energy and emissions associated with the production and delivery of the fuels as well as the energy and emissions released when the fuels are burned. Before each fuel is usable, it must be mined, as in the case of coal or uranium, or extracted from the earth in some manner. Further processing is often necessary before the fuel is usable. For example, coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils, and "wet" natural gas is processed to produce natural gas liquids for fuel or feedstock.

To distinguish between environmental emissions from the combustion of fuels and emissions associated with the production of fuels, different terms are used to describe the different emissions. The combustion products of fuels are defined as *combustion data*. Energy consumption and emissions which result from the mining, refining, and transportation of fuels are defined as *precombustion data*. Precombustion data and combustion data together are referred to as *fuel-related data.*

Fuel-related data are developed for fuels that are burned directly in industrial furnaces, boilers, and transport vehicles. Fuel-related data are also developed for the production of electricity. These data are assembled into a database from which the specific fuel requirements at the fabrication steps may be drawn and connected in sequence for the cradle-to-gate inventory. These datasets include energy requirements and environmental emissions for the production and combustion of process fuels. Energy data are developed in the form of units of each primary fuel required per unit of each fuel type. For electricity production, federal government statistical records provided data for the amount of fuel required to produce electricity from each fuel source, and the total amount of electricity generated from petroleum, natural gas, coal, nuclear, hydropower, and other (solar, geothermal, etc.). Literature sources and federal government statistical records provided data for the emissions resulting from the combustion of fuels in utility boilers, industrial boilers, stationary equipment such as pumps and compressors, and transportation equipment. Because electricity and other fuels are required in order to produce electricity and primary fuels, there is a complex and technically infinite set of interdependent steps involved in fuel modeling. An input-output modeling matrix is used for these calculations.

In 2003, Franklin Associates updated our fuels and energy database for inclusion in the U.S. LCI database. Emissions for fuels extraction and processing were updated in 2011. This fuels and energy database, which is published in the U.S LCI Database, is used in this analysis.

Electricity Grid Fuel Data

In general, detailed data do not exist on the fuels used to generate the electricity consumed by each industry. Electricity production and distribution systems in the United States are interlinked and are not easily separated. Users of electricity, in general, cannot specify the fuels used to produce their share of the electric power grid. Therefore, the U.S. national average fuel consumption by electrical utilities is used.

Transportation Data

This LCI include transportation requirements between manufacturing steps. For upstream processes (such as crude oil extraction, fuels production, etc.) the transportation modes and distances are based on average industry data. For incoming transport at the material production and processing steps, the transportation requirements are based on the weighted averages for transportation modes and distances compiled in the primary data collection.

Water Data

Water consumption data for the investigated UPR, E-Glass, and polymer composites processing are from the primary sources (collected for this study). In the environmental profile results, water consumption data for upstream processes are from primary data collection for associated product systems when possible. When primary data has not been available, water consumption is modeled using values reported in literature. In some cases, consumptive use data may not be available. The ecoinvent database[5], a European LCI database with data for many unit processes, includes water in the life cycle inventory as an input, and does not record water released to the environment (i.e. as an emission) or water consumed. However, ecoinvent is currently one of the most comprehensive LCI sources on water for upstream processes; many other available databases do not report water input/use as an inventory item. Therefore, when primary data or literature values are not available, ecoinvent data are utilized for the water calculations. When utilizing ecoinvent, the data is adapted to represent consumptive use to the extent possible (i.e., incorporating volumes of fresh water removed from the environment and not internally recirculated).

Data Accuracy

An important issue to consider when using LCI study results is the reliability of the data. In a complex study with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single point estimates. However, the reliability of the study can be assessed in other ways.

A key question is whether the LCI profiles are accurate. The accuracy of an environmental profile depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to model composites input materials and products, many numbers in the LCI are added together for a total numeric result. Each number by itself may contribute little to the total, so the accuracy of each number by itself has a small effect on the overall accuracy of the total. There is no widely accepted analytical method for assessing the accuracy of each number to any degree of confidence. For many chemical processes, the data sets are based on actual plant data reported by plant personnel. The data reported may represent operations for the previous year or may be representative of engineering and/or accounting

5 Ecoinvent Centre (2010), ecoinvent data v2.2. ecoinvent reports No. 1-25, Swiss Centre for Life Cycle Inventories. Retrieved from the SimaPro LCA software v7.2.3.

methods. All data received are evaluated to determine whether or not they are representative of the typical industry practices for that operation or process being evaluated. Taking into consideration budget issues and limited industry participation, the data used in this report are believed to be the best that can be currently obtained.

There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For process steps that make a larger than average contribution to the total, special care is taken with the data quality. It is assumed that with careful scrutiny of the data, any errors will be random.

There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of material required for a process. This number will affect every step in the production sequence prior to the process. Errors such as this that propagate throughout the system are more significant in steps that are closest to the end of the production sequence. For example, changing the weight of an input to the final processing step for a composites product changes the amounts of material inputs to that process, and so on back to the quantities of crude oil and natural gas extracted.

In summary, for the particular data sources used and for the specific methodology described in this report, the results of this report are believed to be as accurate and reasonable as possible.

Assumptions & Limitations

Although the foreground processes in this analysis were populated with primary data and the background processes come from reliable databases and secondary data, most analyses still have limitations. Further, it is necessary to make a number of assumptions when modeling, which could influence the final results of a study. Key limitations and assumptions of this analysis are described in this section.

Geographic Scope. Data for foreign processes are generally not available. This is usually only a consideration for the production of oil that is obtained from overseas. In cases such as this, the energy requirements and emissions are assumed to be the same as if the materials originated in the United States. Since foreign standards and regulations vary from those of the United States, it is acknowledged that this assumption may introduce some error. Transportation of crude oil used for petroleum fuels and resins is modeled based on the current mix of domestic and imported crude oil used.

Water Use. Details on sources and quality of water consumption data have been discussed. However, it should be mentioned in this section on limitations that there is currently a lack of water use data on a unit process level for life cycle inventories. In addition, water use data that are available from different sources do not use a consistent method of distinguishing between consumptive use and non-consumptive use of water or clearly identifying the water sources used (freshwater versus saltwater, groundwater versus surface water). A recent article in the International Journal of Life Cycle Assessment summarized the status and deficiencies of water use data for LCA, including the statement, "To date, data availability on freshwater use proves to be a limiting factor for establishing meaningful water footprints of products."[6] The article goes on to define the need for a standardized reporting format for water use, taking into account water type and quality as well as spatial and temporal level of detail. To address many of the inconsistencies in LCA water reporting, the International Standardization Organization is in preliminary stages of developing a water footprint standard (14046**,** *Water footprint – Requirements and guidelines),* which is slated to be completed in 2012.[7]

LCI Methodology

The accuracy of the study is directly related to the quality of input data. The development of methodology for the collection of data is essential to obtaining quality data. Careful adherence to that methodology determines not only data quality but also objectivity.

Data Collection/Verification

The process of gathering data is an iterative one. The ACMA contacted member companies (and one non-member company) that agreed to participate in this inventory by collecting process data. Data collection sheets were developed specifically for the investigated materials and processes were provided to assist in gathering the necessary LCI data. Upon receipt of the completed worksheets, the data were evaluated for completeness and reviewed. Data suppliers were then contacted again to discuss the data, process technology, waste treatment, identify coproducts, and any assumptions necessary to understand the data and boundaries. After each dataset was completed and verified, the datasets for each material or process were aggregated into a single set of data for that material or process by weighting the facility's data by its plant production amount percentage. In this way, a representative set of data can be estimated from a limited number of data sources. The material or process dataset were then documented and returned with the averaged dataset to each data supplier for their review.

Confidentiality

Franklin Associates takes care to protect data that is considered confidential by individual data providers. In order to protect confidential data sets provided by individual material or processing facilities, only weighted average data sets can be shown for each type of facility.

Objectivity

Each unit process in the life cycle study is researched independently of all other processes. No calculations are performed to link processes together with the production of their raw materials until *after* data gathering and review are complete. This allows objective review of individual data sets before their contribution to the overall life cycle results has been determined. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than their effect on the overall outcome of the study.

[6] Koehler, Annette. "Water use in LCA: managing the planet's freshwater resources." Int J Life Cycle Assess (2008) 13:451-455.

[7] ISO considers potential standard on water footprint. Viewed at: http://www.iso.org/iso/iso-focus-plus_index/iso-focusplus_online-bonus-articles/isofocusplus_bonus_water-footprint.htm.

Material Requirements

Once the LCI study boundaries have been defined and individual processes identified, a material balance is performed for each individual process. This analysis identifies and quantifies the input raw materials required per standard unit of output, such as 1,000 pounds of manufactured composites product, for each individual process included in the LCI. The purpose of the material balance is to determine the appropriate weight factors used in calculating the total energy requirements and environmental emissions associated with each process studied. Energy requirements and environmental emissions are determined for each process and expressed in terms of the standard unit of output.

Energy Requirements

The average energy requirements for each process identified in the LCI are first quantified in terms of fuel or electricity units, such as cubic feet of natural gas, gallons of diesel fuel, or kilowatt-hours (kWh) of electricity. The fuel used to transport raw materials to each process is included as a part of the LCI energy requirements. Transportation energy requirements are developed in the conventional units of ton-miles by each transport mode (e.g. truck, rail, barge, etc.). Government statistical data for the average efficiency of each transportation mode are used to convert from ton-miles to fuel consumption.

Once the fuel consumption for each industrial process and transportation step is quantified, the fuel units are converted from their original volume or mass units to an equivalent energy value based on standard conversion factors. The conversion factors have been developed to account for the energy required to extract, transport, and process the fuels and to account for the energy content of the fuels. The energy to extract, transport, and process fuels into a usable form is labeled precombustion energy. For electricity, precombustion energy calculations include adjustments for the average efficiency of conversion of fuel to electricity and for transmission losses in power lines based on national averages. The LCI methodology assigns a fuel-energy equivalent to raw materials that are derived from fossil fuels. Therefore, the total energy requirement for coal, natural gas, or petroleum based materials includes the fuel-energy of the raw material (called energy of material resource or inherent energy).

The energy values for fuels and electricity consumed in each industrial process are summed and categorized into an energy profile according to the six basic energy sources listed below:

- Natural gas
- Petroleum
- Coal
- Nuclear
- Hydropower
- Biomass

Also included in the LCI energy profile are the energy values for all transportation steps and all fossil fuel-derived raw materials.

Environmental Emissions

Environmental emissions are categorized as atmospheric emissions, waterborne emissions, and solid wastes and represent discharges into the environment after the effluents pass through existing emission control devices. Similar to energy, environmental emissions associated with processing fuels into usable forms are also included in the inventory. When it is not possible to obtain actual industry emissions data, published emissions standards are used as the basis for determining environmental emissions.

Atmospheric Emissions: These emissions include substances classified by regulatory agencies as pollutants, as well as selected non-regulated emissions such as carbon dioxide. For each process, atmospheric emissions associated with the combustion of fuel for process or transportation energy, as well as any emissions released from the process itself, are included in this cradle-to-gate inventory results. The amounts reported represent actual discharges into the atmosphere after the effluents pass through existing emission control devices. Some of the more commonly reported atmospheric emissions are: carbon dioxide, carbon monoxide, non-methane hydrocarbons, nitrogen oxides, particulates, and sulfur oxides. The emissions discussion in the results focuses on greenhouse gas emissions, expressed in pounds of carbon dioxide equivalents.

Waterborne Emissions: As with atmospheric emissions, waterborne emissions include all substances classified as pollutants. The values reported are the average quantity of pollutants still present in the wastewater stream after wastewater treatment and represent discharges into receiving waters. This includes both process-related and fuel-related waterborne emissions. Some of the most commonly reported waterborne emissions are: acid, ammonia, biochemical oxygen demand (BOD), chemical oxygen demand (COD), chromium, dissolved solids, iron, and suspended solids.

Solid Wastes: This category includes solid wastes generated from all sources that are landfilled or disposed of in some other way, such as incineration with or without energy recovery. These include industrial process- and fuel-related wastes, as well as the material components that are disposed. Examples of industrial process wastes are residuals from chemical processes and manufacturing scrap that is not recycled or sold. Examples of fuel-related solid wastes are ash generated by burning coal to produce electricity, or particulates from fuel combustion that are collected in air pollution control devices.

Because this analysis is limited to composites manufacturing unit processes and cradle-to-gate results for composites products, postconsumer wastes are not included. Only industrial wastes from processes and fuel-production throughout the fabrication processes are considered. Examples of industrial solid wastes are wastewater treatment sludge, solids collected in air pollution control devices, scrap or waste materials from manufacturing operations that are not recycled or sold, and fuel combustion residues such as the ash generated by burning coal.

LCI Practitioner Methodology Variation

There is general consensus among life cycle practitioners on the fundamental methodology for performing LCIs.[8] However, for some specific aspects of life cycle inventory, there is some minor variation in methodology used by experienced practitioners. These areas include the method used to allocate energy requirements and environmental releases among more than one useful product produced by a process and the method used to account for the energy contained in material feedstocks. LCI practitioners vary to some extent in their approaches to these issues. The following sections describe the approach to each issue used in this study.

Allocation Procedures

For processes that produce more than one useful output, this LCA follows the allocation guidelines in ISO 14044: 2006. The preferred hierarchy for handling allocation as outlined in ISO 14044, Section 4.3.4.2 is (1) avoid allocation where possible, either by further subdivision of processes or by system expansion, (2) allocate flows based on direct physical relationships to product outputs, (3) use some other relationship between elementary flows and product output. PAS 2050 also uses this hierarchy.

No single allocation method is suitable for every scenario. The method used for handling product allocation will vary from one system to another but choosing parameters is not arbitrary. ISO 14044, Section 4.3.4.2 states that "the inventory is based on material balances between input and output. Allocation procedures should therefore approximate as much as possible such fundamental input/output relationships and characteristics."

Some processes lend themselves to physical allocation because they have physical parameters that provide a good representation of the environmental burdens of each co-product. Examples of parametric bases for various allocation methods are mass, stoichiometric, elemental, reaction enthalpy, and economic. For the processes in this analysis where allocation cannot be avoided, simple mass and enthalpy relationships have been chosen as the common parametric basis for allocation. However, these allocation methods are not selected as a default choice, but made on a case by case basis after due consideration of the chemistry and production mode of the investigated system.

When the co-product is heat or steam or a co-product sold for use as a fuel, the energy content of the exported heat, steam, or fuel is treated as an energy credit for that process. When the co-product is a material, the process inputs and emissions are allocated to the primary product and co-product material(s) on a mass basis. Allocation based on economic value can also be used to partition process burdens among useful co-products; however, this approach is less preferred under ISO life cycle standards, as it depends on the economic market, which can change dramatically over time depending on many factors unrelated to the chemical and physical relationships between process inputs and outputs.

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8 International Standards Organization. ISO 14040:2006 Environmental management—Life cycle assessment—Principles and framework, ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines.

Energy of Material Resource

For some raw materials, such as petroleum, natural gas, and coal, the amount consumed in all industrial applications as fuel far exceeds the amount consumed as raw materials (feedstock) for products. The primary use of these materials in the marketplace is for energy. The total amount of these materials can be viewed as an energy pool or reserve. This concept is illustrated in Figure 3. The use of a certain amount of these materials as feedstocks for products, rather than as fuels, removes that amount of material from the energy pool, thereby reducing the amount of energy available for consumption. This use of available energy as feedstock is called the energy of material resource (EMR) and is included in the inventory. The energy of material resource represents the amount the energy pool is reduced by the consumption of fuel materials as raw materials in products and is quantified in energy units.

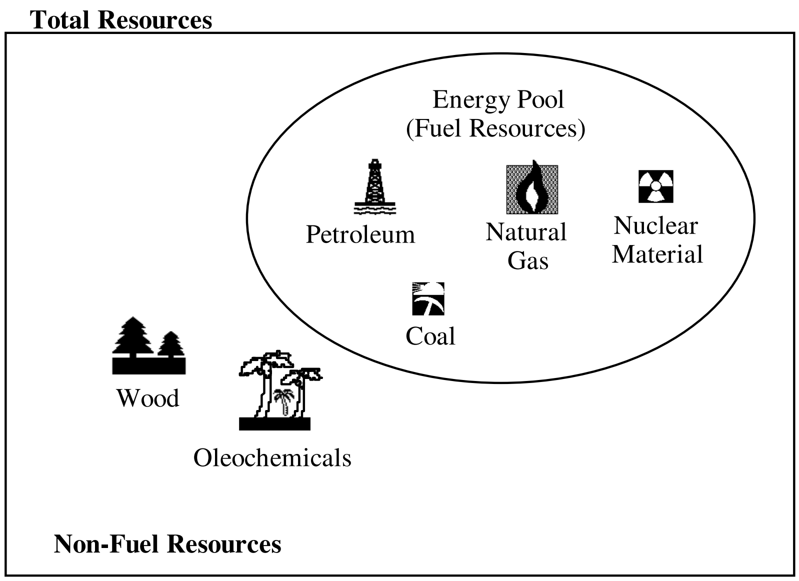

Figure 3. Illustration of the Energy of Material Resource Concept

EMR is the energy content of the fuel materials *input* as raw materials or feedstocks. EMR assigned to a material is *not* the energy value of the final product, but is the energy value of the raw material at the point of extraction from its natural environment. For fossil fuels, this definition is straightforward. For instance, petroleum is extracted in the form of crude oil. Therefore, the EMR for petroleum is the higher heating value of crude oil.

Once the feedstock is converted to a product, there is energy content that could be recovered, for instance through combustion in a waste-to-energy waste disposal facility. The energy that can be recovered in this manner is always somewhat less than the feedstock energy because the steps to convert from a gas or liquid to a solid material reduce the amount of energy left in the product itself.

In North America, energy content is most often quoted as higher heating value (HHV); this value is determined when the product is burned and the product water formed is condensed. The use of HHV is considered preferable from the perspective of energy efficiency analysis, as it is a better measure of the energy inefficiency of processes.[9] Lower heating values (LHV), or net heating values, measure the heat of combustion when the water formed remains in the gaseous state. The difference between the HHV and the LHV depends on the hydrogen content of the product. As the carbon amount of the combusted material climbs higher, the difference in these two values levels off to approximately 7.5 percent.[10]

The materials which are primarily used as fuels can change over time and with location. In industrially developed countries, the material resources whose primary use is for fuel have traditionally been petroleum, natural gas, coal, and nuclear material. While some wood is burned for energy, the primary use for wood in such as context is as a material input for products such as paper and lumber. Similarly, some oleochemical oils such as palm oils are burned for fuels, often referred to as "bio-diesel." However, as in the case of wood, their current primary consumption is as raw materials for products such as soaps, surfactants, cosmetics, etc. Because biomass has not been a common fuel source in industry in developed countries, the feedstock energy of biomass material inputs has not traditionally been reported by Franklin Associates.

However, with the increasing use of biomass as feedstock for biofuels, for example, corn-derived ethanol and soy-derived biodiesel, as well as the growing efforts to use cellulosic biomass as fuel feedstocks, it is worth tracking energy of material resource for biomass resources as well as fossil resources. In this analysis, biomass EMR is included in the cradle-to-product LCI energy results for wood-derived packaging material.

Practical Application of the LCI Data

The unit process tables at the beginning of each subsequent LCI chapter contain gate-to-gate process data for each product system. Chapter 2 and Chapter 3 also contain cradle-to-gate LCI results for the UPR and E-Glass respectively. These system processes are fully "rolled-up" data sets; that is, they include the burdens for all the processes required to produce the material and energy inputs for the polymer composites input material. Fully rolled-up datasets include not only the direct burdens for the material production or composites processing step but also the upstream burdens for the production and combustion of all fuels used in the processes, as well as the production of all input materials used in the process, and the production and combustion of fuel required to deliver materials used in the process. The advantage of using rolled-up data sets is that all the related data have been aggregated into a single data set. However, an important disadvantage of using rolled-up data sets is that the contributing data are "locked in" to the aggregated total so that it is generally not possible to directly adjust the total end results to reflect any subsequent changes in any individual contributing data sets (for example, a reduction in natural gas use at the processing step or a change in the mix of fuels used to produce the grid electricity used in the processing step).

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9 Worrell, Ernst, Dian Phylipsen, Dan Einstein, and Nathan Martin. (2000). Energy Use and Energy Intensity of the U.S. Chemical Industry. Ernest Orlando Lawrence Berkeley National Laboratory. April, 2000. p. 12.

10 Seddon, Dr. Duncan. (2006). Gas Usage & Value. PennWell Books. p. 76. Figure 4-1.

When life cycle practitioners construct models for product systems, they normally construct the models by linking **unit process** data sets (such as the data sets shown for the gate-to-gate product systems in the following chapters), rather than rolled-up data sets like much of the data in this report. In unit process modeling, the quantities of material inputs and fuel inputs to each unit process are linked to data sets for the production of those materials and for production and combustion of fuels. This modeling approach is the approach that was used in this analysis to construct the fully rolled-up datasets. In the unit process modeling approach, the linked data will automatically adjust for changes in any contributing process or fuel-related dataset. In a full cradle-to-grave composites **product** LCIs, the data sets for the materials used in the product would be combined with the data for the composites processing, use and end-of-life management. The full cradle-to-grave model of a composites product will depend on the specific resin, E-Glass reinforcement, and other material inputs, the product application, and the allocation method chosen for postconsumer recycling, if any, in the composites product system.

CHAPTER 2. UNSATURATED POLYESTER RESIN (UPR)

INTRODUCTION

This chapter describes the production of unsaturated polyester resin (UPR), presents the compiled gate-to-gate unit process LCI data for production of UPR, and presents LCI results for cradle-to-gate production of 1,000 pounds of UPR in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of UPR Input Material

UPR can form very durable compounds and coatings; it is the most commonly used thermoset resin used in manufacturing composites materials. UPR end markets are primarily construction, automotive, marine, and are increasingly used to produce infrastructural components required for items such as wind energy and bridge construction. For reinforced applications, the function of UPR in the composites material is to provide a matrix for structural reinforcements and to distribute and transfer load between the reinforcement fibers and adjacent structures. UPR is also used in non-reinforced composite applications such as sinks, counters, surfaces and polyer concrete applications. For non-reinforced applications, UPR is selected for use because of its durability and design flexibility.

UPRs are produced by a polycondensation of dicarboxylic acids and glycol monomers in a heated kettle. When the reaction is complete, the resulting fluid polyester is cooled and blended with a vinylic reactive monomer. Styrene is the most common reactive diluent used in UPR production. Water is a by-product of the esterification reaction and is continuously removed during the esterification step to drive the reaction to completion. This water is sent to a thermal oxidizer to eliminate the hydrocarbons. The waste heat generated from the thermal oxidation process is sometimes utilized to produce steam energy for re-use within the UPR production facility. In some manufacturing sites, the oxidized vapor is released directly to the air without capture and re-use of the waste heat. The final UPR product is shipped to composite fabricators via drum, tote, or bulk tankers where it is combined with other materials, such as fibers and fillers, and processed into a finished or semi-finished part. The properties of UPR depend on the types and proportions of monomers (i.e., acids and glycols) reacted.

Figure 4 displays a summary of the material inputs used to manufacture UPR. Further information on the data sources of these material inputs are shown in Appendix B.

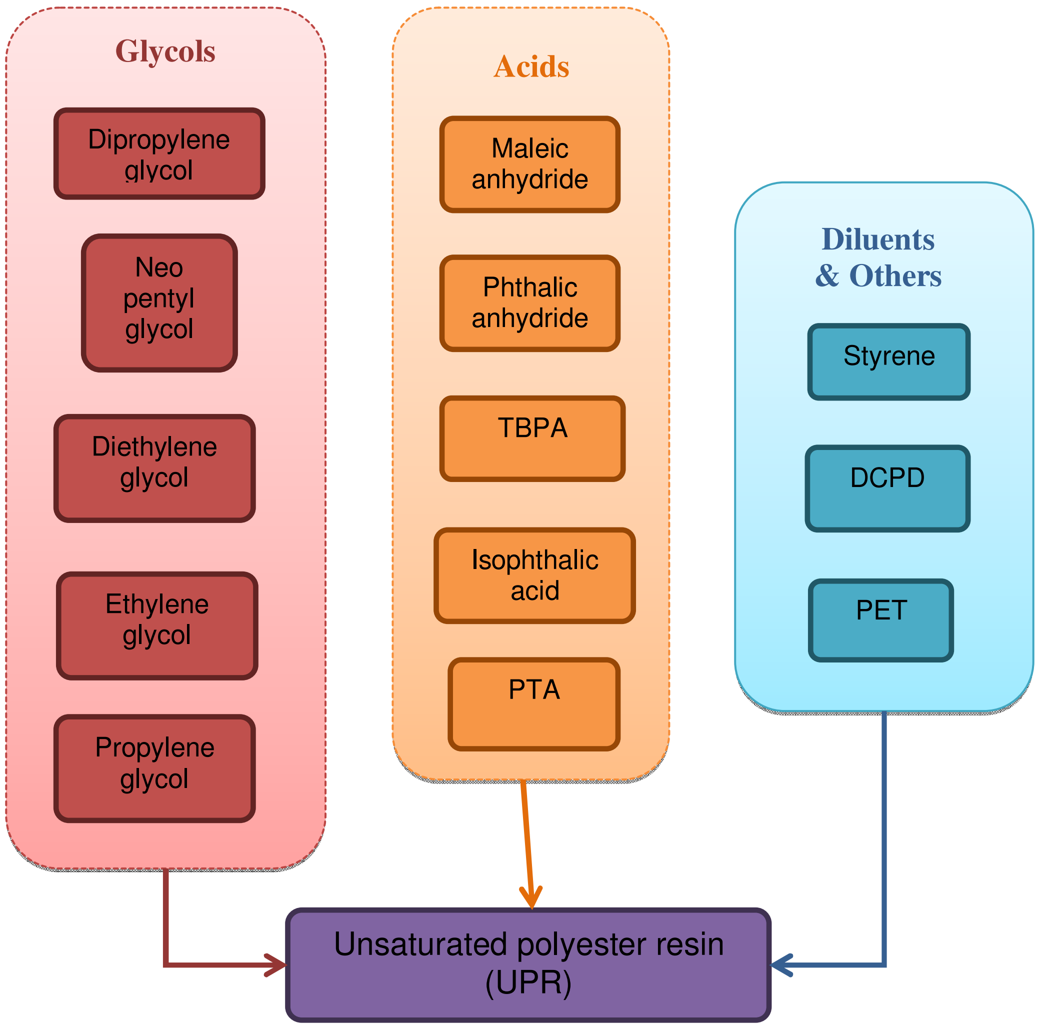

Figure 4. Summary of UPR Production

Table 2 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of UPR in 2010 in the US. For the portion of water created that produces steam energy, the hydrocarbon content of the reaction by-product is used to calculate the amount of natural gas and oil required to produce the hydrocarbons and is no longer available as Energy of Material Resources or EMR. The amounts of natural gas and oil extracted from nature for EMR and fuel use sum to zero and only reflect the change in the inventory of feedstock versus expended energy. As the amount of natural gas used as fuel to the thermal oxidizer is already included in the total process energy requirements, adding the amount of produced steam energy would double-count the energy requirement. Therefore, the steam energy produced for each 1,000 pounds of UPR production, about 0.18 million British thermal units (Btu), is excluded from the total process energy requirements. In terms of process energy consumption, the average UPR facility meets most of its process energy demand (86 percent) with natural gas combustion. Electricity is used to meet a significant share, about 13.5 percent, of the process energy demand; whereas, distillate combustion and petroleum coke are used in smaller amounts. An average of 8.9 pounds of solid waste are generated for every 1,000 pounds of UPR produced: 24 percent are landfilled (including some packaging waste from incoming materials), 15 percent are non-hazardous materials that are incinerated, 21 percent are hazardous materials which are incinerated with energy recovery, and 40 percent of the solid waste is sold for recycling.

Table 2. LCI Unit Process Data for UPR Production

	English units (Basis: 1,000 lb)		SI units (Basis: 1,000 kg)	
Outputs to Technosphere				
Unsaturated Polyester Resin (UPR)	1,000	lb	1,000	kg
Material sold for recycling	3.60	lb	3.60	kg
Inputs from Nature				
Natural gas (EMR)	-2.30	lb	-2.30	kg
Natural gas (fuel)	2.30	lb	2.30	kg
Crude oil (EMR)	-0.510	lb	-0.510	kg
Crude oil (fuel)	0.510	lb	0.510	kg
Inputs from Technosphere (to Product)				
Dicyclopentadiene (DCPD)	90.0	lb	90.0	kg
Diethylene glycol	100	lb	100	kg
Dipropylene glycol	15.0	lb	15.0	kg
Ethylene glycol	20.0	lb	20.0	kg
Maleic anhydride	180	lb	180	kg
Neo pentyl glycol	14.0	lb	14.0	kg
Phthalic anhydride	74.0	lb	74.0	kg
Polyethylene terephthalate (PET)	15.0	lb	15.0	kg
Propylene glycol	81.0	lb	81.0	kg
Isophthalic acid	29.0	lb	29.0	kg
Purified terephthalic acid (PTA)	13.0	lb	13.0	kg
Styrene	330	lb	330	kg
Tetrabromophthalic anhydride (TBPA)	7.10	lb	7.10	kg
Process Water Consumption	68.0	gal	567	liter
Energy Usage				
Process Energy				
Electricity (grid)	87.2	kwh	192	kwh
Natural gas	1,849	cu ft	115	cu meters
Petroleum Coke	0.020	lb	0.020	kg
Distillate oil	0.027	gal	0.23	liter
Incoming Materials Transportation Energy				
Combination truck	76.1	ton-miles	245	tonne-km
Diesel	0.80	gal	6.67	liter
Rail	669	ton-miles	2,154	tonne-km
Diesel	1.66	gal	13.9	liter

Table 2. (Cont'd) LCI Unit Process Data for UPR Production

Environmental Emissions				
Atmospheric Emissions				
Aniline, N,N-dimethyl-	1.5E-05	lb	1.5E-05	kg `
Butanol	2.0E-04	lb	2.0E-04	kg
Carbon dioxide, fossil	37.0	lb	37.0	kg
Carbon monoxide	0.27	lb	0.27	kg
Dicyclopentadiene	0.0039	lb	0.0039	kg
Ethylene glycol	0.0075	lb	0.0075	kg
Heat, waste	140	lb	140	kg
Hydrocarbons, unspecified	0.042	lb	0.042	kg
Maleic anhydride	0.0092	lb	0.0092	kg
Methane	7.1E-04	lb	7.1E-04	kg
Methyl methacrylate	0.024	lb	0.024	kg
Nitrogen oxides	0.031	lb	0.031	kg
NMVOCs	0.028	lb	0.028	kg
Particulates, < 10 um	0.0043	lb	0.0043	kg
Particulates, < 2.5 um	0.0078	lb	0.0078	kg
Particulates, unspecified	0.13	lb	0.13	kg
Phthalic acid	0.013	lb	0.013	kg
Styrene	0.13	lb	0.13	kg
Sulfur oxides	1.9E-04	lb	1.9E-04	kg
Toluene	0.0012	lb	0.0012	kg
VOCs, unspecified	0.023	lb	0.023	kg
Xylene	9.7E-04	lb	9.7E-04	kg
Waterborne Emissions				
Aluminum	1.4E-04	lb	1.4E-04	kg
BOD5, Biological Oxygen Demand	1.10	lb	1.10	kg
Cadmium	7.4E-07	lb	7.4E-07	kg
Chromium	5.0E-06	lb	5.0E-06	kg
COD, Chemical Oxygen Demand	1.10	lb	1.10	kg
Cyanide	3.8E-06	lb	3.8E-06	kg
Dissolved solids	0.054	lb	0.054	kg
Lead	4.5E-05	lb	4.5E-05	kg
Nickel	1.9E-06	lb	1.9E-06	kg
Oils, unspecified	0.010	lb	0.010	kg
Suspended solids, unspecified	0.59	lb	0.59	kg
Zinc	3.1E-05	lb	3.1E-05	kg
Solid Wastes				
Landfilled	1.60	lb	1.60	kg
Burned	1.30	lb	1.30	kg
Waste-to-Energy	1.90	lb	1.90	kg

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for UPR Input Material

For UPR production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average UPR production, material inputs include styrene, maleic anhydride, diethylene glycol, dicyclopentadiene, propylene glycol, phthalic anhydride, purified terephthalic acid (PTA), ethylene glycol, polyethylene terephthalate (PET), dipropylene glycol, neo-pentyl glycol, and tetrabromophthalic anhydride. LCI data for production of olefins, styrene, ethylene glycol, PTA, PET, are taken from the ACC resin data revised in 2011. The LCI data for ethylene glycol is used to reflect diethylene glycol as they are co-produced. Likewise, ethylene production taken from the 2011 ACC resin database is used as a proxy for dicyclopentadiene as it is co-produced with steam cracking of naphtha & gas to ethylene. Propylene glycol (also used as a proxy for dipropylene glycol), maleic anhydride, and phthalic anhydride were adapted from ecoinvent to reflect use of energy and material inputs for the US context. LCI data for neo-plenty glycol and tetrabromophthalic anhydride inputs were estimated using literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the UPR production step as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the UPR production step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of UPR production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the UPR production process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the UPR production process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the UPR production process itself.

Energy Results

Cumulative energy consumption for production of UPR is shown by energy category and process step in Table 3 and Figure 5.

Table 3. Cradle-to-Gate Cumulative Energy Demand for UPR Production (Million Btu of energy per 1,000 pounds of UPR)

	Material Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.74	0.0020	0.092	**0.83**	**2.4%**
Coal	2.04	0.0053	0.24	**2.29**	**6.6%**
Natural Gas	15.6	0.010	2.20	**17.8**	**52%**
Petroleum	13.4	0.21	0.036	**13.6**	**39%**
Hydro	0.085	2.3E-04	0.011	**0.096**	**<1%**
Recovered	-0.090	0.000	0.000	**-0.090**	**<1%**
Biomass	0.0034	5.0E-06	2.3E-04	**0.0036**	**<1%**
Renewables	0.0094	2.5E-05	0.0011	**0.011**	**<1%**
TOTAL (1)	**31.8**	**0.23**	**2.58**	**34.6**	**100%**
PERCENT TOTAL (1)	**92%**	**<1%**	**7.5%**	**100.0%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

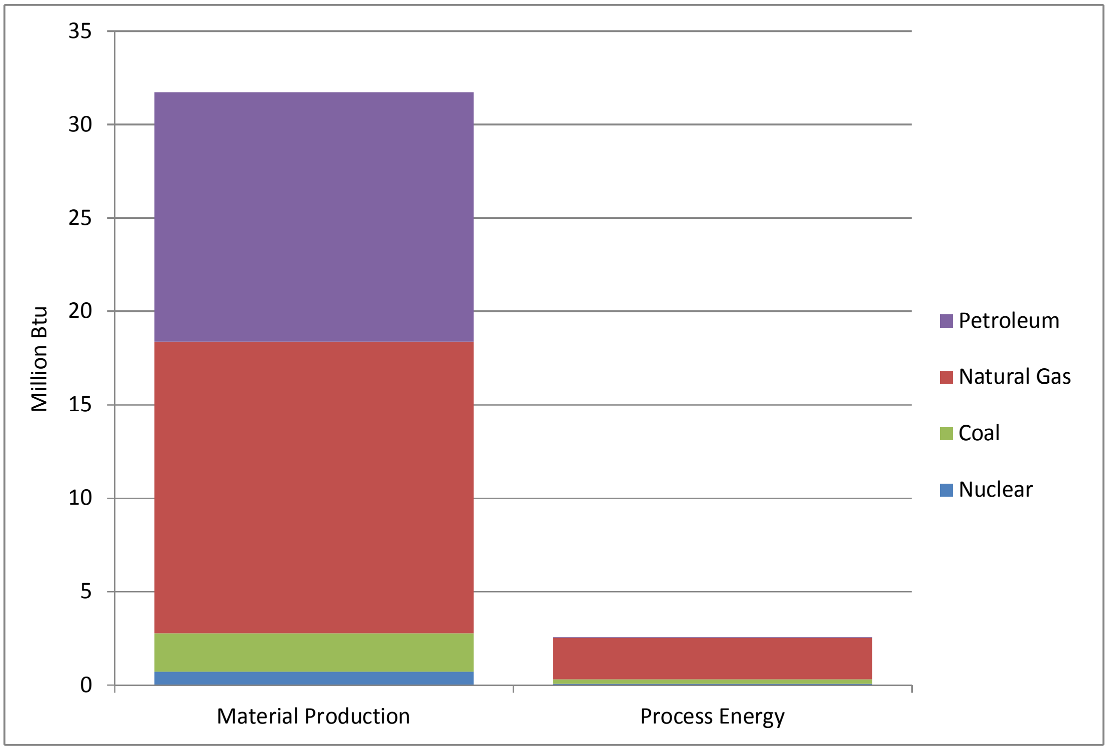

Figure 5. Cradle-to-Gate Cumulative Energy Demand for UPR Production (Million Btu of energy per 1,000 pounds of UPR)

The cradle-to-gate results show that the bulk of total energy consumption for UPR production is due to the requirements for production of the input materials. Conversely, the process energy is only 7.5 percent of the total. Transport energy requirements are insignificant relative to those for material production and process energy. As shown in Table 4 and in Figure 6, 83 percent of energy requirements for the gate-to-gate manufacturing step (i.e., process energy) are in providing natural gas heat for the UPR reaction, with about 17 percent is for providing electricity to the background processes, and the remaining less than one percent is due to the use of distillate fuels at the UPR production facility (e.g., to move materials on-site).

Table 4. Unit Process Energy Demand for UPR Production
(Million Btu of energy per 1,000 pounds of UPR)

	Electricity Inputs	Natural Gas Fuel	Distillate Fuel	TOTAL (1)	PERCENT TOTAL (1)
Nuclear	0.086	0.0057	4.1E-05	**0.092**	**3.6%**
Coal	0.23	0.015	1.1E-04	**0.24**	**9.4%**
Natural Gas	0.079	2.12	2.0E-04	**2.20**	**85%**
Petroleum	0.024	0.0076	0.0042	**0.036**	**1.4%**
Hydro	0.010	6.6E-04	4.8E-06	**0.011**	**<1%**
Renewables	2.2E-04	1.4E-05	1.0E-07	**2.3E-04**	**<1%**
TOTAL (1)	**0.43**	**2.15**	**0.0045**	**2.58**	**100%**
PERCENT TOTAL (1)	**17%**	**83%**	**<1%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

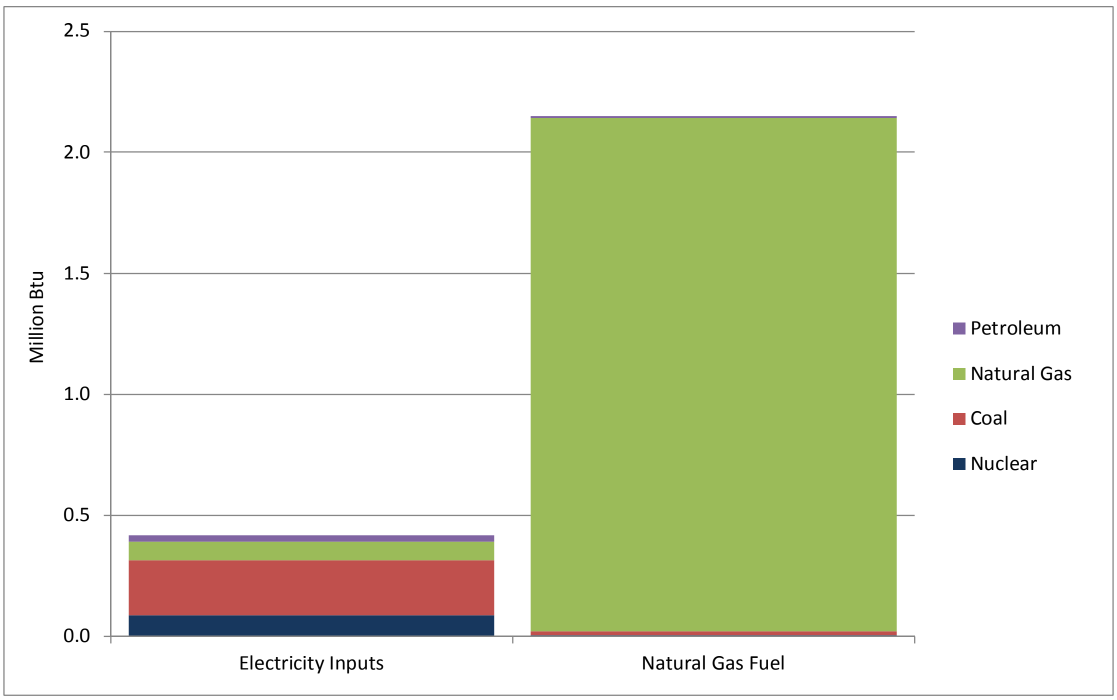

Figure 6. Unit Process Energy Demand for UPR Production
(Million Btu of energy per 1,000 pounds of UPR)

About half of the energy demand for production of UPR materials is energy of material resources (EMR). EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 5 and Figure 7 show the relative amounts of cradle-to-gate EMR versus expended energy demand for UPR production. Note the negative values for natural gas and petroleum EMR in process energy reflect the conversion of hydrocarbon materials to expended energy for the oxidation of the water produced during the reaction.

Table 5. EMR vs. Expended Cradle-to-Gate Energy Demand for UPR Production (Million Btu of energy per 1,000 pounds of UPR)

	Material Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	16.1	0.23	2.64	**19.0**	**55%**
Natural Gas EMR	7.20	0	-0.049	**7.15**	**21%**
Petroleum EMR	8.43	0	-0.0096	**8.42**	**24%**
Biomass EMR	1.1E-15	0	0	**1.1E-15**	**<1%**
TOTAL (1)	**31.8**	**0.23**	**2.58**	**34.6**	**100%**
PERCENT TOTAL (1)	**92%**	**<1%**	**7.5%**	**100.0%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

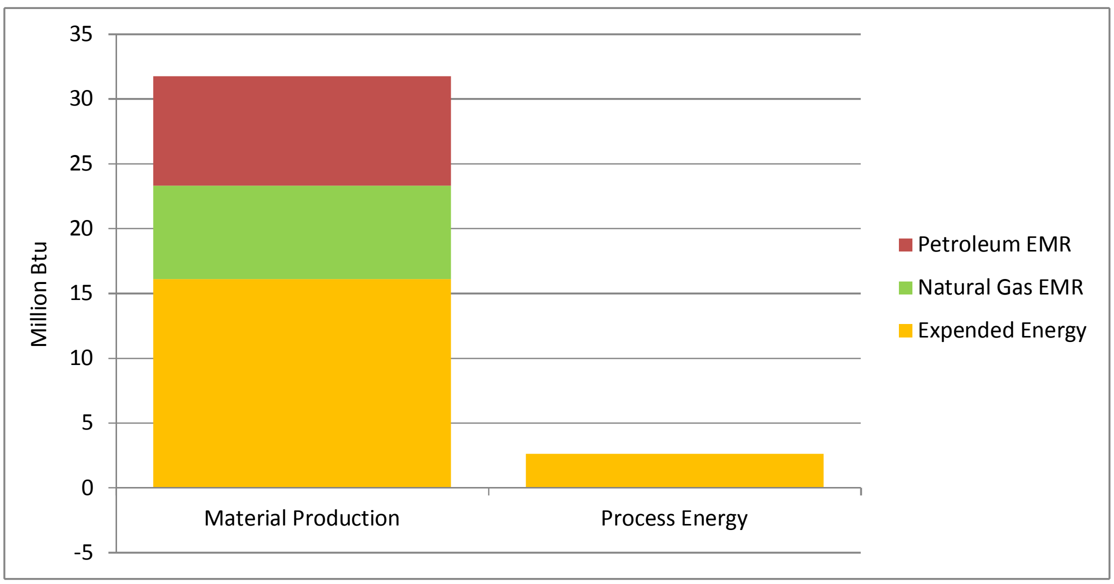

Figure 7. EMR vs. Expended Cradle-to-Gate Energy Demand for UPR Production (Million Btu of energy per 1,000 pounds of UPR)

Water Use Results

Consumptive water use for cradle-to-gate production of UPR is shown by life cycle phase in Table 6 and Figure 8.

Table 6. Cradle-to-Gate Water Use for UPR Production
(Gallons of water per 1,000 pounds of UPR)

	Material Production	Incoming Transport	Process Energy	Process Water	TOTAL (1)
Per 1,000 lb UPR	1,213	8.17	96.0	68.3	**1,386**
% TOTAL (1)	**88%**	**<1%**	**6.9%**	**4.9%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

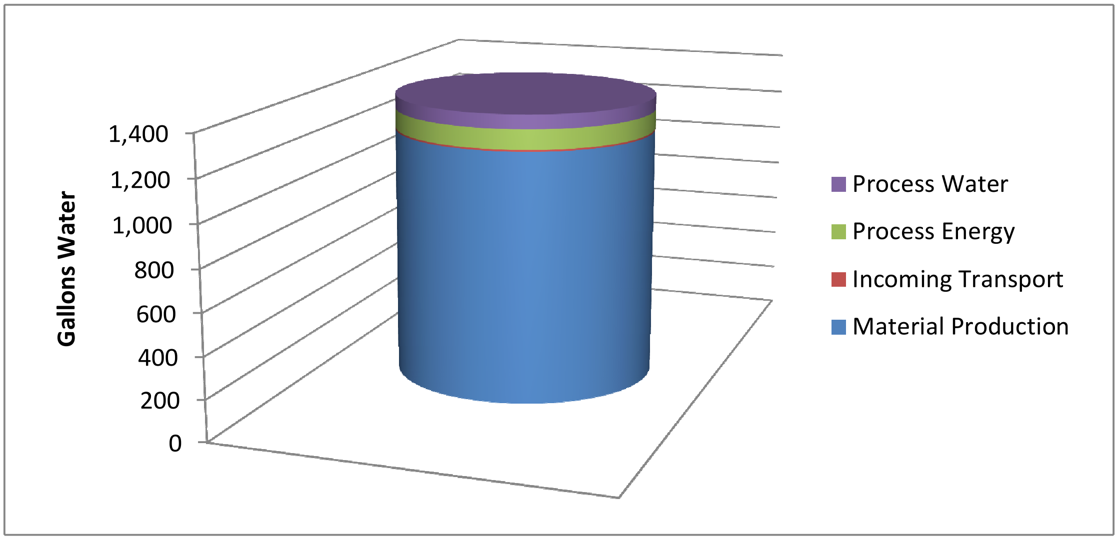

Figure 8. Cradle-to-Gate Water Use for UPR Production
(Gallons of water per 1,000 pounds of UPR)

The 'material production' results represent water consumption associated with the steps to extract and process the input materials required for UPR production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from UPR production process. The cradle-to-gate results show that the bulk of water is consumed in production of the material inputs. Water is consumed during production of the fuels and electricity used in the fabrication process, and this category consumes about seven percent of the cradle-to-gate total. Water consumed at the UPR production facility, 68.3 gallons per 1,000 pounds of UPR, comprises about five percent. The remaining consumption occurs from the production of fuels required for transporting incoming materials to the UPR production facility.

Solid Waste Results

Solid waste generation for cradle-to-gate production of UPR is shown by process step in Table 7 and Figure 9.

Table 7. Cradle-to-Gate Solid Waste Generation for UPR Production (Pounds of solid waste per 1,000 pounds of UPR)

	Material Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	24.8	0	1.4E-06	1.60	**26.4**	**20%**
Incinerated	2.33	0	0	1.30	**3.63**	**2.7%**
Waste-to-Energy	0.016	0	0	1.90	**1.92**	**1.4%**
Fuel-Related	88.4	0.55	11.8	0	**101**	**76%**
TOTAL (1)	**116**	**0.55**	**11.8**	**4.80**	**133**	**100%**
PERCENT TOTAL (1)	**87%**	**<1%**	**8.9%**	**3.6%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

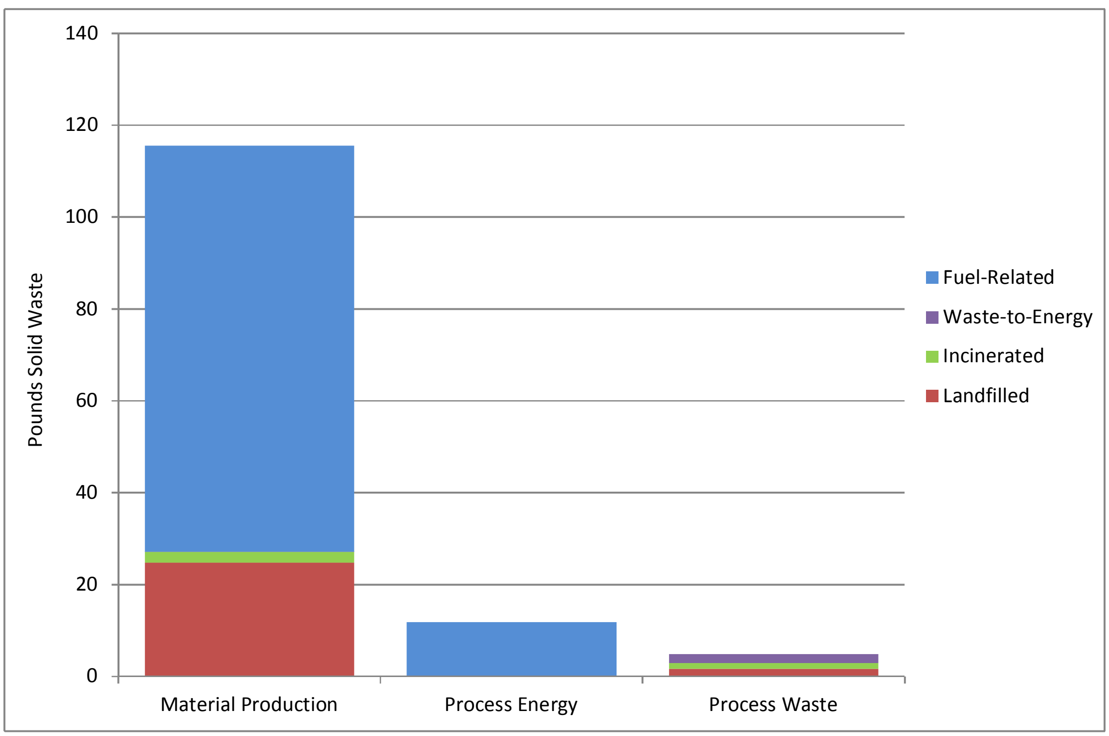

Figure 9. Cradle-to-Gate Solid Waste Generation for UPR Production (Pounds of solid waste per 1,000 pounds of UPR)

The cradle-to-gate results for solid waste generation indicate that the bulk of generation occurs during the production of the materials required for UPR production. About 9 percent of total generation is due to the production and combustion of the fuels required directly for operations and to produce electricity required for the UPR production process. Solid waste generated during the production at the UPR production facility is low relative to the material and process energy phases. Due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the UPR) no postconsumer wastes are modeled. The disposition of the produced UPR depends on the product application (reinforced composites matrix, gel coat, etc.), its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of UPR and include both process and fuel-related emission, production of materials, production and combustion of fuels required for transporting the materials, production and combustion of fuels required for process energy as well as production of electricity required for process energy, and uncaptured emissions resulting from the kettle reactions themselves at the UPR production facility. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for the production of UPR include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the UPR production facility, and from (4) the UPR facility itself during kettle reactions. Non-fuel related air emissions at the UPR production facility include volatilized hydrocarbons and particulate matter from the reaction as well as waste heat from the oxidation of the overhead losses. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate UPR life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using

International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and 298 for nitrous oxide.[11] GHG results for production of UPR are shown in Table 8 and Figure 10.

Table 8. Cradle-to-Gate GHGs for UPR Production
(Pounds CO2 equivalents per 1,000 pounds of UPR)

	Material Production	Incoming Transport	Process Energy	Process Emissions	**TOTAL (1)**	**PERCENT TOTAL (1)**
Fossil CO2	2,271	34.4	325	37.0	**2,668**	**87%**
Methane	337	1.67	36.1	0.018	**375**	**12%**
Nitrous Oxide	10.1	0.27	0.53	0	**10.9**	**<1%**
Others	4.12	0.0033	0.0013	0	**4.13**	**<1%**
TOTAL (1)	**2,623**	**36.3**	**362**	**37.0**	**3,058**	**100%**
PERCENT TOTAL (1)	**86%**	**1.2%**	**12%**	**1.2%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

11 The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

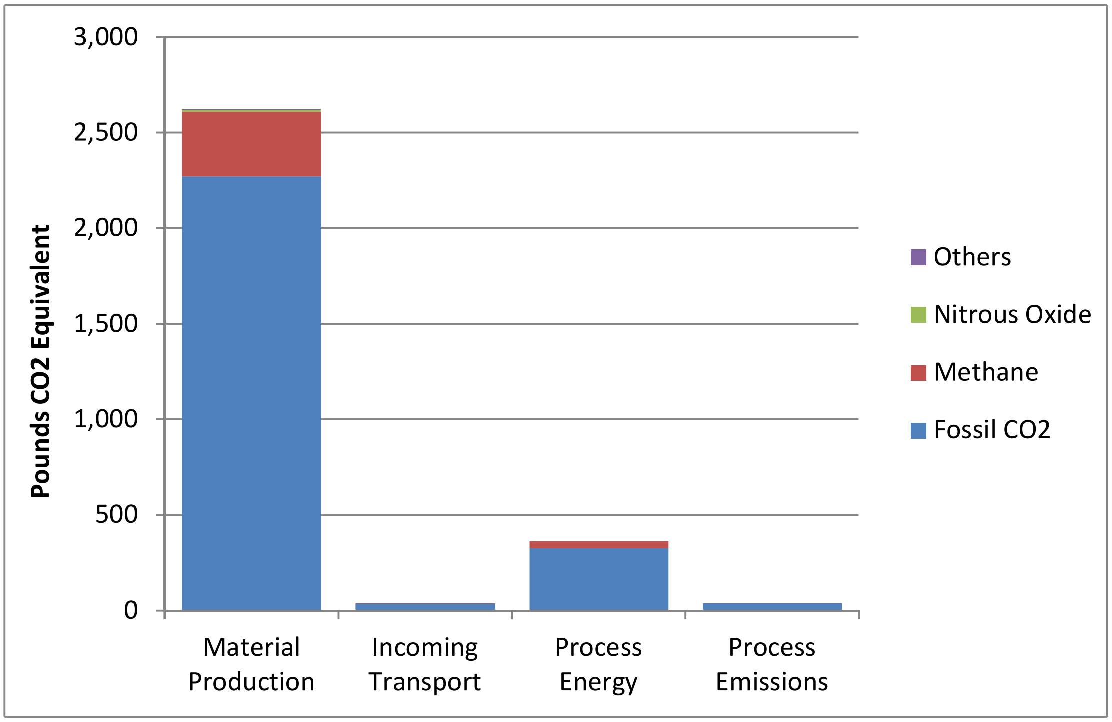

Figure 10. Cradle-to-Gate GHGs for UPR Production (Pounds CO2 equivalents per 1,000 pounds of UPR)

The results show that the bulk of GHG emissions are associated with production of materials required for UPR production. The production of the materials requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. The production of electricity and production and combustion of fuels used at the UPR production facility also figure significantly in total GHG emissions. GHG emissions reported for UPR production comprise less than two percent of the cradle-to-gate life cycle global warming potential (GWP) total. Likewise, GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute less than two percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributors to the GWP of the GHGs; methane emissions have the second largest contribution, and nitrous oxide emissions the third largest contribution. Several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate UPR production LCI are included in Appendix A.

CHAPTER 3. GENERAL GRADE FIBERGLASS (E-GLASS)

INTRODUCTION

This chapter describes the production of general grade fiberglass (E-Glass), presents the compiled gate-to-gate unit process LCI data for production of E-Glass, and presents LCI results for cradle-to-gate production of 1,000 pounds of E-Glass in terms of cumulative energy requirements, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of E-Glass Input Material

E-Glass is used in many product applications as it is a lightweight material that is easy to mold and lends a plethora of advantageous properties to a composites materials. These include tensile and compressive strength for structural durability and excellent insulating and chemical resistance properties for use in aviation, marine, and automotive industries as well as for applications like hot tubs, storage and septic tanks, and sewage pipes.

To produce glass fibers suitable for reinforcement, raw materials such as silica sand, limestone, clay, fluorspar, colemanite, dolomite, borates, and others are combined in a batch. This batch is sent to a refractory-lined glass furnace to gradually melt the raw materials required into liquid molten form. The molten glass is extruded through bushings, which contain bundles of very small holes, to produce E-Glass fibers with diameters in the 5-25 micron range. These fibers are then coated with a sizing solution. This sizing helps protect the glass fibers for processing. It also ensures proper bonding to the resin matrix. The individual fibers are then bundled together in large numbers to provide a roving.

Figure 11 displays a summary of the material inputs used to manufacture E-Glass. Further information on the data sources of these material inputs are shown in Appendix B.

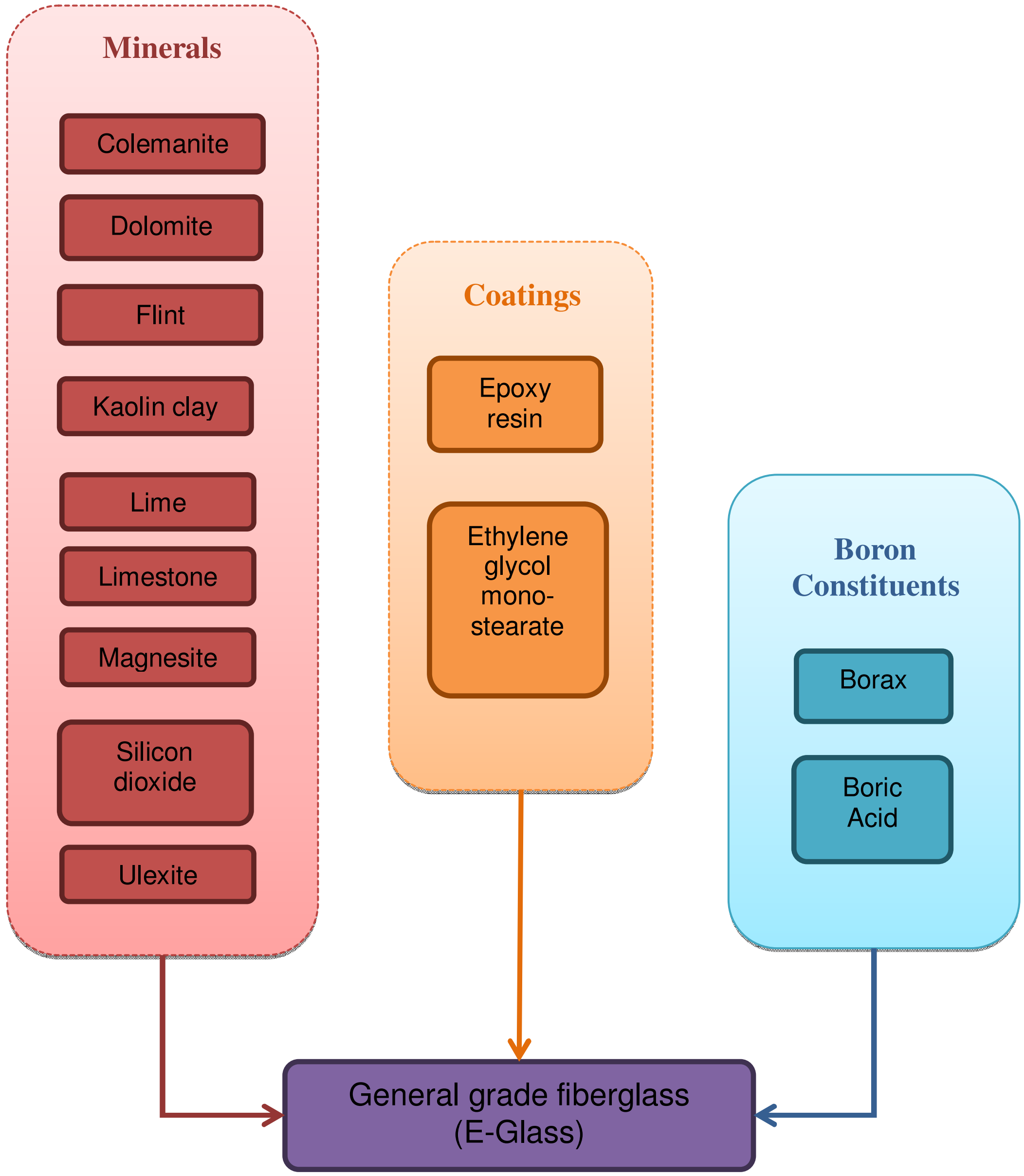

Figure 11. Summary of E-Glass Material Inputs

Table 9 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of E-Glass in the US. Only one company provided waterborne emissions for the production of E-Glass. Due to confidentiality issues, these waterborne emissions have been removed from the gate-to-gate unit process dataset. All carbon dioxide shown for the unit process dataset comes from the calcining of limestone or other carbon-bearing minerals.

In terms of process energy consumption, the average E-Glass facility meets approximately 60 percent of its process energy demand with electricity. Natural gas combustion is also used to meet a significant share, about 40 percent, of the process energy demand; whereas, LPG combustion and residual oil combustion are used in minute amounts. An average of 46 pounds of landfilled solid waste are generated for every 1,000 pounds of E-Glass produced. Approximately 360 lb of carbon dioxide is released from the burning of minerals. This has been considered as a fossil source, like oil minerals are buried beneath the earth and have no way to reabsorb the carbon dioxide as do biogenic sources (e.g. trees).

Table 9. LCI Unit Process Data for E-Glass Production

	English units (Basis: 1,000 lb)		SI units (Basis: 1,000 kg)	
Outputs to Technosphere				
General grade fiberglass (E-Glass)	1,000	lb	1,000	kg
Inputs from Technosphere (to Product)				
Clay	350	lb	350	kg
Limestone	320	lb	320	kg
Silicon dioxide	310	lb	310	kg
Flint	74.0	lb	74.0	kg
Ulexite	59.0	lb	59.0	kg
Burnt lime	32.0	lb	32.0	kg
Borax	18.0	lb	18.0	kg
Boric acid	13.0	lb	13.0	kg
Magnesite	8.60	lb	8.60	kg
Dolomite	7.80	lb	7.80	kg
Colemanite	5.20	lb	5.20	kg
Epoxy resin	2.80	lb	2.80	kg
Ethylene glycol	0.32	lb	0.32	kg
Process Water Consumption	777	gal	6,480	liter
Energy Usage				
Process Energy				
Electricity (grid)	577	kwh	1,272	kwh
Natural gas	3,893	cu ft	243	cu meters
LPG	0.026	gal	0.22	liter
Residual oil	0.013	gal	0.11	liter
Incoming Materials Transportation Energy				
Combination truck	20.5	ton-miles	66.0	tonne-km
Diesel	0.22	gal	1.80	liter
Rail	172	ton-miles	553	tonne-km
Diesel	0.43	gal	3.56	liter
Ocean freighter	97.0	ton-miles	312	tonne-km
Diesel	0.018	gal	0.15	liter
Residual	0.17	gal	1.38	liter

Table 9. (Cont'd) LCI Unit Process Data for E-Glass Production

Environmental Emissions						
Atmospheric Emissions						
Carbon dioxide, fossil	360	lb	(1)	360	kg	(1)
Carbon monoxide	0.023	lb		0.023	kg	
Hydrogen fluoride	0.046	lb		0.046	kg	
Methanol	0.083	lb		0.083	kg	
Nitrogen oxides	0.15	lb		0.15	kg	
Organic substances, unspecified	0.067	lb		0.067	kg	
Particulates, < 10 um	0.87	lb		0.87	kg	
Styrene	0.22	lb		0.22	kg	
Sulfur oxides	0.42	lb		0.42	kg	
VOC, unspecified	0.59	lb		0.59	kg	
Xylene	0.056	lb		0.056	kg	
Solid Wastes						
Landfilled	163	lb		163	kg	

(1) Carbon dioxide emissions are the result of mineral burning.

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for E-Glass Input Material

For E-Glass production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average E-Glass production, material inputs include clay, limestone, silica (silicon dioxide), flint, ulexite, calcium oxide (burnt lime), borax, boric acid, magnesite, dolomite, colemanite, epoxy resin, and ethylene glycol monostearate. LCI data for production of limestone, calcium oxide, magnesite, flint, and dolomite are taken from the NREL US LCI Database. The LCI data for limestone is used to reflect dolomite, flint, and magnesite as a surrogate. Borax, colemanite, and epoxy resin were adapted from ecoinvent to reflect use of energy and material inputs for the US context. LCI data for ethylene glycol monostearate were estimated using literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database. The Franklin Associates Private LCI Database was also used for clay, silica, boric acid, and ulexite. Soda ash from trona mining is used as a proxy for ulexite production as ulexite is associated with trona deposits and is found in CA and NV.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the E-Glass production step, as provided by ACMA member companies. The production and combustion of fuels used

for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.

3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the E-Glass production step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of E-Glass production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the E-Glass production process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the E-Glass production process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the E-Glass production process itself.

Energy Results

Cumulative energy consumption for production of E-Glass is shown by energy category and process step in Table 10 and Figure 12.

Table 10. Cradle-to-Gate Cumulative Energy Demand for E-Glass Production (Million Btu of energy per 1,000 pounds of E-Glass)

	Material Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.14	0.0014	1.27	**1.41**	**11%**
Coal	0.47	0.0036	3.35	**3.82**	**31%**
Natural Gas	0.88	0.0068	5.39	**6.27**	**51%**
Petroleum	0.18	0.14	0.37	**0.69**	**5.6%**
Hydro	0.016	1.6E-04	0.15	**0.16**	**1.3%**
Recovered	-5.3E-07	0	0	**-5.3E-07**	**<1%**
Biomass	5.7E-04	3.4E-06	0.0032	**0.0037**	**<1%**
Renewables	0.0016	1.7E-05	0.016	**0.017**	**<1%**
TOTAL (1)	**1.68**	**0.15**	**10.5**	**12.4**	**100%**
PERCENT TOTAL (1)	**14%**	**1.2%**	**85%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

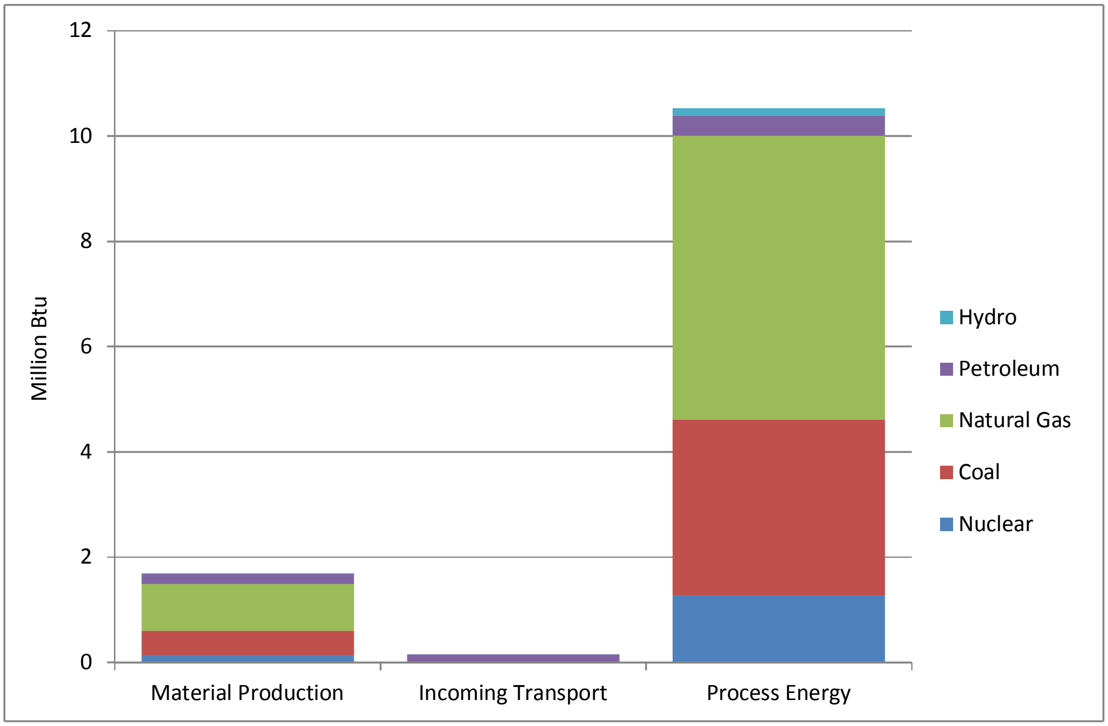

Figure 12. Cradle-to-Gate Cumulative Energy Demand for E-Glass Production (Million Btu of energy per 1,000 pounds of E-Glass)

The cradle-to-gate results show that the bulk of total energy consumption for E-Glass production is due to the requirements for production of the E-Glass at the production step. Conversely, the material production energy is only 14 percent of the total. The incoming materials are mostly mining and mineral processing steps which use small amounts of energy. Transport energy requirements are insignificant (approximately 1 percent) relative to those for material production and process energy.. As shown in Table 11 and in Figure 13, 59 percent of energy requirements for the gate-to-gate manufacturing step (i.e., process energy) are in providing electricity for the E-Glass reaction, about 41 percent is for providing heat using natural gas, and the remaining less than one percent is due to the use of residual and LPG fuels at the E-Glass production facility.

Table 11. Unit Process Energy Demand for E-Glass Production
(Million Btu of energy per 1,000 pounds of E-Glass)

	Electricity Inputs	Natural Gas Fuel	Residual Fuel	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	1.26	0.011	2.1E-05	**1.27**	**12%**
Coal	3.32	0.030	5.5E-05	**3.35**	**32%**
Natural Gas	1.15	4.24	1.0E-04	**5.39**	**51%**
Petroleum	0.35	0.015	0.0022	**0.37**	**3.5%**
Hydro	0.14	0.0013	2.4E-06	**0.15**	**1.4%**
Recovered	0	0	0	**0**	**<1%**
Renewables	0.0031	2.9E-05	5.2E-08	**0.0032**	**<1%**
TOTAL (1)	**6.22**	**4.30**	**0.0024**	**10.5**	**100%**
PERCENT TOTAL (1)	**59%**	**41%**	**<1%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

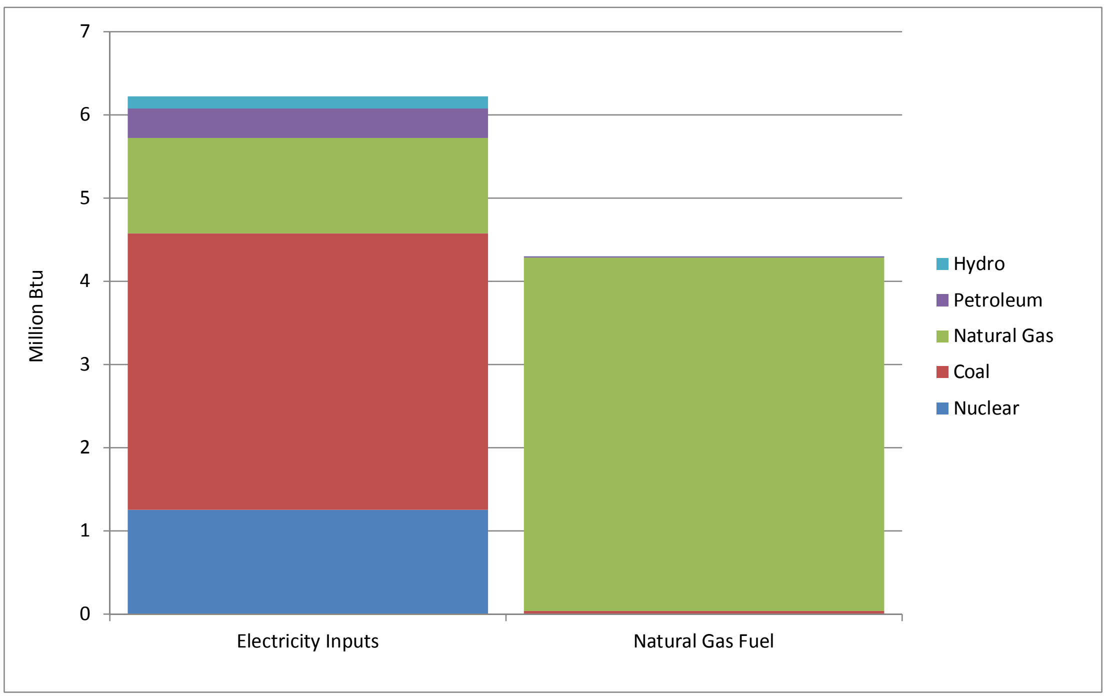

Figure 13. Unit Process Energy Demand for E-Glass Production
(Million Btu of energy per 1,000 pounds of E-Glass)

The E-Glass material shows very little energy of material resources (EMR). EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins. EMR is shown in the cradle-to-gate E-Glass energy due to small amounts of chemicals used within the sizing; however, these EMR amounts are less than one percent in total. Table 12 and Figure 14 show the relative amounts of cradle-to-gate EMR versus expended energy demand for E-Glass production.

Table 12. EMR vs. Expended Cradle-to-Gate Energy Demand for E-Glass Production (Million Btu of energy per 1,000 pounds of E-Glass)

	Material Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	1.68	0.15	10.5	**12.4**	**100%**
Natural Gas EMR	0.0039	0	0	**0.0039**	**<1%**
Petroleum EMR	1.7E-04	0	0	**1.7E-04**	**<1%**
Biomass EMR	2.4E-06	0	0	**2.4E-06**	**<1%**
TOTAL (1)	**1.68**	**0.15**	**10.5**	**12.4**	**100%**
PERCENT TOTAL (1)	**14%**	**1.2%**	**85.2%**	**100.0%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

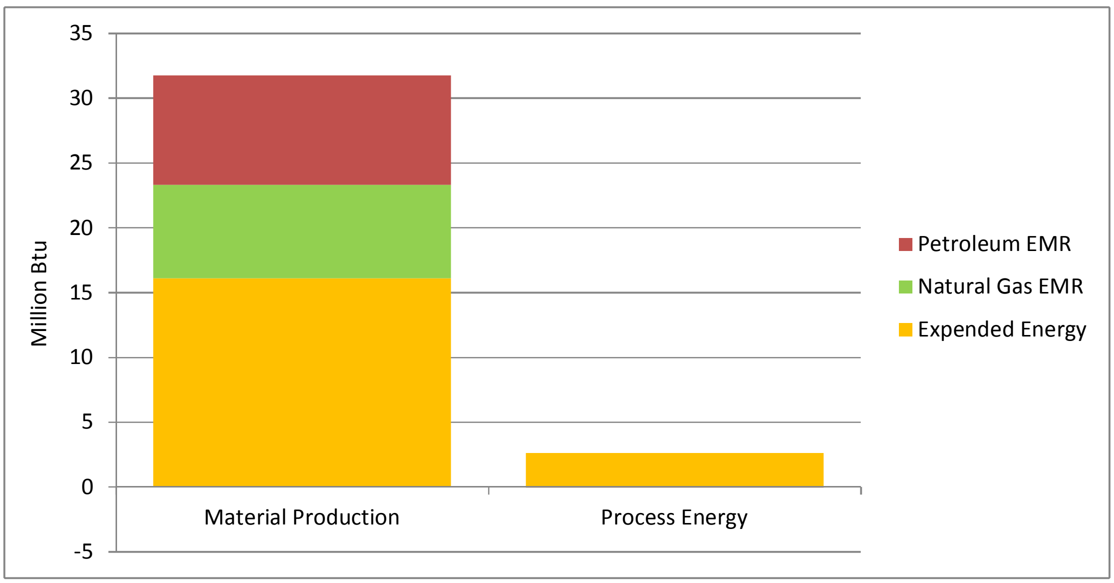

Figure 14. EMR vs. Expended Cradle-to-Gate Energy Demand for E-Glass Production (Million Btu of energy per 1,000 pounds of E-Glass)

Water Use Results

Consumptive water use for cradle-to-gate production of E-Glass is shown by life cycle phase in Table 13 and Figure 15.

Table 13. Cradle-to-Gate Water Use for E-Glass Production
(Gallons of water per 1,000 pounds of E-Glass)

	Material Production	Incoming Transport	Process Energy	Process Water	TOTAL (1)
Per 1,000 lb E-Glass	159	5.54	1,041	777	**1,982**
% TOTAL (1)	**8%**	**<1%**	**53%**	**39%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

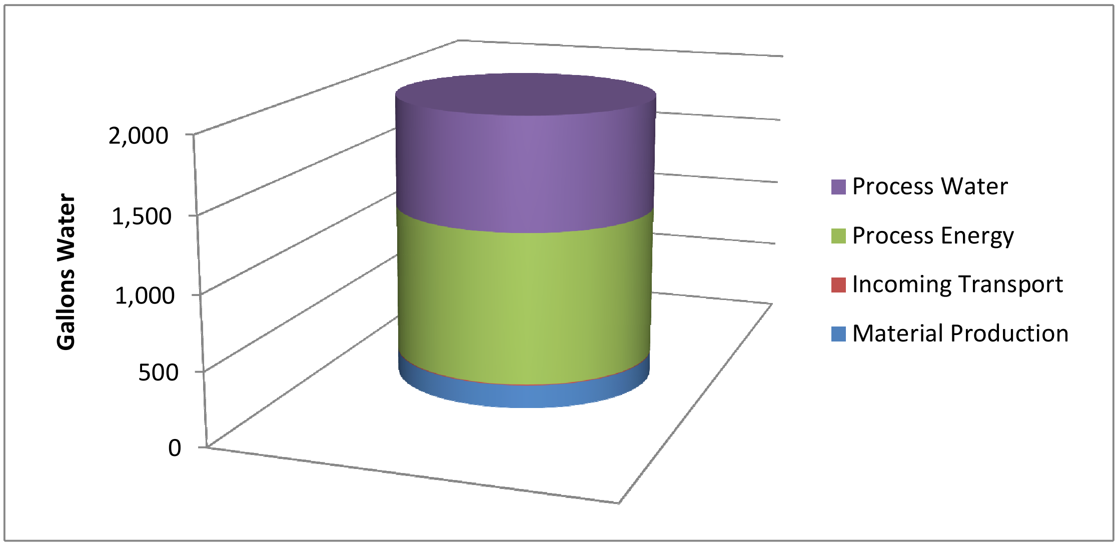

Figure 15. Cradle-to-Gate Water Use for E-Glass Production
(Gallons of water per 1,000 pounds of E-Glass)

The 'material production' results represent water consumption associated with the steps to extract and process the input materials required for E-Glass production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from E-Glass production process, such as water to cool the glass fibers. The cradle-to-gate results show that over 50 percent of the water is consumed in production of the fuels and electricity generation. Water is consumed during production of the material inputs used in the fabrication process, and this category consumes about eight percent of the cradle-to-gate total. Water consumed at the E-Glass production facility, 777 gallons per 1,000 pounds of E-Glass, comprises 39 percent. Less than 1 percent of the water consumption occurs from the production of fuels required for transporting incoming materials to the E-Glass production facility.

Solid Waste Results

Solid waste generation for cradle-to-gate production of E-Glass is shown by process step in Table 14 and Figure 16.

Table 14. Cradle-to-Gate Solid Waste Generation for E-Glass Production (Pounds of solid waste per 1,000 pounds of E-Glass)

	Material Production	Incoming Transport	Process Energy	Process Waste	TOTAL (1)	PERCENT TOTAL (1)
Landfilled	252	0	0	163	**416**	**73%**
Incinerated	0.039	0	0	0	**0.039**	**<1%**
Waste-to-Energy	2.5E-05	0	0	0	**2.5E-05**	**<1%**
Fuel-Related	18.6	0.37	135	0	**154**	**27%**
TOTAL (1)	**271**	**0.37**	**135**	**163**	**570**	**100%**
PERCENT TOTAL (1)	**48%**	**<1%**	**24%**	**29%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

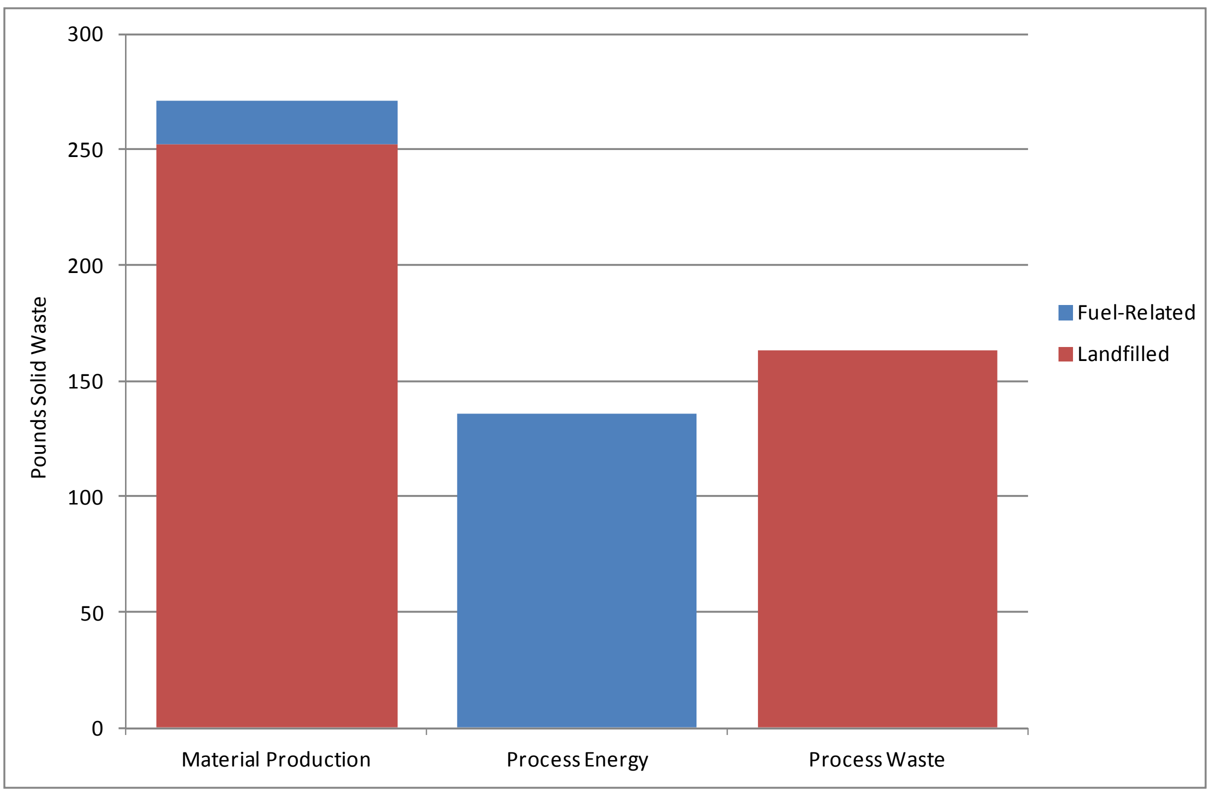

Figure 16. Cradle-to-Gate Solid Waste Generation for E-Glass Production (Pounds of solid waste per 1,000 pounds of E-Glass)

The cradle-to-gate results for solid waste generation indicate that the bulk of generation occurs during the production of the materials required for E-Glass production. Thirty percent of total generation is due to the production and combustion of the fuels required directly for operations and to produce electricity required for E-Glass production. Solid waste generated at the E-Glass production facility is low relative to the material and process energy phases at 10 percent of the total solid wastes. Also, because this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the E-Glass) no postconsumer wastes are modeled. The disposition of the produced E-Glass depends on the product application (reinforced composites matrix, gel coat, etc.), its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of E-Glass and include both process and fuel-related emissions, production of materials, production and combustion of fuels required for transporting the materials, production and combustion of fuels required for process energy as well as production of electricity required for process energy, and uncaptured emissions resulting from the E-Glass production facility. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for each production of E-Glass include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the E-Glass production facility, and from (4) the E-Glass facility itself. Non-fuel related air emissions at the E-Glass production facility include volatilized hydrocarbons and particulate matter from the reaction as well as waste heat from the oxidation of the overhead losses. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate E-Glass life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. GHG results for production of E-Glass are shown in Table 15 and Figure 17.

Table 15. Cradle-to-Gate GHGs for E-Glass Production
(Pounds CO2 equivalents per 1,000 pounds of E-Glass)

	Material Production	Incoming Transport	Process Energy	Process Emissions	TOTAL (1)	PERCENT TOTAL (1)
Fossil CO2	271	23.7	1,454	360	**2,109**	**92%**
Methane	21.2	1.14	119	0	**141**	**6.2%**
Nitrous Oxide	2.35	0.19	6.42	0	**8.96**	**<1%**
Others	24.7	0.0023	0.0064	0	**24.7**	**1.1%**
TOTAL (1)	**319**	**25.0**	**1,580**	**360**	**2,284**	**100%**
PERCENT TOTAL (1)	**14%**	**1.1%**	**69%**	**16%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

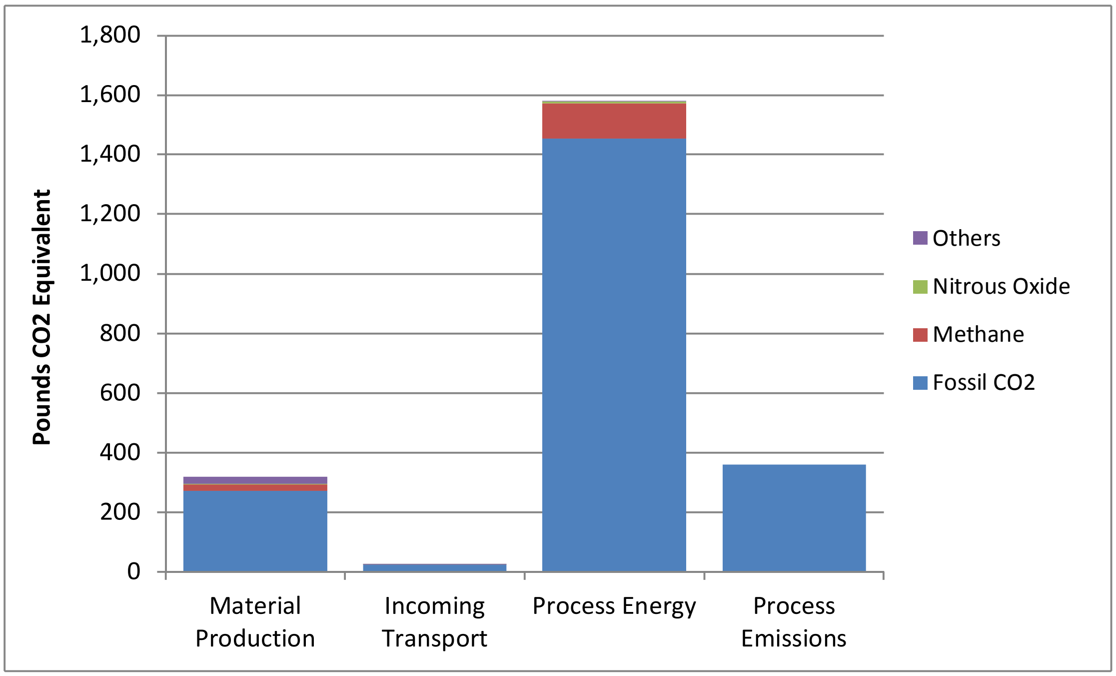

Figure 17. Cradle-to-Gate GHGs for E-Glass Production
(Pounds CO2 equivalents per 1,000 pounds of E-Glass)

The results show that the bulk of GHG emissions are associated with fuels production and combustion required for E-Glass production. The production of the incoming materials and the E-Glass production facility produce very close amounts of GHG emissions at 14 and 16 percent, respectively. GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute one percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributors to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution, and other GHG emissions contribute one percent. The overall GWP of the nitrous oxide is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate E-Glass production LCI are included in Appendix A.

CHAPTER 4. COMPRESSION MOLDING

INTRODUCTION

This chapter describes the production of composites from the compression molding process, presents the compiled gate-to-gate unit process LCI data for production of compression molded composites, and presents LCI results for cradle-to-gate production of 1,000 pounds of compression molded composites in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of Compression Molded Composites

Compression molding is a processing method that uses thermoset resins or thermoplastic resins to produce a number of complex, high strength FRP composites. Only thermoset resins are considered in this analysis. Thermoset resins typically start out as liquids or solids with a low melting point that are cured in situ (i.e., at the point of application undergoing a non-reversible chemical reaction) using a catalyst and/or heat. Once a thermoset resin is cured, it cannot melt or be reshaped. For this process, the molding material, or charge, is placed in an open mold. The mold halves are forced together, or compressed, using a hydraulic ram or plug, and pressure is applied which causes the plastic to flow into the mold cavities. If the molding material is a thermoset resin, the applied heat and pressure cause the polymer to irreversibly cure, therefore the material is permanently solidified and cooling is not necessary. Once the molding material is cured, the mold is opened and the part is removed. Any overflow (flash) remaining on the part is broken off and/or compressed air is used to eliminate residual plastic in the mold.

Compression molding is used to create a range of composites parts, from marine and automotive to small complex parts for high precision engineering components. A variety of materials and ancillary products may be used as inputs in this manufacturing technique but typically they include:

- Glass fiber combined with a thermosetting resin forms an FRP composite product,
- Initiators to promote the curing process between the resin and the glass fiber, and
- Thickeners and filler materials for structural reinforcement
- Processing aids such as mold-release agents are also typically utilized

Other additives such as pigments and fire retardants may be added and depend on the application and characteristics desired for the final product. The final compression molding composites part is shipped to users. The properties of a compression molded composites depend on the types and proportions of resins, glass fiber, fillers, and additives incorporated.

Figure 18 displays a summary of the material inputs used to manufacture compression molded composites. Further information on the data sources of these material inputs are shown in Appendix B.

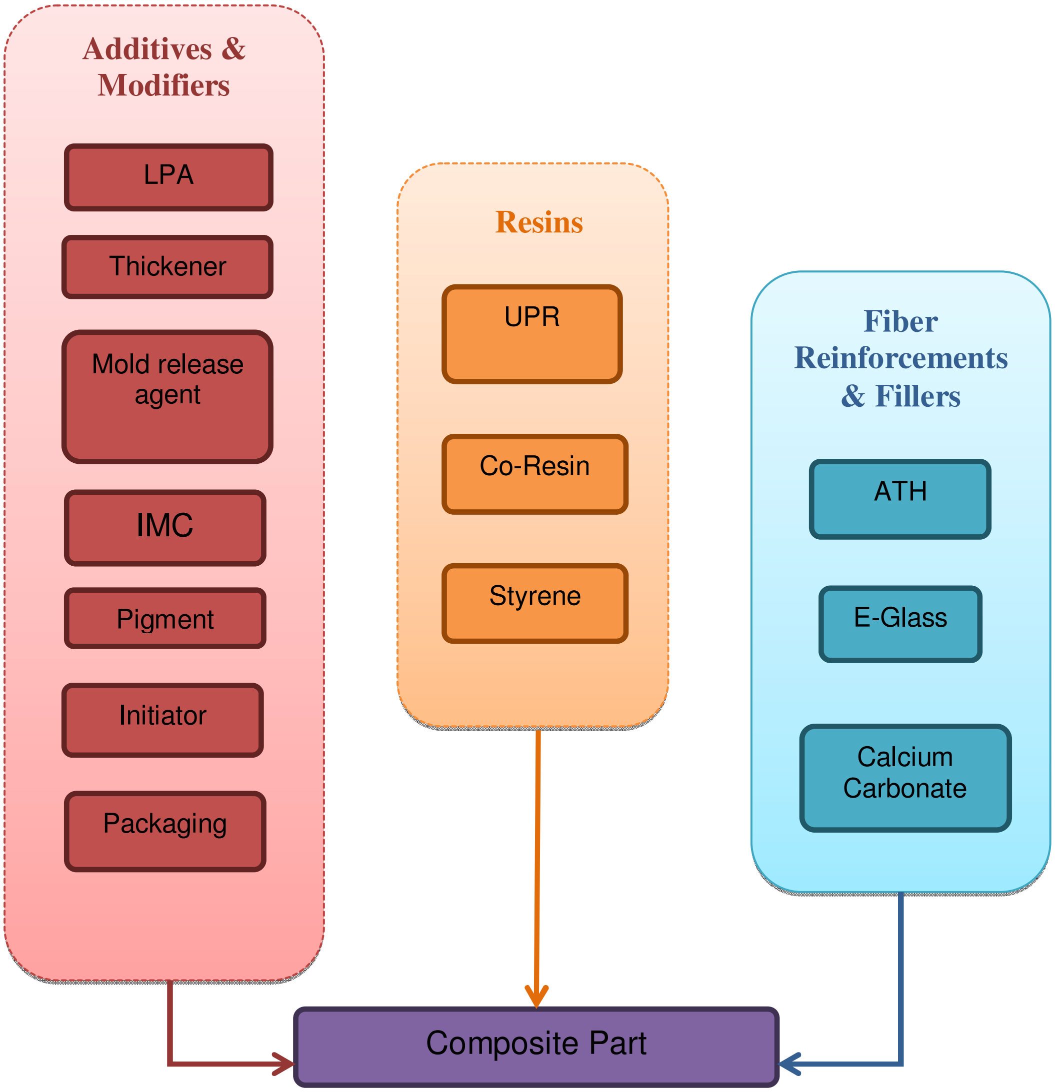

Figure 18. Summary of Material Inputs to the Compression Molded Composites Products

Table 16 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of compression molded composites in 2010 in the US. In terms of process energy consumption, the average compression molding facility meets almost all of its process energy demand (98 percent) with electricity. Natural gas is required for less than 2 percent of the process energy demand; whereas, LPG and diesel combustion are used in smaller amounts. An average of 94 pounds of solid waste are generated for every 1,000 pounds of compression molded composites produced: more than 95 percent of those solid wastes are landfilled, with the remaining 5 percent incinerated, incinerated with energy recovery, and sold for recycling.

Table 16. LCI Unit Process Data for Production of Compression Molded Composites

	English units (Basis: 1,000 lb)		SI units (Basis: 1,000 kg)	
Outputs to Technosphere				
Compression molded composite part	1,000	lb	1,000	kg
Material sold for reccling	1.40	lb	1.40	kg
Inputs from Technosphere (to Product)				
Aluminium trihydrate	240	lb	240	kg
Corrugated boxes	27.0	lb	27.0	kg
Co-resin, UPR & styrene based	15.0	lb	15.0	kg
E-Glass	280	lb	280	kg
Styrene, at plant/US	34.0	lb	34.0	kg
In-mold coating (IMC), styrene-based	8.70	lb	8.70	kg
Limestone	220	lb	220	kg
Low profile additive (LPA)	19.0	lb	19.0	kg
MEKP initiator	8.50	lb	8.50	kg
Pigment	8.10	lb	8.10	kg
Thickener	11.0	lb	11.0	kg
UPR	170	lb	170	kg
Mold-release agent	14.0	lb	14.0	kg
Process Water Consumption	53.5	gal	446	liter
Energy Usage				
Process Energy				
Electricity (grid)	723	kwh	1,594	kwh
Natural gas	127	cu ft	7.93	cu meters
LPG	0.32	gal	2.67	liter
Diesel	0.029	gal	0.24	liter
Incoming Materials Transportation Energy				
Combination truck	376	ton-miles	1,210	tonne-km
Diesel	3.95	gal	32.9	liter
Ocean freighter	333	ton-miles	1,072	tonne-km
Diesel	0.063	gal	0.53	liter
Residual	0.57	gal	4.75	liter
Environmental Emissions				
Atmospheric Emissions				
Ammonia	0.0026	lb	0.0026	kg
Carbon dioxide, fossil	0.094	lb	0.094	kg
Nitrogen	5.80	lb	5.80	kg
Nitrogen oxides	0.21	lb	0.21	kg
Oxygen	0.37	lb	0.37	kg
Particulates, unspecified	0.094	lb	0.094	kg
Styrene	2.20	lb	2.20	kg
Sulfur oxides	0.0011	lb	0.0011	kg
VOCs, unspecified	0.39	lb	0.39	kg
Solid Wastes				
Landfilled	90.0	lb	90.0	kg
Burned	2.90	lb	2.90	kg
Waste-to-Energy	1.40	lb	1.40	kg

(1) Carbon dioxide emissions are the result of mineral burning.

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for Compression Molded Composites

For compression molded composites production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs: a) UPR , b) E-Glass, and c) other materials, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average compression molded composites production, material inputs include: E-Glass, aluminum trihydrate, calcium carbonate, UPR, styrene, low-profile additive (LPA), co-resin, mold-release agent, thickener, in-mold coating (IMC), initiator, and pigment.
   a. UPR: LCI data for the production of the UPR materials are taken from the ACMA averages presented in Chapter 2.
   b. E-Glass: LCI data for the production of the E-Glass materials are taken from the ACMA averages present in Chapter 3.
   c. Other Materials: The composition of the methyl ethyl ketone peroxide (MEKP)-based initiator, styrene-based IMC, mold-release agent, and the UPR- and styrene-based co-resin materials used to model the LCI results are based on averages of formulations for each material provided by the ACMA member companies. Energy consumption and transportation in production of these materials are based on average requirements for organic chemicals per the Franklin Associates Private LCI Database. LCI data for production of styrene are taken from the ACC resin data revised in 2011.A 50:50 split of LCI data for production of magnesium and calcium hydroxides from the Franklin Associates Private US LCI Database and the US LCI Database, respectively, was used as a proxy to represent thickener material (i.e., LCI data for clay mining was used as a proxy for extraction of magnesium hydroxide and hydrated lime as a proxy for calcium hydroxide. A 50:50 split of LCI data for titanium dioxide (TiO) and carbon black, from the Franklin Associates Private LCI Database and US-adapted ecoinvent LCI database, respectively, was used as a proxy for pigment materials. LCI data for aluminum trihydrate comes from the EcoInvent database. LCI data for limestone mining from the US LCI Database were used to reflect calcium carbonate material inputs. LCI data for production of the average corrugated box, adapted from the Corrugated Packaging Alliance (CPA) were used to reflect the input of corrugated materials for packaging.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the compression molding step, as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the compression molding step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.

4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of compression molded composites production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the compression molded composites production process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the compression molding process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the compression molding process itself.

Energy Results

Cumulative energy consumption for production of compression molded composites is shown by energy category and process step in Table 17 and Figure 19.

Table 17. Cradle-to-Gate Cumulative Energy Demand for Production of Compression Molded Composites (Million Btu of energy per 1,000 pounds of Compression Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.14	0.39	0.17	0.0076	1.57	**2.29**	**10%**
Coal	0.39	1.07	0.48	0.020	4.16	**6.12**	**26%**
Natural Gas	3.03	1.76	2.10	0.037	1.58	**8.50**	**36%**
Petroleum	2.31	0.20	2.78	0.77	0.47	**6.53**	**27%**
Hydro	0.016	0.046	0.020	8.7E-04	0.18	**0.26**	**1.1%**
Recovered	-0.015	-1.8E-07	-0.0010	0	0	**-0.016**	**<1%**
Biomass	6.2E-04	0.0010	0.21	1.9E-05	0.0039	**0.21**	**<1%**
Renewables	0.0018	0.0048	0.0021	9.3E-05	0.019	**0.028**	**<1%**
TOTAL (1)	**5.88**	**3.47**	**5.75**	**0.84**	**7.99**	**23.9**	**100%**
PERCENT TOTAL (1)	**25%**	**15%**	**24%**	**3.5%**	**33%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

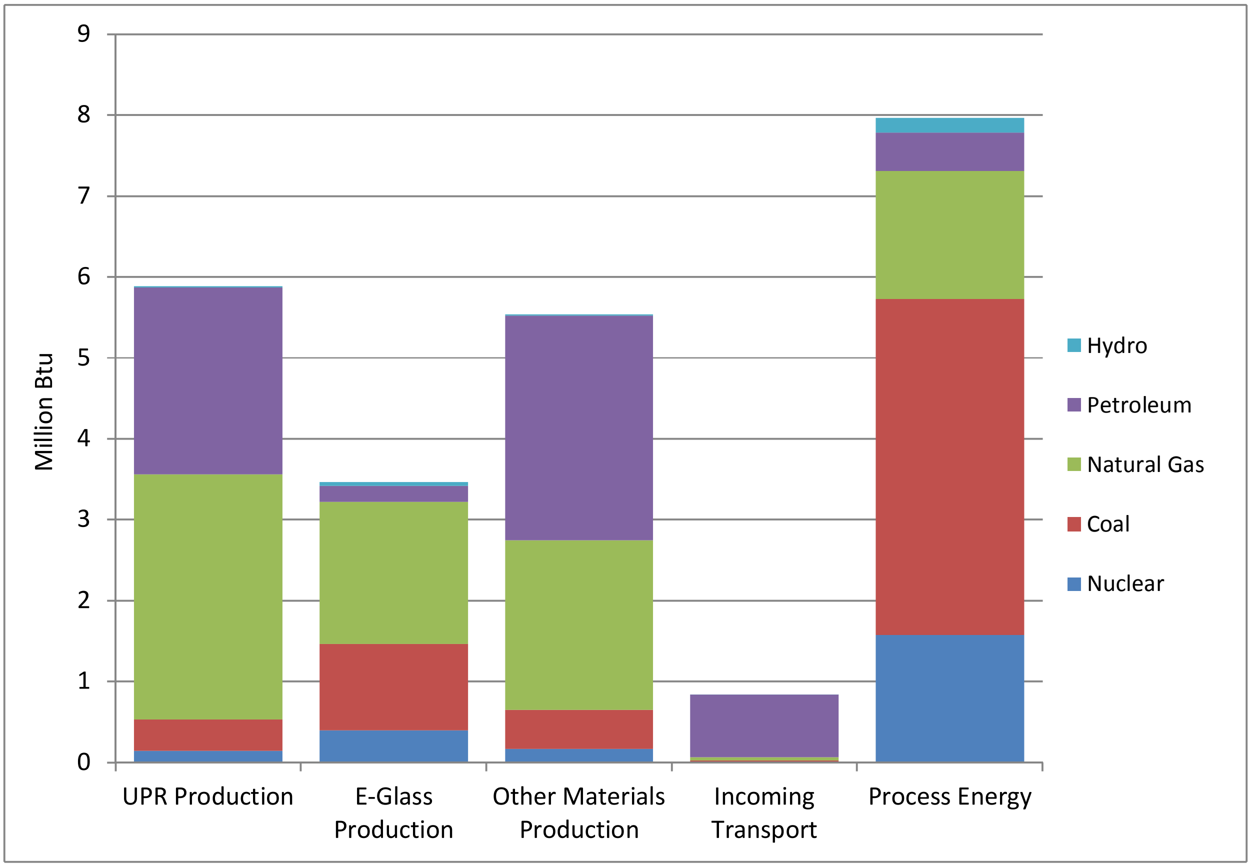

Figure 19. Cradle-to-Gate Cumulative Energy Demand for Production of Compression Molded Composites (Million Btu of energy per 1,000 pounds of Compression Molded Composites)

The cradle-to-gate results show that inputs materials and process energy contribute the bulk of total energy demand for compression molded composites production. Of the input materials, energy demand for production of UPR and other material inputs outweigh that for E-Glass inputs. However, process energy alone contributes 33 percent to total energy demand. Transport energy requirements are insignificant relative to those for material production and process energy. As shown in Table 18 and in Figure 20, 98 percent of energy requirements for the gate-to-gate manufacturing step (i.e., process energy) are in providing electricity for the compression molding process, and the remaining two percent is due to the use of natural gas, distillate fuels at the compression molding facility.

Table 18. Unit Process Energy Demand for Production of Compression Molded Composites (Million Btu of energy per 1,000 pounds of Compression Molded Composites)

	Electricity Inputs	Natural Gas Fuel	Diesel Fuel	LPG Fuel	TOTAL (1)	PERCENT TOTAL (1)
Nuclear	1.57	3.8E-04	4.3E-05	3.0E-04	**1.57**	**20%**
Coal	4.16	0.0010	1.1E-04	8.0E-04	**4.16**	**52%**
Natural Gas	1.44	0.14	2.1E-04	0.0015	**1.58**	**20%**
Petroleum	0.44	5.0E-04	0.0044	0.031	**0.47**	**5.9%**
Hydro	0.18	4.3E-05	5.0E-06	3.5E-05	**0.18**	**2.3%**
Renewables	0.0039	9.4E-07	1.1E-07	7.6E-07	**0.0039**	**<1%**
TOTAL (1)	**7.79**	**0.14**	**0.0047**	**0.033**	**7.97**	**100%**
PERCENT TOTAL (1)	**98%**	**1.8%**	**<1%**	**<1%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

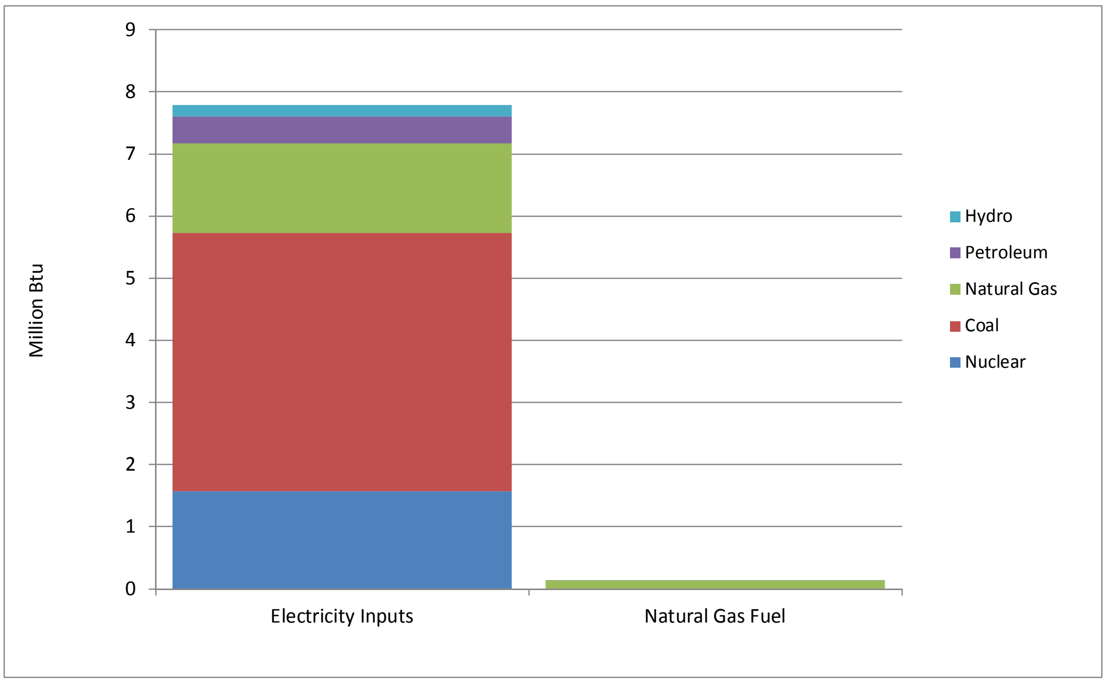

Figure 20. Unit Process Energy Demand for Production of Compression Molded Composites (Million Btu of energy per 1,000 pounds of Compression Molded Composites)

About a sixth of the energy demand for production of compression molded composite materials is energy of material resources (EMR). EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins or corrugated fiber. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 19 and Figure 21 show the relative amounts of cradle-to-gate EMR versus expended energy demand for compression molded composites production. Note the bulk of the materials EMR demand is due to natural gas and petroleum inputs to UPR and other materials.

Table 19. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Compression Molded Composites
(Million Btu of energy per 1,000 pounds of Compression Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	TOTAL (1)	PERCENT TOTAL (1)
Expended Energy	3.23	3.47	3.93	0.84	7.99	**19.5**	**81%**
Natural Gas EMR	1.22	0.0012	0.64	0	0	**1.86**	**8%**
Petroleum EMR	1.43	4.8E-05	0.99	0	0	**2.42**	**10%**
Biomass EMR	1.9E-16	2.4E-14	0.19	0	0	**0.19**	**<1%**
TOTAL (1)	**5.88**	**3.47**	**5.75**	**0.84**	**7.99**	**23.9**	**100%**
PERCENT TOTAL (1)	**25%**	**15%**	**24%**	**3.5%**	**33%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

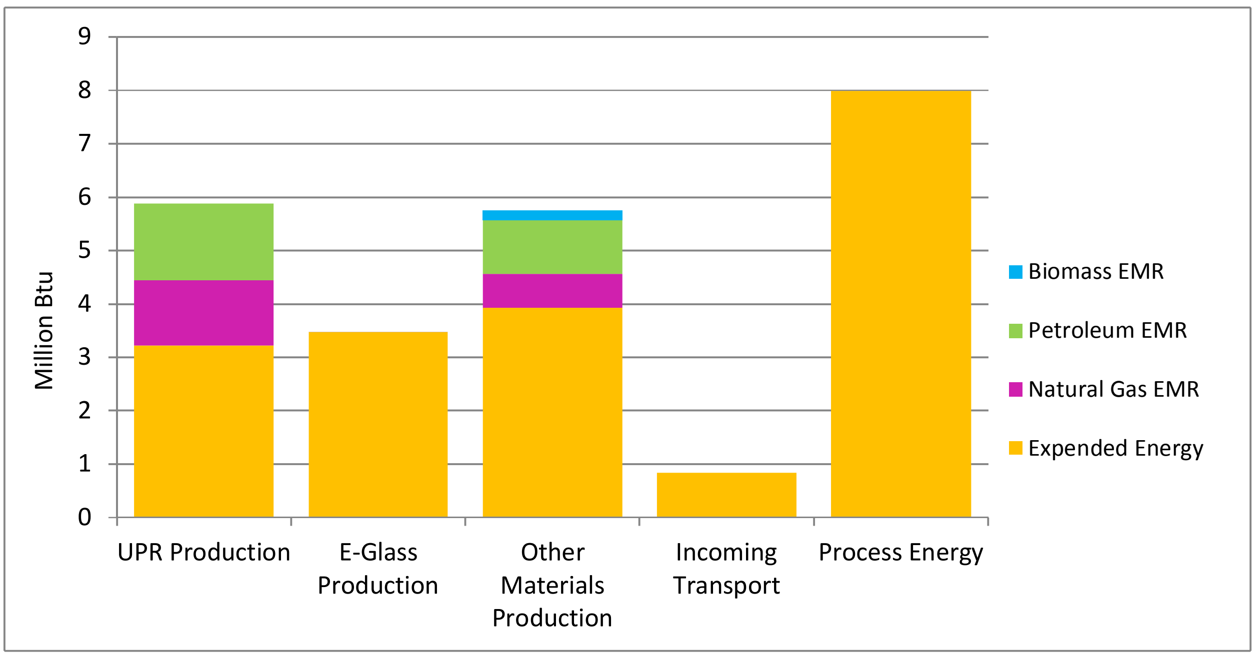

Figure 21. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Compression Molded Composites
(Million Btu of energy per 1,000 pounds of Compression Molded Composites)

Water Use Results

Consumptive water use for cradle-to-gate production of compression molded composites is shown by life cycle phase in Table 20 and Figure 22.

Table 20. Cradle-to-Gate Water Use for Production of Compression Molded Composites (Gallons of water per 1,000 pounds of Compression Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Water	**TOTAL (1)**
Per 1,000 lb Composite	236	555	421	30.5	1,236	53.9	**2,532**
% TOTAL (1)	**9.3%**	**22%**	**17%**	**1.2%**	**49%**	**2.1%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

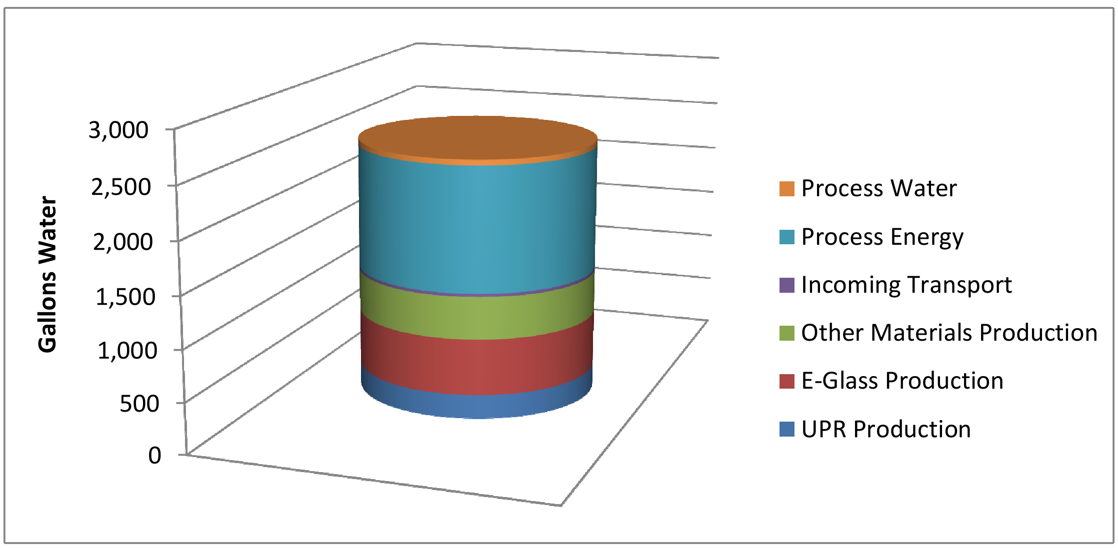

Figure 22. Cradle-to-Gate Water Use for Production of Compression Molded Composites (Gallons of water per 1,000 pounds of Compression Molded Composites)

The 'material production' results represent water consumption associated with the steps to extract and process the materials required for compression molded composites production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from compression molding process. The cradle-to-gate results show that the much of the total water demand is water consumed in production of energy used in the compression molding process, though water consumed during the production of the input materials also contributes significantly. Water is consumed during production of the fuels and electricity used in the fabrication process and this category consumes about nearly half of the cradle-to-gate total. Water consumed at the compression molding facility itself, 53.5 gallons per 1,000 pounds of composites product, only comprises about two percent of the total cradle-to-gate demand. The remaining consumption occurs from the production of fuels required for transporting incoming materials to the compression molding facility.

Solid Waste Results

Solid waste generation for cradle-to-gate production of compression molded composites is shown by process step in Table 21 and Figure 23.

Table 21. Cradle-to-Gate Solid Waste Generation for Production of Compression Molded Composites (Pounds of solid waste per 1,000 pounds of Compression Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	4.49	116.3	135	0	0	90.0	**346**	**57%**
Incinerated	0.62	0.012	0.60	0	0	2.90	**4.13**	**<1%**
Waste-to-Energy	0.33	3.6E-06	0.012	0	0	1.40	**1.74**	**<1%**
Fuel-Related	17.1	43.2	29.1	2.07	162	0	**254**	**42%**
TOTAL (1)	**22.6**	**160**	**165**	**2.07**	**162**	**94.3**	**606**	**100%**
PERCENT TOTAL (1)	**3.7%**	**26%**	**27%**	**<1%**	**27%**	**16%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

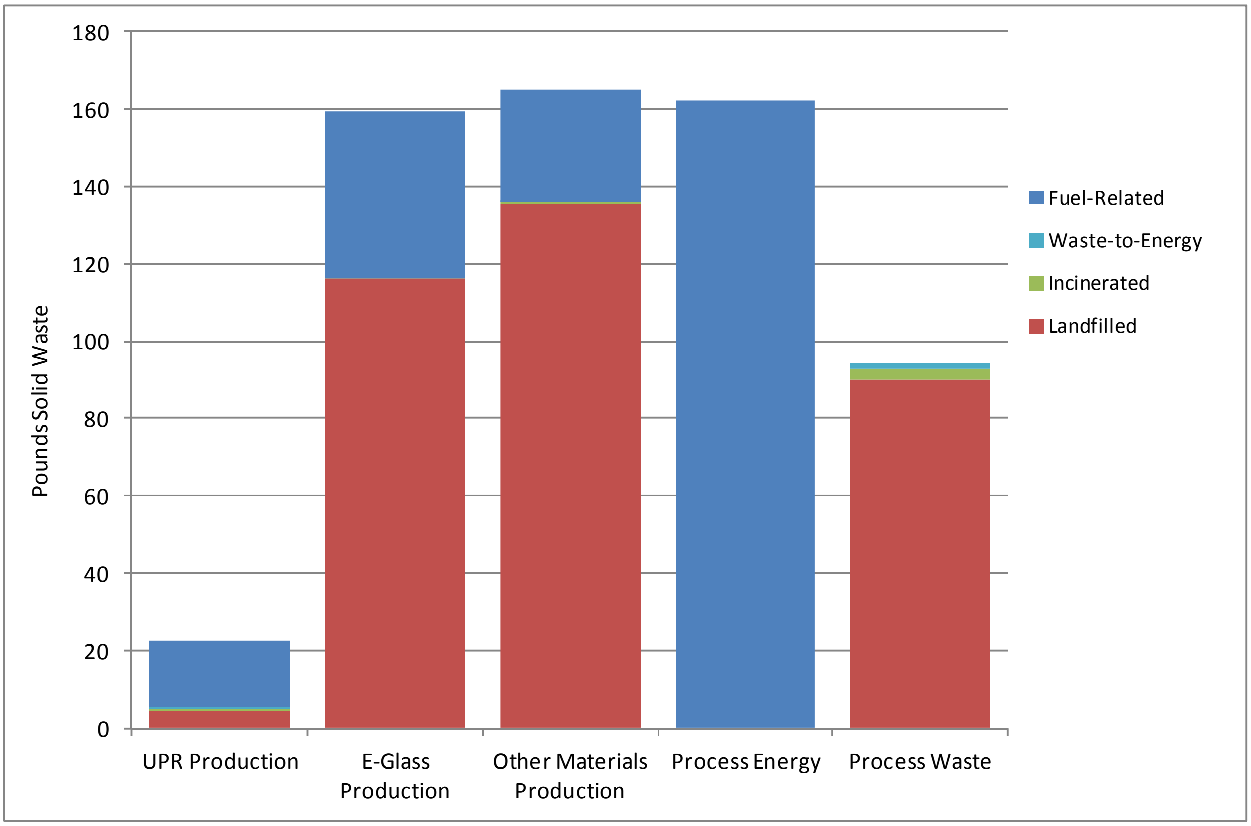

Figure 23. Cradle-to-Gate Solid Waste Generation for Production of Compression Molded Composites (Pounds of solid waste per 1,000 pounds of Compression Molded Composites)

The cradle-to-gate results for solid waste generation indicate that the bulk of generation is evenly split between the production of the E-Glass, other materials and the production of fuels and electricity required for compression molded composites production, about 27 percent in each case. For solid waste generated during the production of the input materials, E-Glass and other materials contribute more significantly than UPR material inputs. Solid waste generated during the production process at the compression molding facility is about 16 percent of the cradle-to-gate total. Waste sold for recycling is considered a co-product of the compression molding process. Therefore, though the amount of solid waste sold for recycling is shown in the unit process table, this amount is not included in the total solid waste generation results presented in this report. Also, due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the compression molded composites) no postconsumer wastes are modeled. The disposition of the produced compression molded composites depends on the product application (reinforced composites matrix, gel coat, etc.), its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of compression molded composites and include both process and fuel-related emission. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for each production of compression molded composites include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the compression molding facility, and from (4) the compression molded composites facility itself. Non-fuel related air emissions at the compression molding facility include volatilized hydrocarbons and particulate matter. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate compression molded composites life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and 298 for nitrous oxide.[12] GHG results for production of compression molded composites are shown in Table 22 and Figure 24.

[12] The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

Table 22. Cradle-to-Gate GHGs for Production of Compression Molded Composites (Pounds CO2 equivalents per 1,000 pounds of Compression Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Emissions	TOTAL (1)	PERCENT TOTAL (1)
Fossil CO2	454	591	560	130	1,190	0.094	**2,925**	**89%**
Methane	63.8	39.6	118	6.18	70.4	0	**298**	**9.1%**
Nitrous Oxide	1.86	2.52	3.00	1.05	7.87	0	**16.3**	**<1%**
Others	0.70	6.93	25.6	0	0	0	**33.2**	**1.0%**
TOTAL (1)	**520**	**640**	**707**	**137**	**1,268**	**0.094**	**3,273**	**100%**
PERCENT TOTAL (1)	**16%**	**20%**	**22%**	**4.2%**	**39%**	**<1%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

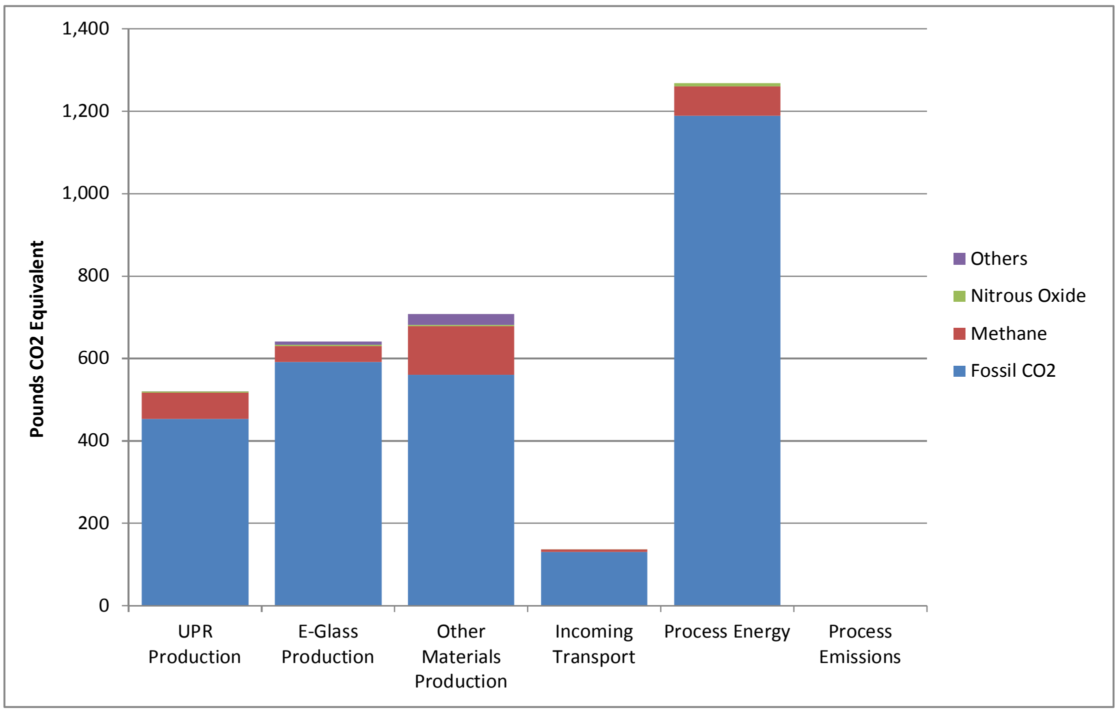

Figure 24. Cradle-to-Gate GHGs for Production of Compression Molded Composites (Pounds CO2 equivalents per 1,000 pounds of Compression Molded Composites)

As can often be the case for LCI results of product systems, the life cycle phases contributing most significantly to energy demand also contribute most significantly to solid waste generation and GHG emissions. The results for solid waste generation and GHG emissions for cradle-to-gate compression molded composites production demonstrate this correlation. The production of the materials requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. The production of electricity and production and combustion of fuels used at the compression molding facility also figure significantly in total GHG emissions. GHG emissions reported for the compression molding process itself comprise less than one percent of the cradle-to-gate life cycle total. Likewise, GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute less than five percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributors to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution, and nitrous oxide emissions the third largest contribution. Several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate compression molded composites production LCI are included in Appendix A.

CHAPTER 5. OPEN MOLDING

INTRODUCTION

This chapter describes the production of composites from the open molding process, presents the compiled gate-to-gate unit process LCI data for production of open molded composites, and presents LCI results for cradle-to-gate production of 1,000 pounds of open molded composites in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of Open Molded Composites

Open molding is a process commonly used to manufacture large FRP composites such as boats, truck bodies and swimming pools. Products derived from the open molding method are manufactured from the exterior to the interior with a specific order of materials being applied to the mold. This order is usually a release agent, a gel coat, a barrier coat, skin laminate, core material, and bulk laminte.

A variety of resins, glass fiber, and fillers may be used in open molding but typically include: UPR, E-Glass, calcium carbonate and alumina trihydrate. The properties of the composite depend on the types and proportions of resins, fillers, and additives incorporated.

There are two types of methods used to apply the layers to the open mold—hand lay-up and spray up. The hand lay-up applies each layer to the mold by hand using a brush or roller on the composites when all layers are on the mold. As each layer is applied to the mold, the layer is cured and, when complete, removed from the mold. The spray up method uses a spray gun to apply the liquid resin matrix and chopped reinforcing fibers simultaneously onto the mold surface. Once the composites product is released from the mold, it is trimmed.

Other additives such as pigments and fire retardants may be added and depend on the application and characteristics desired for the final product. The final open molding composites part is shipped to users. The properties of open molded composites depend on the types and proportions of resins, glass fiber, fillers, and additives incorporated.

Figure 25 displays a summary of the material inputs used to manufacture open molded composites. Further information on the data sources of these material inputs are shown in Appendix B.

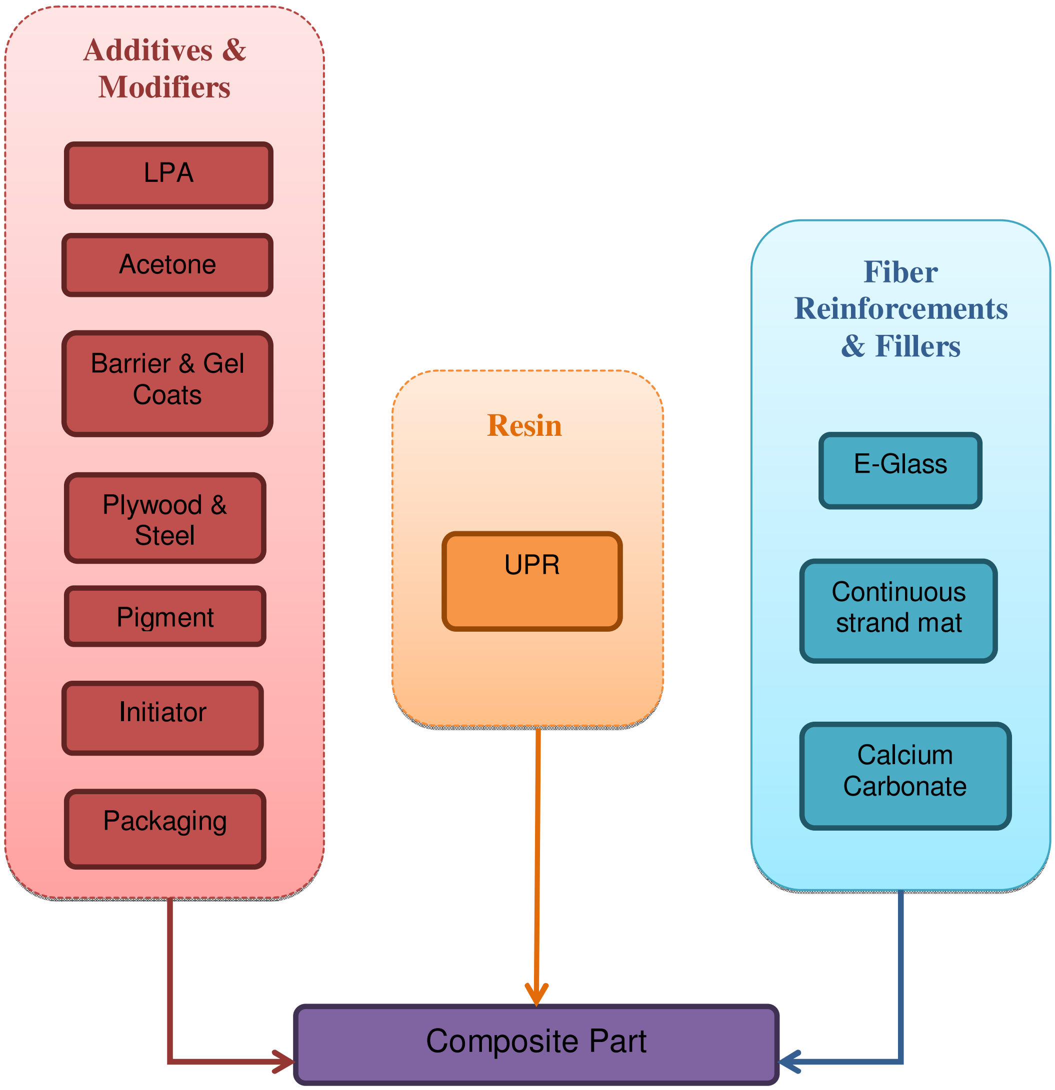

Figure 25. Summary of Material Inputs to the Open Molded Composites Product

Table 23 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of open molded composites in 2010 in the US. In terms of process energy consumption, the average open molding facility meets almost all of its process energy demand (98 percent) with electricity. Natural gas, LPG, ethanol, and diesel combustion are used in smaller amounts and make up the remaining 2 percent of the energy.

An average of 189 pounds of solid waste are generated for every 1,000 pounds of open molded composites produced: 90 percent of those solid wastes are landfilled, with the remaining 10 percent incinerated, incinerated with energy recovery, and sold for recycling. The landfilled solid wastes include trimmings, packaging waste, wood, and various other process wastes.

The amount of water consumed for the open molding is 887 gallons consumed per 1,000 pounds of open molded composites. This too is dependent on the type of product. Some open molders consumed no water; while others had to hydrotest their products and consumed a large amount of water.

Table 23. LCI Unit Process Data for Production of Open Molded Composites

	English units (Basis: 1,000 lb)			SI units (Basis: 1,000 kg)		
Outputs to Technosphere						
Open molded composite part	1,000	lb		1,000	kg	
Materials sold for recycling	11.0	lb		11.0	kg	
Inputs from Technosphere (to Product)						
Acetone	4.60	lb		4.60	kg	
Basic oxygen furnace (BOF) steel	25.0	lb		25.0	kg	
Corrugated boxes & packaging	20.0	lb	*	20.0	kg	*
General grade glass fiber, (E-Glass)	120	lb		120	kg	
Fiberglass, continuous strand mat	90.0	lb		90.0	kg	
Gelcoat, UPR-styrene-based	65.0	lb		65.0	kg	
Barrier coat, UPR-styrene-based	15	lb		15.0	kg	
Limestone	200.0	lb		200	kg	
MEKP initiator	11.00	lb		11.0	kg	
Plywood	39.00	lb		39.0	kg	
Softwood lumber	10.0	lb	*	10.0	kg	*
UPR	520	lb		520	kg	
Process Water Consumption	887	gal		7,401	liter	
Energy Usage						
Process Energy						
Electricity (grid)	497	kwh		1,096	kwh	
Natural gas	28.1	cu ft		1.75	cu meters	
LPG	2.89	gal		24.1	liter	
Diesel	0.18	gal		1.50	liter	
Ethanol	0.21	gal		1.75	liter	
Incoming Materials Transportation Energy						
Combination truck	532	ton-miles		1,712	tonne-km	
Diesel	5.59	gal		46.6	liter	
Rail	62.2	ton-miles		200	tonne-km	
Diesel	0.15	gal		1.29	liter	
Ocean freighter	321	ton-miles		1,033	tonne-km	
Diesel	0.061	gal		0.51	liter	
Residual	0.55	gal		4.58	liter	
Environmental Emissions						
Atmospheric Emissions						
Methyl methacrylate	0.16	lb		0.16	kg	
Particulates, > 2.5 um, and < 10um	0.36	lb		0.36	kg	
Styrene	37.0	lb		37.0	kg	
VOCs, unspecified	12.0	lb		12.0	kg	
Solid Wastes						
Landfilled	170	lb		170	kg	
Burned	5.00	lb		5.00	kg	
Waste-to-Energy	2.50	lb		2.50	kg	

* Less than 3 companies reported this emission. To protect the confidentiality of the amount, but also to represent known emissions, the order of magnitude has been retained.

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for Open Molded Composites

For open molded composites production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs, a) UPR , b) E-Glass, and c) other materials, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average open molded composites production, material inputs include: E-Glass, continuous strand mat fiberglass, calcium carbonate, UPR, low-profile additive (LPA), acetone, gel-coat (UPR styrene based), barrier coat (UPR styrene based), initiator, plywood/lumber, steel, and pigment.
   a. UPR: LCI data for the production of the UPR materials are taken from the ACMA averages presented in Chapter 2.
   b. E-Glass: LCI data for the production of the E-Glass materials are taken from the ACMA averages present in Chapter 3. Also included here is the continuous strand mat. No data was available for this material; however, as this is produced in the same fashion as E-Glass, the average E-Glass data has been substituted for continuous strand mat. It should be noted that due to added material (e.g. the mat) and energy for drying that is not taken into account in this analysis, the total energy and emissions for continuous strand mat may be understated somewhat.
   c. Other Materials: The composition of the methyl ethyl ketone peroxide (MEKP)-based initiator used to model the LCI results are based on averages of formulations for each material provided by the ACMA member companies. Energy consumption and transportation in production of these materials are based on average requirements for organic chemicals per the Franklin Associates Private LCI Database. A 50:50 slit of LCI data for titanium dioxide (TiO) and carbon black, from the Franklin Associates Private LCI Database and US-adapted ecoinvent LCI database, respectively, was used as a proxy for pigment materials. LCI data for limestone mining from the US LCI Database were used to reflect calcium carbonate material inputs. The gel coat and barrier coat layers were based on the UPR data in Chapter 2 per information provided by the processors. The steel, lumber and plywood data are taken from the U.S. LCI Database. LCI data for production of the average corrugated box, adapted from the Corrugated Packaging Alliance (CPA) were used to reflect the input of corrugated materials for packaging.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the open molding step, as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the open molding process. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.

4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of open molded composites production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the open molded composites production process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the open molding process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the open molding process itself.

Energy Results

Cumulative energy consumption for production of open molded composites is shown by energy category and process step in Table 24 and Figure 26.

Table 24. Cradle-to-Gate Cumulative Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.43	0.30	0.11	0.011	1.09	**1.94**	**6.3%**
Coal	1.19	0.80	0.44	0.028	2.88	**5.34**	**17%**
Natural Gas	9.26	1.32	1.73	0.052	1.04	**13.4**	**43%**
Petroleum	7.08	0.15	1.26	1.07	0.36	**9.92**	**32%**
Hydro	0.050	0.034	0.013	0.0012	0.13	**0.22**	**<1%**
Recovered	-0.047	-1.4E-07	-0.003	0	-5.8E-05	**-0.049**	**<1%**
Biomass	0.0019	7.8E-04	0.15	2.6E-05	0.0027	**0.16**	**<1%**
Renewables	0.0055	0.0036	0.0013	1.3E-04	0.013	**0.024**	**<1%**
TOTAL (1)	**18.0**	**2.60**	**3.71**	**1.16**	**5.51**	**31.0**	**100%**
PERCENT TOTAL (1)	**58%**	**8.4%**	**12%**	**3.8%**	**18%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

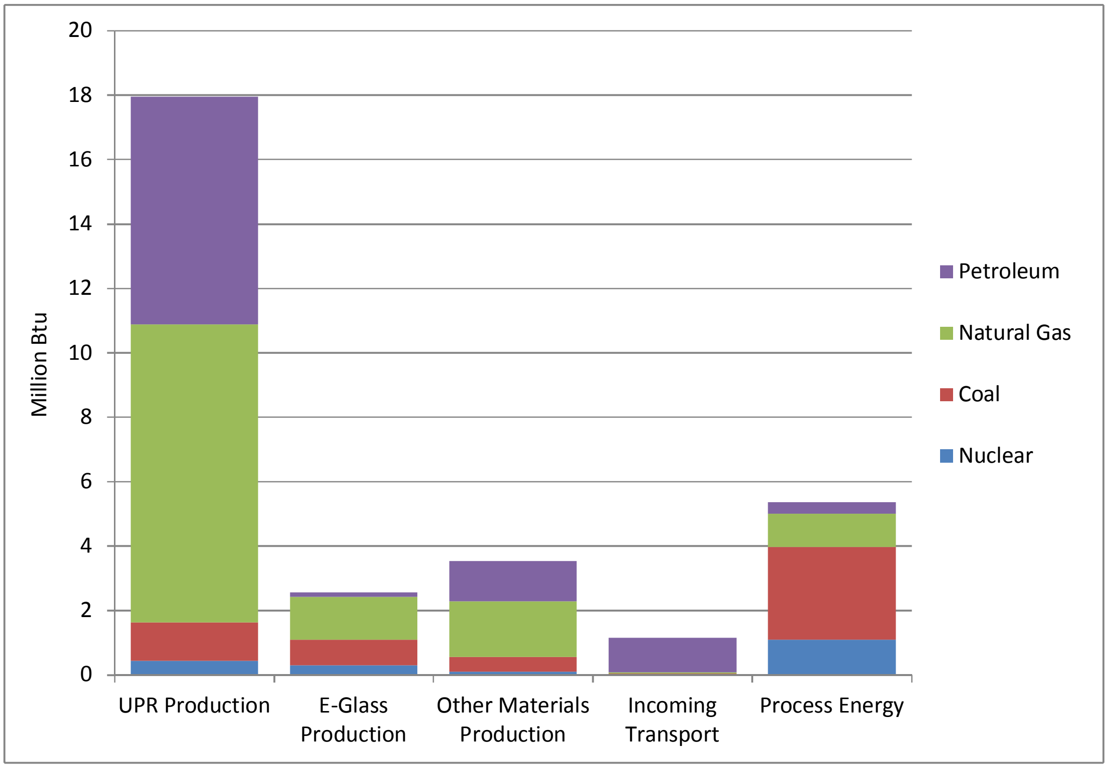

Figure 26. Cradle-to-Gate Cumulative Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

The cradle-to-gate results show that the UPR input and process energy contribute the bulk of total energy demand for open molded composites production. Of the input materials, energy demand for the production of UPR inputs outweigh that for E-Glass and other material inputs. However, the open molding process energy alone contributes 18 percent to total energy demand. Transport energy requirements are insignificant (4 percent of the total) relative to those for material production and process energy. As shown in Table 25 and in Figure 27, 98 percent of energy requirements for the gate-to-gate manufacturing step (i.e., process energy) are in providing electricity for the open molding process, and the remaining two percent is due to the use of natural gas, distillate fuels at the compression molding facility. Coal is utilized at approximately 50 percent within the electricity grid. This can be seen within the process energy bar of in Figure 26 as well.

Table 25. Unit Process Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

	Natural Gas Fuel	Electricity Inputs	Diesel Fuel	LPG Fuel	Ethanol Fuel	TOTAL (1)	PERCENT TOTAL (1)
Nuclear	8.5E-05	1.09	2.7E-04	2.7E-04	5.0E-04	**1.09**	**20%**
Coal	2.3E-04	2.88	7.1E-04	7.1E-04	0.0022	**2.88**	**52%**
Natural Gas	0.032	1.00	0.0013	0.0013	0.012	**1.04**	**19%**
Petroleum	1.1E-04	0.30	0.027	0.027	0.0032	**0.36**	**6.6%**
Hydro	9.9E-06	0.13	3.1E-05	3.1E-05	5.8E-05	**0.13**	**2.3%**
Renewables	2.1E-07	0.0027	6.7E-07	6.7E-07	1.2E-06	**0.0027**	**<1%**
TOTAL (1)	**0.032**	**5.39**	**0.030**	**0.030**	**0.018**	**5.50**	**100%**
PERCENT TOTAL (1)	**<1%**	**98%**	**<1%**	**<1%**	**<1%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

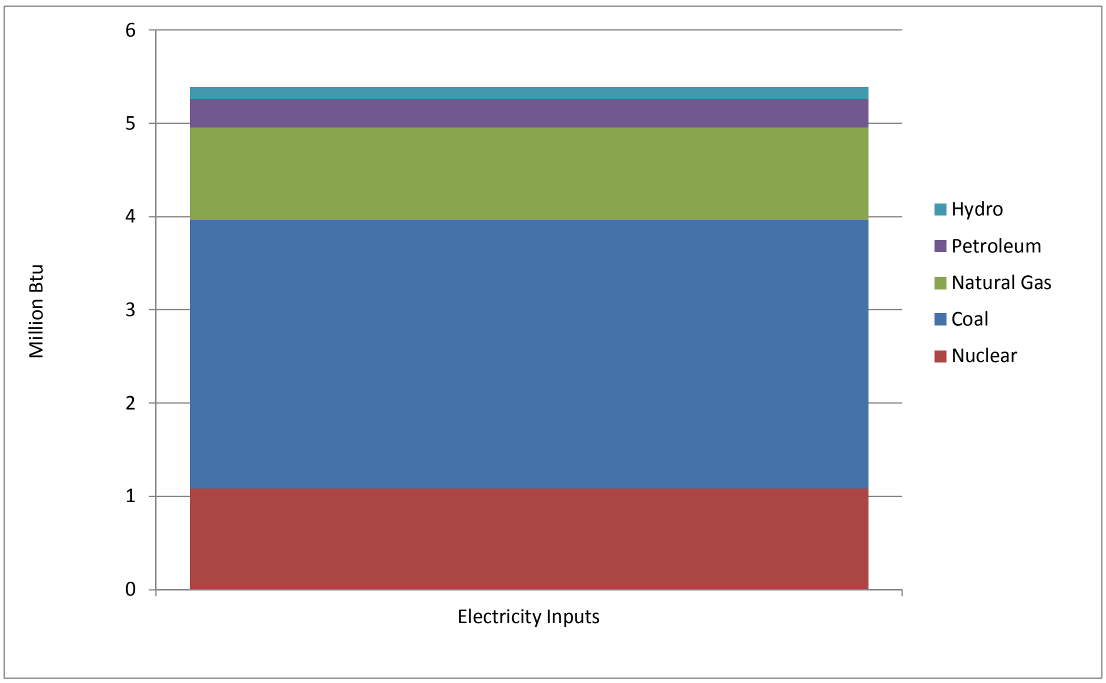

Figure 27. Unit Process Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

About a third of the energy demand for the cradle-to-gate production of open molded composite materials is energy of material resources. EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins or corrugated fiber. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 26 and Figure 28 show the relative amounts of cradle-to-gate EMR versus expended energy demand for open molded composites production. More than 85 percent of the total EMR comes from the UPR production, with most of the remaining EMR coming from other materials, which include a number of resin based materials.

Table 26. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	9.87	2.60	2.27	1.16	5.51	**21.4**	**69%**
Natural Gas EMR	3.72	9.3E-04	0.53	0	5.9E-04	**4.25**	**14%**
Petroleum EMR	4.38	3.6E-05	0.78	0	8.5E-09	**5.15**	**17%**
Biomass EMR	5.9E-16	1.8E-14	0.14	0	6.5E-15	**0.14**	**<1%**
TOTAL (1)	**18.0**	**2.60**	**3.71**	**1.16**	**5.51**	**31.0**	**100%**
PERCENT TOTAL (1)	**58%**	**8.4%**	**12%**	**3.8%**	**18%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

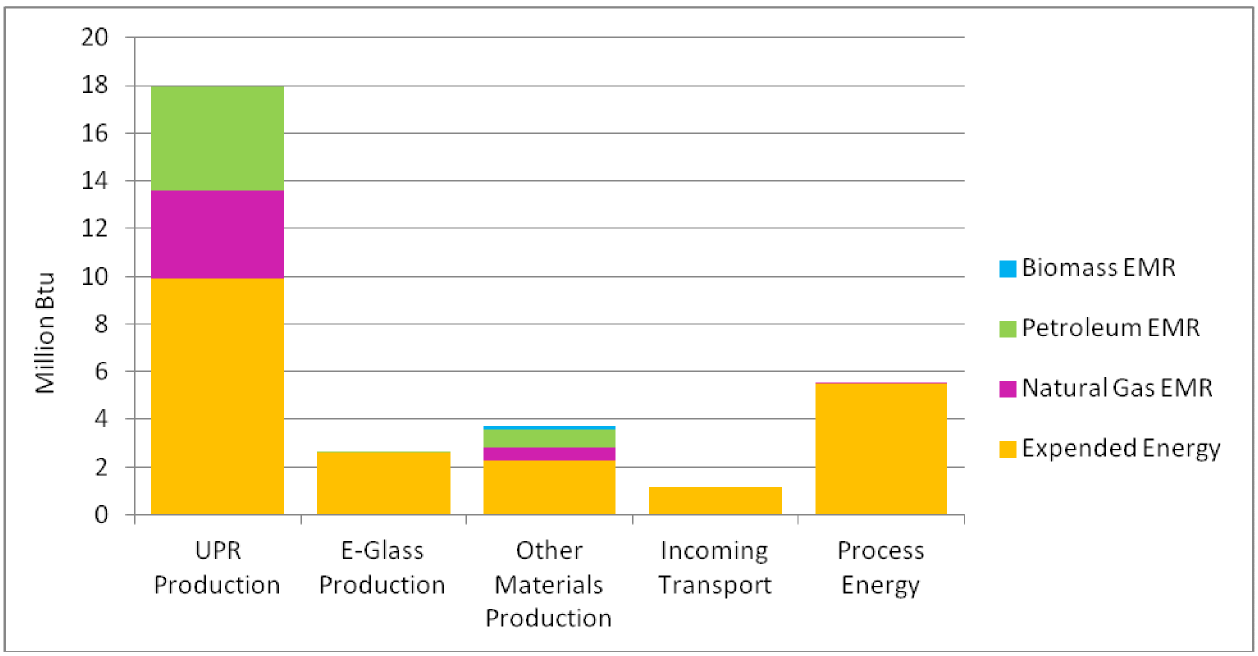

Figure 28. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Open Molded Composites (Million Btu of energy per 1,000 pounds of Open Molded Composites)

Water Use Results

Consumptive water use for cradle-to-gate production of open molded composites is shown by life cycle phase in Table 27 and Figure 29.

Table 27. Cradle-to-Gate Water Use for Production of Open Molded Composites (Gallons of water per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Water	**TOTAL (1)**
Per 1,000 lb UPR	720	416	265	42.3	857	887	**3,188**
% TOTAL (1)	**23%**	**13%**	**8%**	**1.3%**	**27%**	**28%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

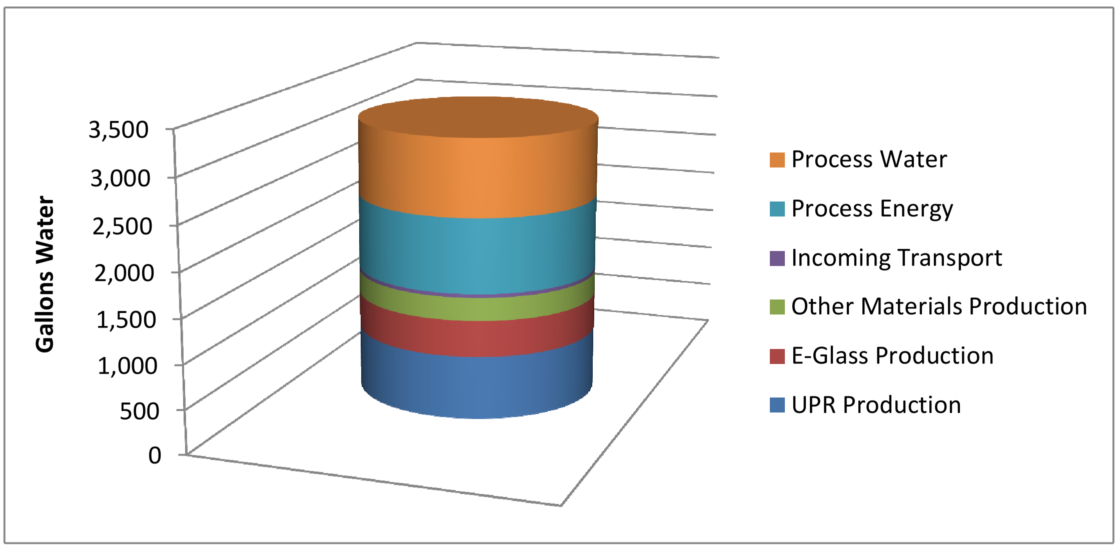

Figure 29. Cradle-to-Gate Water Use for Production of Open Molded Composites (Gallons of water per 1,000 pounds of Open Molded Composites)

The 'material production' results represent water consumption associated with the steps to extract and process the materials required for open molded composites production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from the open molding process. The cradle-to-gate results show that more than half of the total water demand is water consumed in production of energy and the process water used in the open molding process, though water consumed during the production of the UPR also contributes significantly. Water consumed at the open molding facility itself, 887 gallons per 1,000 pounds of composites product, comprises about 28 percent of the total cradle-to-gate demand. However, this water amount is quite variable in this process as it is dependent on the type of product. Some open molders consumed no water; while others used hydrotesting of their products and consumed a large amount of water. Approximately 1 percent of the consumption occurs from the production of fuels required for transporting incoming materials to the open molding facility.

Solid Waste Results

Solid waste generation for cradle-to-gate production of open molded composites is shown by process step in Table 28 and Figure 30.

Table 28. Cradle-to-Gate Solid Waste Generation for Production of Open Molded Composites (Pounds of solid waste per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	13.7	87.2	14.4	0	0.0096	170	**285**	**55%**
Incinerated	1.89	0.0088	0.47	0	2.9E-05	5.00	**7.36**	**1.4%**
Waste-to-Energy	1.00	2.7E-06	0.054	0	1.4E-09	2.50	**3.55**	**<1%**
Fuel-Related	52.4	32.4	17.8	2.87	112	0	**218**	**42%**
TOTAL (1)	**69.0**	**120**	**32.7**	**2.87**	**112**	**178**	**514**	**100%**
PERCENT TOTAL (1)	**13%**	**23%**	**6.4%**	**<1%**	**22%**	**35%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

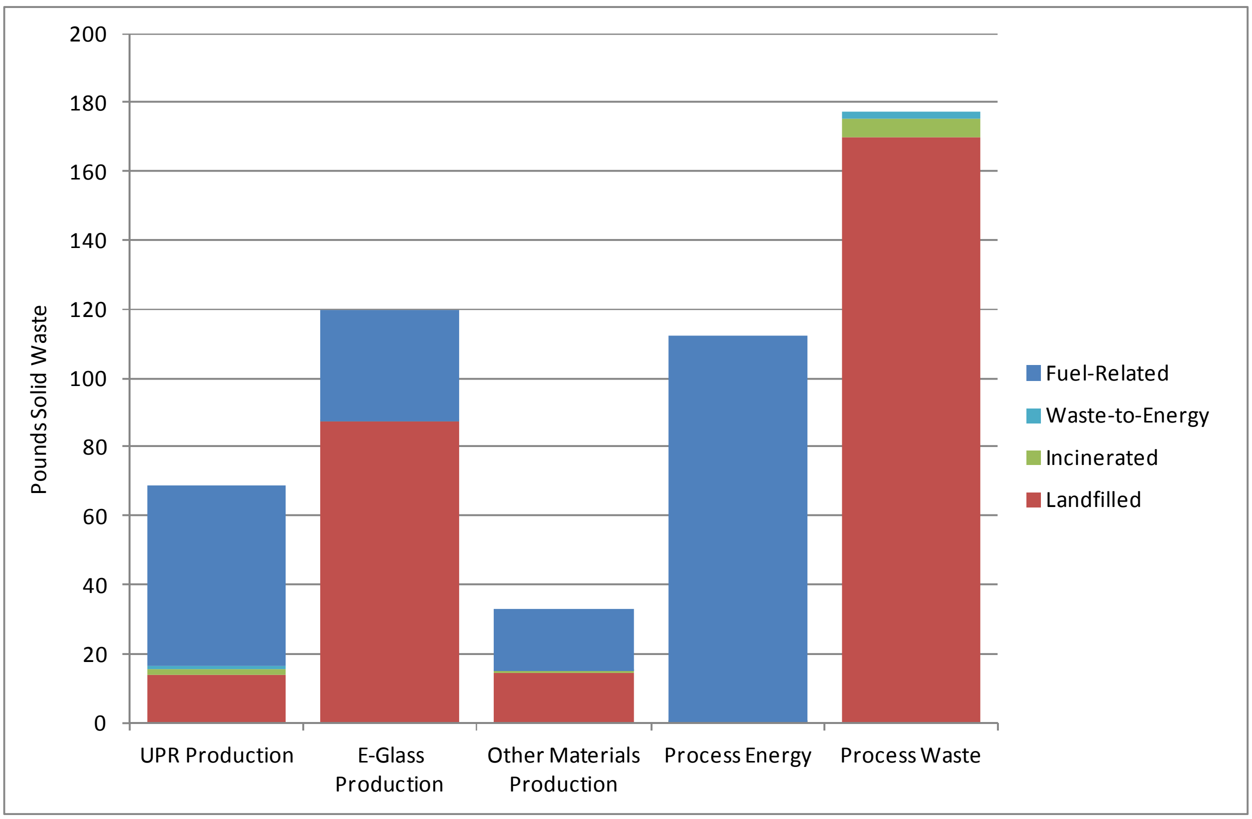

Figure 30. Cradle-to-Gate Solid Waste Generation for Production of Open Molded Composites (Pounds of solid waste per 1,000 pounds of Open Molded Composites)

The cradle-to-gate results for solid waste generation indicate that the largest percentage of generation comes from the open molding process itself. The solid waste amount within the processing facility varies depending on the type of product being produced, which affects the trim amount discarded. E-Glass production and the production of fuels and electricity required for open molded composites production make up about 23 percent of the total solid waste in each case. For solid waste generated during the production of the remaining input materials, UPR contributes more significantly than other material inputs. Solid waste generated at the open molding facility is about 35 percent of the cradle-to-gate total. Waste sold for recycling is considered a co-product of the open molding process. Therefore, though the amount of solid waste sold for recycling is shown in the unit process table, this amount is not included in the total solid waste generation results presented in this report. Also, due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the open molded composites) no postconsumer wastes are modeled. The disposition of the produced open molded composites depends on the product application, its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of open molded composites and include both process and fuel-related emissions. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for each production of open molded composites include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the open molding facility, and from (4) the open molded composites facility itself. Non-fuel related air emissions at the open molding facility include styrene from the reaction as well as volatilized hydrocarbons from the mold release and spray application. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and

298 for nitrous oxide.[13] GHG results for production of open molded composites are shown in Table 29 and Figure 31.

Table 29. Cradle-to-Gate GHGs for Production of Open Molded Composites
(Pounds CO2 equivalents per 1,000 pounds of Open Molded Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Fossil CO2	1,387	443	339	180	822	**3,172**	**91%**
Methane	195	29.7	42.0	8.57	48.2	**323**	**9.2%**
Nitrous Oxide	5.68	1.89	1.73	1.44	5.51	**16.2**	**<1%**
Others	1.70	5.19	-14.9	0	0.0078	**-8.04**	**<1%**
TOTAL (1)	**1,590**	**480**	**368**	**190**	**876**	**3,504**	**100%**
PERCENT TOTAL (1)	**45%**	**14%**	**10%**	**5.4%**	**25%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

13 The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

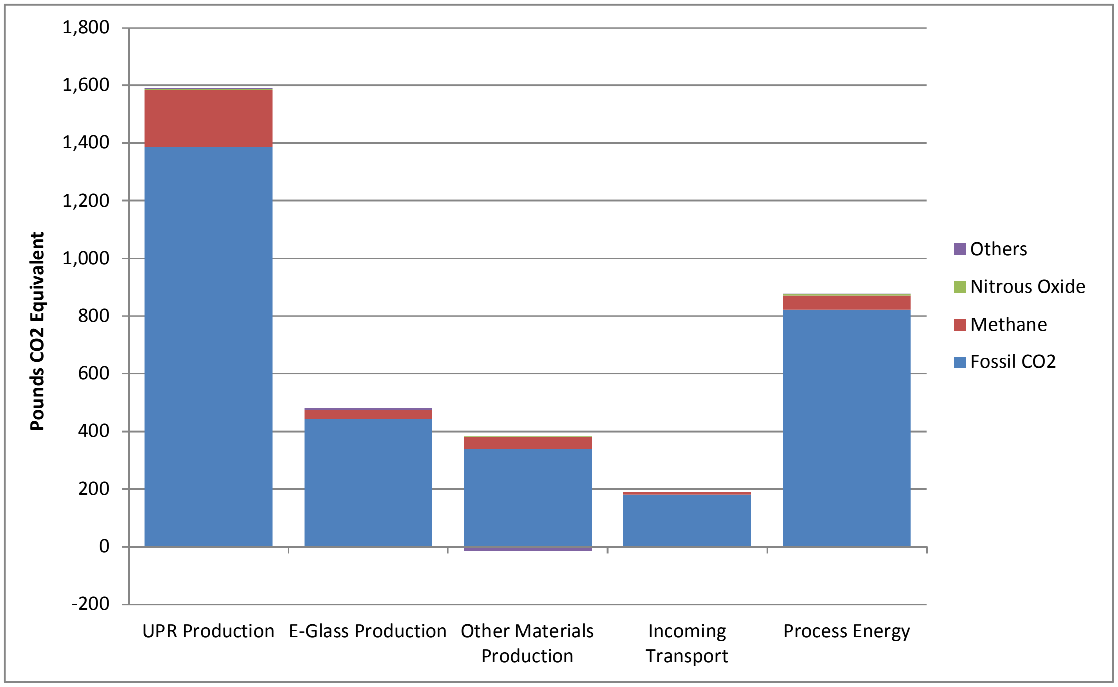

Figure 31. Cradle-to-Gate GHGs for Production of Open Molded Composites (Pounds CO2 equivalents per 1,000 pounds of Open Molded Composites)

As can often be the case for LCI results of product systems, the life cycle phases contributing most significantly to energy demand also contribute most significantly to GHG emissions. The results for GHG emissions for cradle-to-gate open molded composites production demonstrate this correlation. The production of the UPR materials requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. The production of electricity and production and combustion of fuels used at the open molding facility also figure significantly in total GHG emissions. No process GHG emissions were reported for the open molding process itself. GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute five percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributor (91 percent) to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution (9 percent). Nitrous oxide and several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate open molded composites production LCI are included in Appendix A.

CHAPTER 6. OPEN MOLD CASTING

INTRODUCTION

This chapter describes the production of composites from the open mold casting process, presents the compiled gate-to-gate unit process LCI data for production of open mold cast composites, and presents LCI results for cradle-to-gate production of 1,000 pounds of open mold cast composites in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of Open Mold Cast Composites

Open molding casting is a process commonly used to manufacture FRP composites products such as wall panels, vanity tops and shower bases. Products derived from the open mold casting are manufactured using a specific order of materials being applied to the mold. This order is usually a release agent, a gel coat, and a paste mix of resin and filler and initiator, .

A variety of resins and fillers may be used in open mold casting but typically include: UPR, calcium carbonate and alumina trihydrate. The properties of depend on the types and proportions of resins, fillers, and additives incorporated. A PET solid state granulate was used for design purposes in some open mold casting operations.

A mold release then clear coat spray is added to the mold. While the spray is drying, a paste is hand-stirred containing the resin, filler, and an initiator. The paste is then placed on the mold by hand, then sits for curing. Once the product is cured, the trim and raised areas are ground away. The product is then shipped out of the processing plant.

Other additives such as pigments and solvents may be added or used and depend on the application and characteristics desired for the final product. The final open mold cast composites is shipped to users. The properties of open mold cast composites depend on the types and proportions of resins, fillers, and additives incorporated.

Figure 32 displays a summary of the material inputs used to manufacture open mold cast composites. Further information on the data sources of these material inputs are shown in Appendix B.

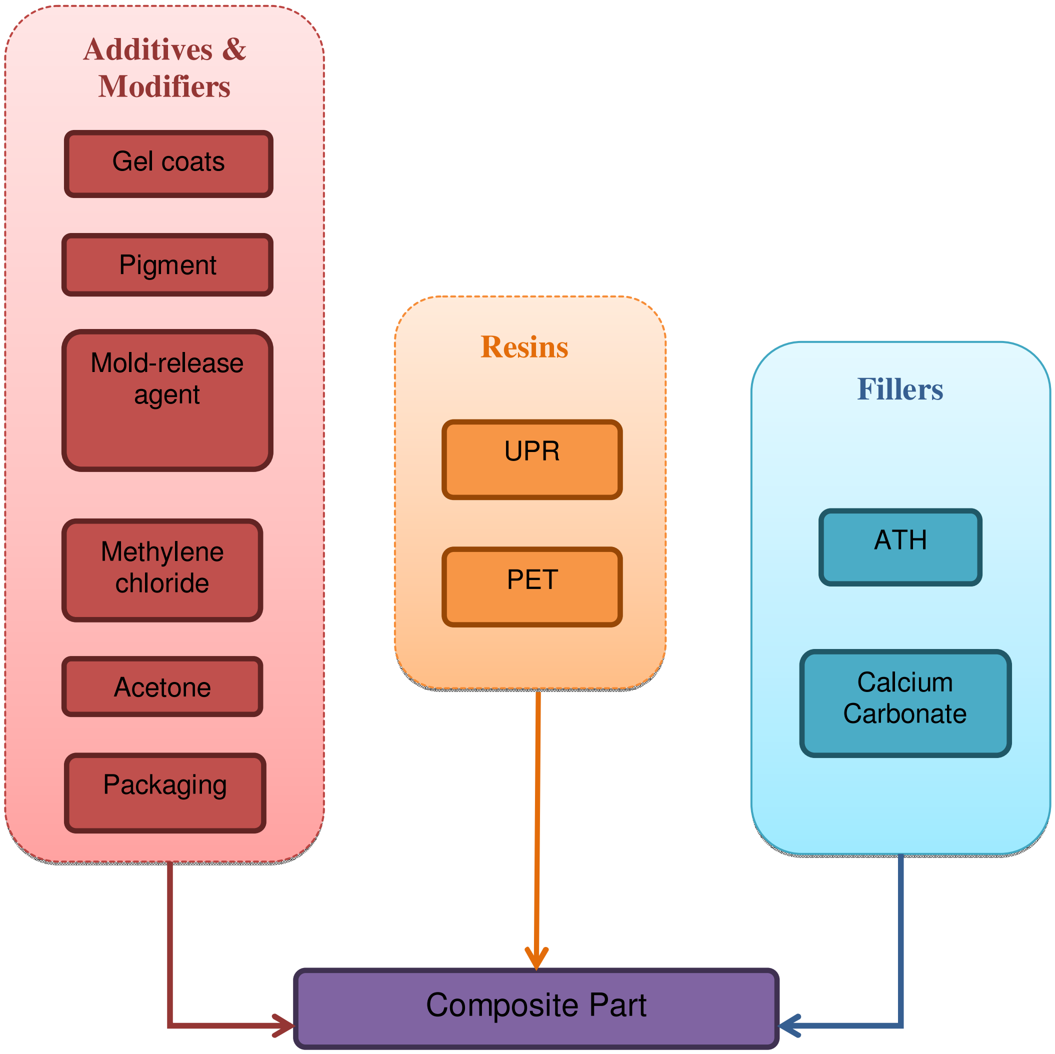

Figure 32. Summary of Material Inputs to Open Mold Cast Composites Products

Table 30 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of open mold cast composites in 2010 in the US. In terms of process energy consumption, the average open mold cast facility meets over 75 percent of its process energy demand with electricity. Natural gas is required for 22 percent of the process energy demand; whereas, LPG combustion is used in smaller amounts. An average of 46 pounds of solid waste are generated for every 1,000 pounds of open mold cast composites produced; 93 percent of those solid wastes are landfilled, with 5 percent incinerated, and the remaining incinerated with energy recovery and sold for recycling. No water consumption is required for this process.

Table 30. LCI Unit Process Data for Production of Open Mold Cast Composites

	English units (Basis: 1,000 lb)		SI units (Basis: 1,000 kg)	
Outputs to Technosphere				
Open cast molding composite part	1,000	lb	1,000	kg
Materials sold for recycling	0.49	lb	0.49	kg
Inputs from Technosphere (to Product)				
Acetone	6.10	lb	6.10	kg
Aluminium trihydrate	46.0	lb	46.0	kg
Dichloromethane	0.15	lb	0.15	kg
Gelcoat, UPR-styrene-based	25.0	lb	25.0	kg
Limestone	710	lb	710	kg
Pigment	3.80	lb	3.80	kg
PET	14.0	lb	14.0	kg
UPR	230	lb	230	kg
Mold-release agent	4.60	lb	4.60	kg
Process Water Consumption	0	gal	0	liter
Energy Usage				
Process Energy				
Electricity (grid)	253	kwh	558	kwh
Natural gas	711	cu ft	44.4	cu meters
LPG	0.68	gal	5.67	liter
Incoming Materials Transportation Energy				
Combination truck	180	ton-miles	579	tonne-km
Diesel	1.89	gal	15.8	liter
Environmental Emissions				
Atmospheric Emissions				
Methane, dichloro-, HCC-30	0.15	lb	0.15	kg
Methyl methacrylate	0.0012	lb	0.0012	kg
Particulates, > 2.5 um, and < 10um	0.019	lb	0.019	kg
Styrene	7.10	lb	7.10	kg
VOC, volatile organic compounds	0.51	lb	0.51	kg
Solid Wastes				
Landfilled	43.0	lb	43.0	kg
Burned	2.60	lb	2.60	kg
Waste-to-Energy	0.030	lb	0.030	kg

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for Open Mold Cast Composites

For open mold cast composites production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs: a) UPR and b) other materials, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average open mold cast composites production, material inputs include: aluminum trihydrate, UPR, mold-release agent, initiator, and pigment.
   a. UPR: LCI data for the production of the UPR materials are taken from the ACMA averages presented in Chapter 2.
   b. Other Materials: The composition of the mold-release agent used is based on averages of formulations for each material provided by the ACMA member companies. Energy consumption and transportation in production of these materials are based on average requirements for organic chemicals per the Franklin Associates Private LCI Database. A 50:50 slit of LCI data for titanium dioxide (TiO) and carbon black, from the Franklin Associates Private LCI Database and US-adapted ecoinvent LCI database, respectively, was used as a proxy for pigment materials. The gel coat layer was based on the UPR data in Chapter 2 per information provided by the processors. LCI data for production of PET are taken from the ACC resin data revised in 2011. LCI data for aluminum trihydrate comes from the EcoInvent database. LCI data for limestone mining from the US LCI Database were used to reflect calcium carbonate material inputs. LCI data for production of the average corrugated box, adapted from the Corrugated Packaging Alliance (CPA) were used to reflect the input of corrugated materials for packaging.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the open mold casting step, as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the open mold casting step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of open mold cast composites production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the open mold cast composites production process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the open mold casting process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the open mold casting process itself.

Energy Results

Cumulative energy consumption for production of open mold casted composites is shown by energy category and process step in Table 31 and Figure 33.

Table 31. Cradle-to-Gate Cumulative Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

	UPR Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.19	0.063	0.0031	0.56	**0.81**	**5.9%**
Coal	0.53	0.19	0.0082	1.47	**2.19**	**16%**
Natural Gas	4.09	0.78	0.015	1.29	**6.18**	**44%**
Petroleum	3.13	0.97	0.32	0.22	**4.64**	**33%**
Hydro	0.022	0.0073	3.6E-04	0.064	**0.094**	**<1%**
Recovered	-0.021	-0.0017	0	0	**-0.022**	**<1%**
Biomass	8.4E-04	1.7E-04	7.8E-06	0.0014	**0.0024**	**<1%**
Renewables	0.0024	7.7E-04	3.8E-05	0.0069	**0.010**	**<1%**
Peat	5.7E-10	9.7E-11	0	0	**6.7E-10**	**<1%**
TOTAL (1)	**7.95**	**2.01**	**0.34**	**3.61**	**13.9**	**100%**
PERCENT TOTAL (1)	**57%**	**14%**	**2.5%**	**26%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

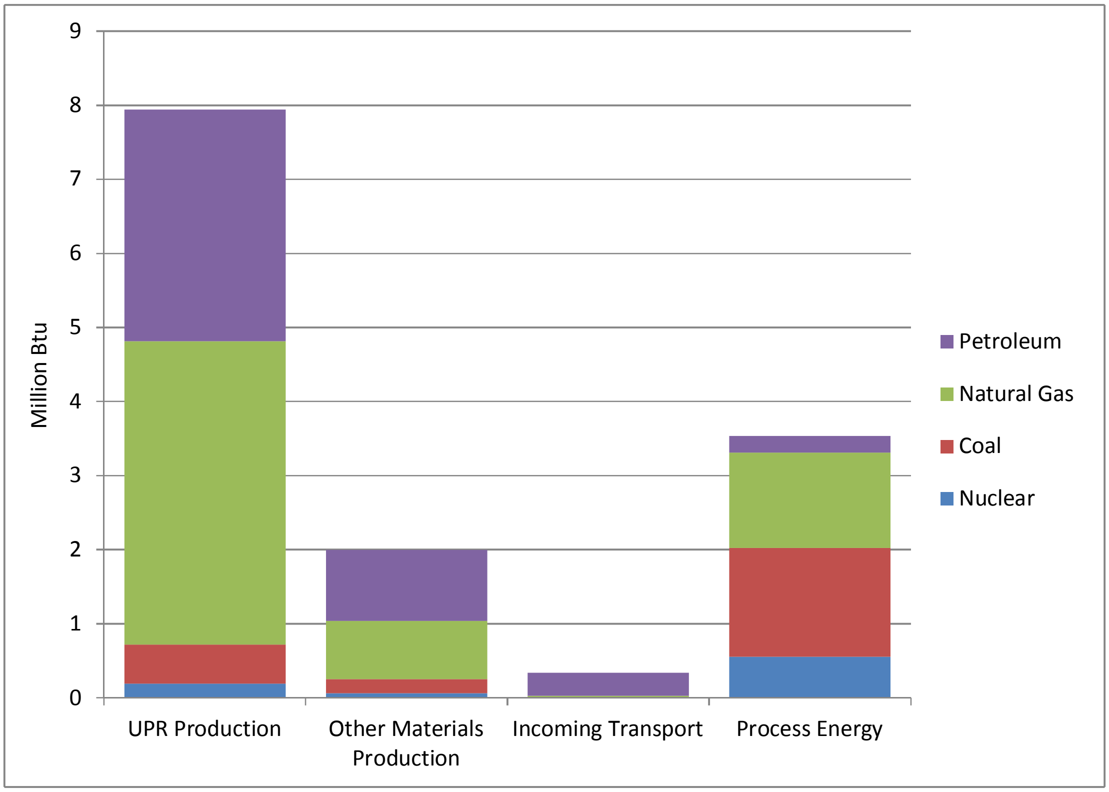

Figure 33. Cradle-to-Gate Cumulative Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

The cradle-to-gate results show that the largest amount of total energy consumption for open mold cast composites production is comes from UPR production, which is 57 percent of the total energy. The open mold casting process energy contributes 26 percent to total energy demand. Transport energy requirements are insignificant (2.5 percent of the total) relative to those for material production and process energy. The remaining 14 percent of the total energy is required to make the other materials. As shown in Table 32 and in Figure 34, electricity makes up three quarters of the total open mold casting process energy. Most of the remaining energy required is from natural gas. It varies by product whether natural gas is used to dry the coating placed on the mold.

Table 32. Unit Process Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

	Electricity Inputs	Natural Gas Fuel	LPG Fuel	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.55	0.0021	6.4E-04	**0.56**	**15%**
Coal	1.46	0.0055	0.0017	**1.47**	**41%**
Natural Gas	0.51	0.78	0.0031	**1.29**	**36%**
Petroleum	0.15	0.0028	0.065	**0.22**	**6.2%**
Hydro	0.064	2.4E-04	7.4E-05	**0.064**	**1.8%**
Renewables	0.0014	5.2E-06	1.6E-06	**0.0014**	**<1%**
TOTAL (1)	**2.74**	**0.79**	**0.070**	**3.60**	**100%**
PERCENT TOTAL (1)	**76%**	**22%**	**2.0%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

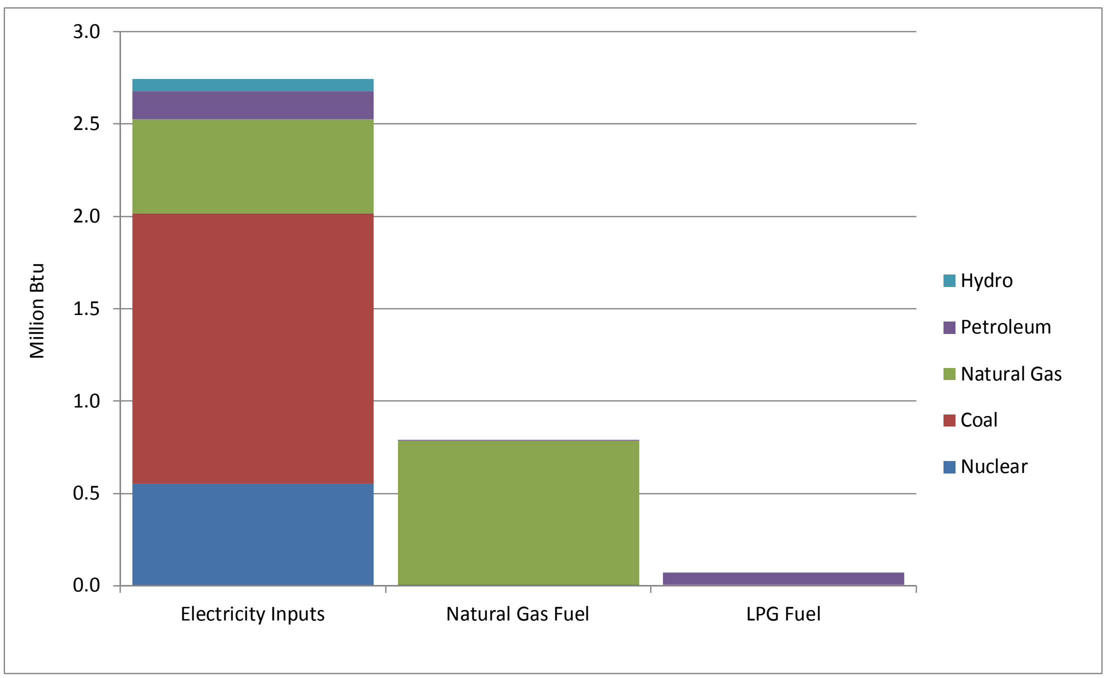

Figure 34. Unit Process Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

About a third of the energy demand for the cradle-to-gate production of open mold cast composite materials is energy of material resources. EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins or corrugated fiber. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 33 and Figure 35 show the relative amounts of cradle-to-gate EMR versus expended energy demand for open mold cast composites production.

Table 33. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

	UPR Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	4.37	1.34	0.34	3.61	**9.66**	**69%**
Natural Gas EMR	1.65	0.25	0	0	**1.89**	**14%**
Petroleum EMR	1.94	0.42	0	0	**2.36**	**17%**
Biomass EMR	2.6E-16	9.4E-17	0	0	**3.6E-16**	**<1%**
TOTAL (1)	**7.95**	**2.01**	**0.34**	**3.61**	13.9	**100%**
PERCENT TOTAL (1)	**57%**	**14%**	**2.5%**	**26%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

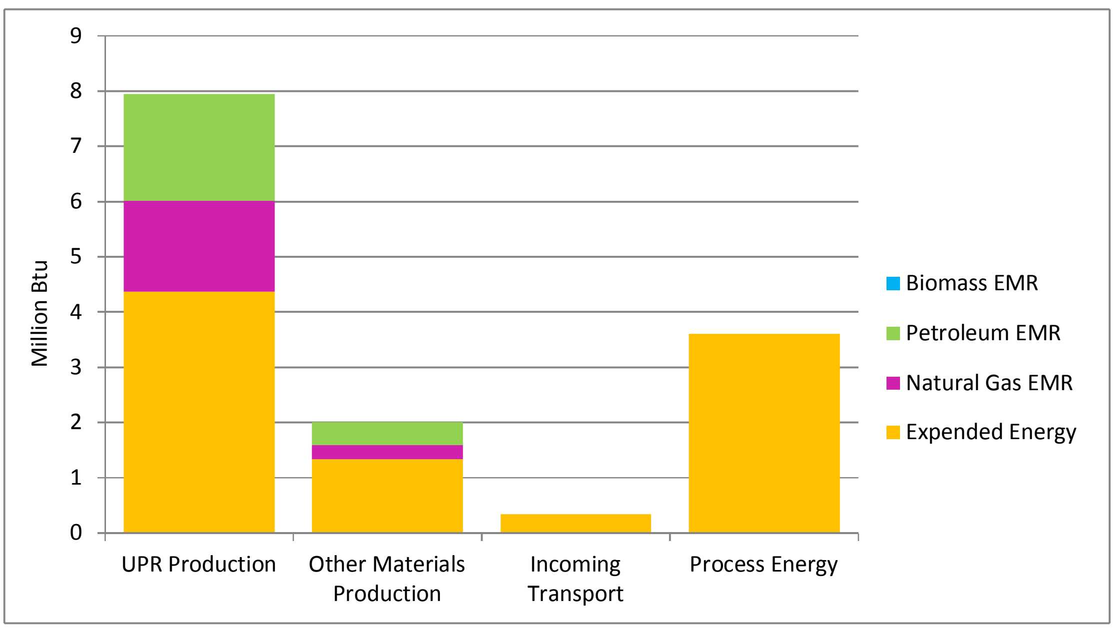

Figure 35. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Open Mold Cast Composites (Million Btu of energy per 1,000 pounds of Open Mold Cast Composites)

Water Use Results

Consumptive water use for cradle-to-gate production of open mold cast composites is shown by life cycle phase in Table 34 and Figure 36.

Table 34. Cradle-to-Gate Water Use for Production of Open Mold Cast Composites (Gallons of water per 1,000 pounds of Open Mold Cast Composites)

	UPR Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**
Per 1,000 lb Composite	319	104	12.5	447	**883**
% TOTAL (1)	**36%**	**12%**	**<1%**	**51%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

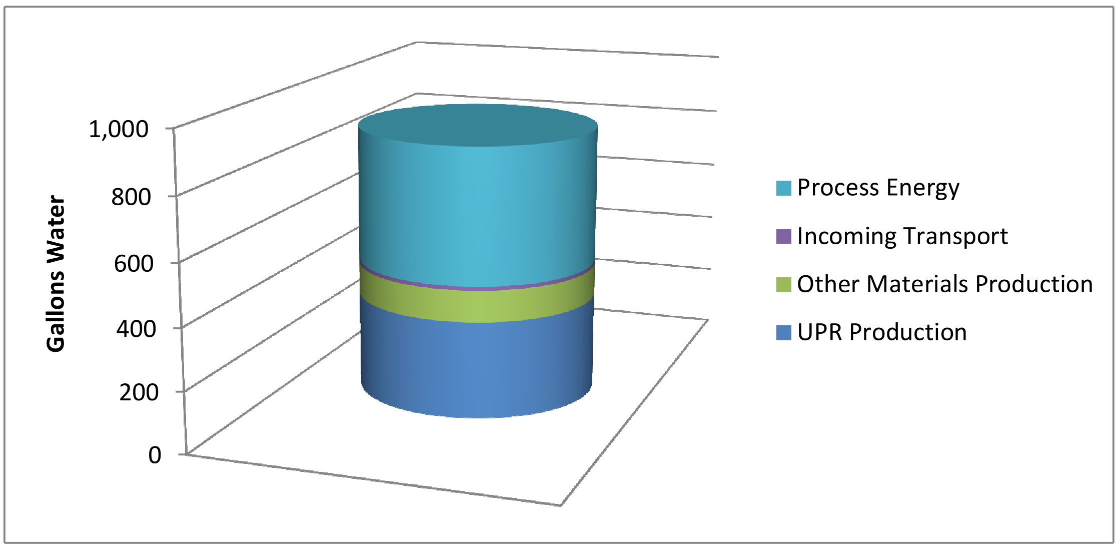

Figure 36. Cradle-to-Gate Water Use for Production of Open Mold Cast Composites (Gallons of water per 1,000 pounds of Open Mold Cast Composites)

The 'material production' results represent water consumption associated with the steps to extract and process the materials required for open mold cast composites production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. No 'process water', which reflects water consumed directly from the open mold casting process, is required. The cradle-to-gate results show that half of the total water demand is water consumed in production of energy, Water consumed during the production of the UPR also contributes significantly at a third of the total consumed water. No water consumed is consumed at the open mold casting facility itself. Less than 1 percent of the consumption occurs from the production of fuels required for transporting incoming materials to the open molding facility. The remaining water consumption comes from the production of other materials.

Solid Waste Results

Solid waste generation for cradle-to-gate production of open mold cast composites is shown by process step in Table 35 and Figure 37.

Table 35. Cradle-to-Gate Solid Waste Generation for Production of Open Mold Cast Composites (Pounds of solid waste per 1,000 pounds of Open Mold Cast Composites)

	UPR Production	Other Materials Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	6.08	27.1	0	0	43.0	**76.2**	**44%**
Incinerated	0.84	0.10	0	0	2.60	**3.54**	**2.0%**
Waste-to-Energy	0.44	0.025	0	0	0.030	**0.50**	**<1%**
Fuel-Related	23.2	10.7	0.85	58.4	0	**93.1**	**54%**
TOTAL (1)	**30.5**	**37.9**	**0.85**	**58.4**	**45.6**	**173**	**100%**
PERCENT TOTAL (1)	**18%**	**22%**	**<1%**	**34%**	**26%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

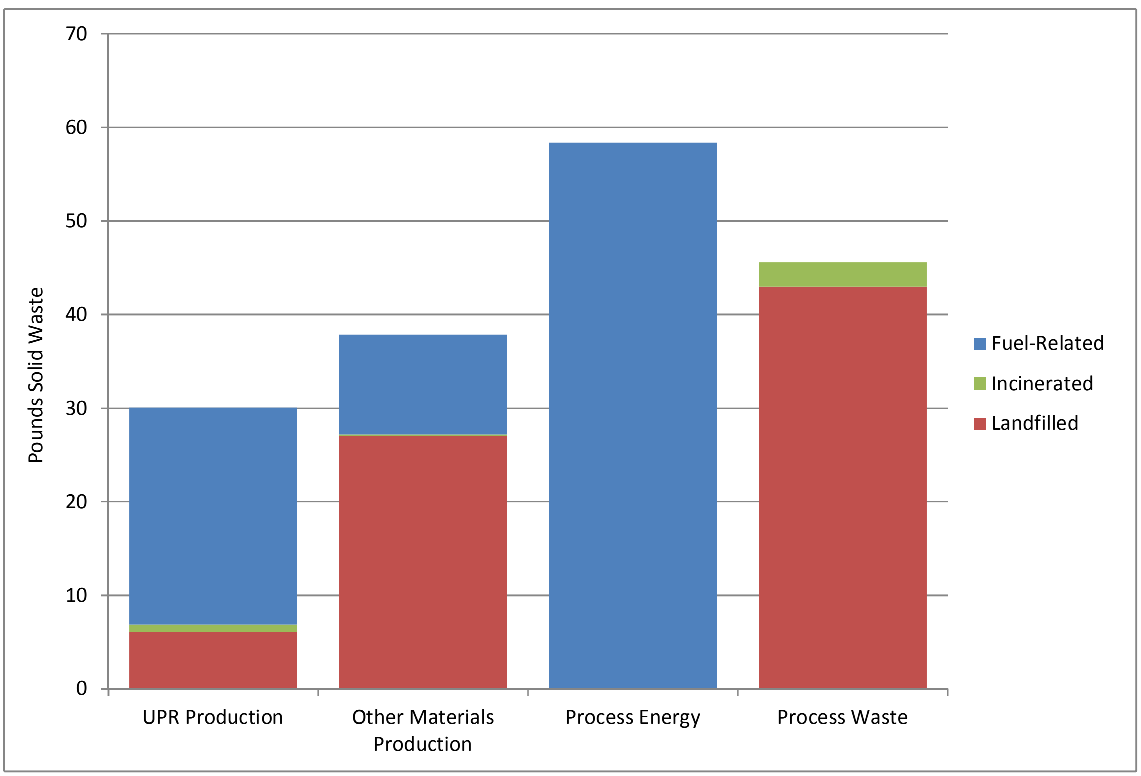

Figure 37. Cradle-to-Gate Solid Waste Generation for Production of Open Mold Cast Composites (Pounds of solid waste per 1,000 pounds of Open Mold Cast Composites)

The cradle-to-gate results for solid waste generation indicate that a third of solid waste generation comes from the production of fuels and electricity required to produce open mold cast composites. The solid waste from the casting process produces a fourth of the total solid waste. The solid waste amount within the processing facility varies depending on the type of product being produced, which affects the trim amount discarded. UPR production and the production of other materials required for open mold cast composites make up 18 and 22 percent of the total solid waste, respectively. Waste sold for recycling is considered a co-product of the open mold casting process. Therefore, though the amount of solid waste sold for recycling is shown in the unit process table, this amount is not included in the total solid waste generation results presented in this report. Also, due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the open mold cast composites) no postconsumer wastes are modeled. The disposition of the produced open mold cast composites depends on the product application, its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of open mold cast composites and include both process and fuel-related emission. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for the production of open mold cast composites include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the open mold casting facility, and from (4) the open mold cast composites facility. Non-fuel related air emissions at the open mold casting facility include styrene released and particulate matter from grinding. Atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and

298 for nitrous oxide.[14] GHG results for production of open mold cast composites are shown in Table 36 and Figure 38.

Table 36. Cradle-to-Gate GHGs for Production of Open Mold Cast Composites (Pounds CO2 equivalents per 1,000 pounds of Open Mold Cast Composites)

	UPR Production	Other Materials Production	Incoming Transport	Process Energy	TOTAL (1)	PERCENT TOTAL (1)
Fossil CO2	614	188	52.9	517	**1,371**	**89%**
Methane	86.3	41.5	2.53	36.3	**167**	**11%**
Nitrous Oxide	2.51	1.12	0.42	2.97	**7.02**	**<1%**
Others	0.75	0.99	0	0	**1.74**	**<1%**
TOTAL (1)	**703**	**232**	**55.8**	**556**	**1,547**	**100%**
PERCENT TOTAL (1)	**45%**	**15%**	**3.6%**	**36%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

[14] The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

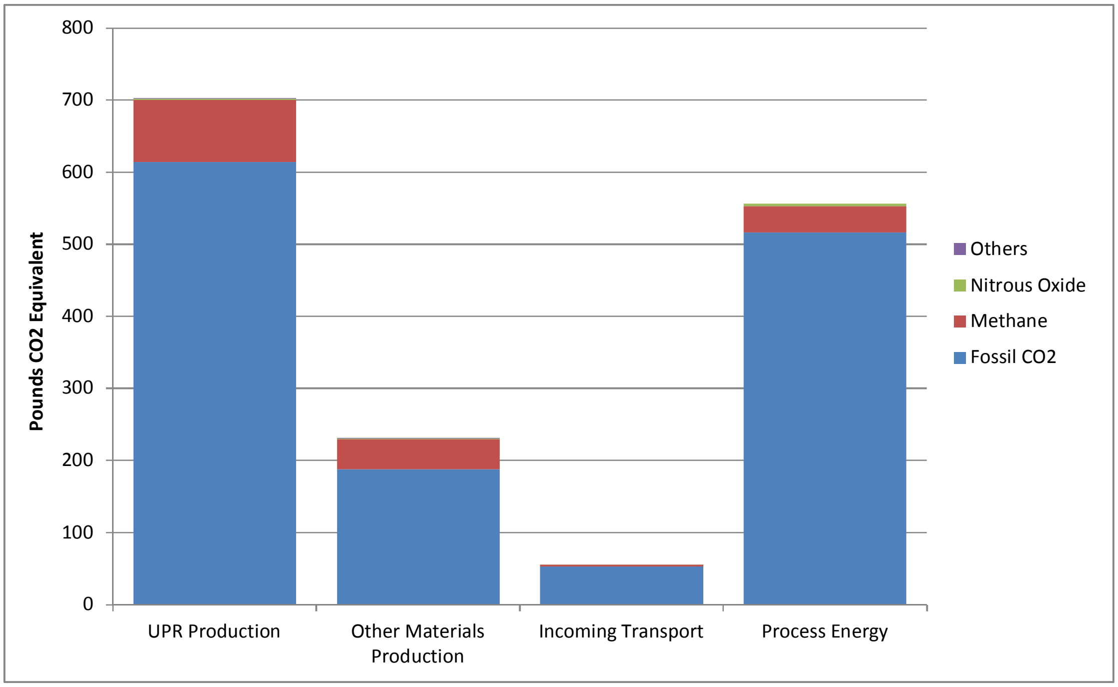

Figure 38. Cradle-to-Gate GHGs for Production of Open Mold Cast Composites (Pounds CO2 equivalents per 1,000 pounds of Open Mold Cast Composites)

As can often be the case for LCI results of product systems, the life cycle phases contributing most significantly to energy demand also contribute most significantly to GHG emissions. The results for GHG emissions for cradle-to-gate open mold cast composites production demonstrate this correlation. The production of the UPR materials requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. UPR production releases 45 percent of the total GWP. The production of electricity and production and combustion of fuels used at the open mold casting facility produces more than a third of the total GHG emissions. No process GHG emissions were reported for the open mold casting process itself. GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute less than five percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributor (89 percent) to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution (11 percent). Nitrous oxide and several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate open mold cast composites production LCI are included in Appendix A.

CHAPTER 7. VACUUM INFUSION

INTRODUCTION

This chapter describes the production of composites from the vacuum infusion process, presents the compiled gate-to-gate unit process LCI data for production of vacuum infused composites, and presents LCI results for cradle-to-gate production of 1,000 pounds of vacuum infused composites in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Production of Vacuum Infused Composites

Vacuum infusion is a process commonly used to manufacture large parts such as boat hulls, bus bodies, or railcar panels. This process is also called resin infusion. A wide variety of fiber and resin combinations can be used to infuse laminates. These typically include: UPR, E-Glass, continuous strand mat, gel coats, limestone, styrene monomer, as well as wood or foam cores and the vacuum bag itself. The properties of the composite depend on the types and proportions of resins, fillers, and additives incorporated. This process produces composites with low void content and excellent mechanical properties due to the high glass fiber content.

The mold used for this process is first prepared using wax, a buffing compound and mold release. A gel coat is then applied to the mold. Reinforcements are then prepared and loaded into the mold. The vacuum is then applied to compact the reinforcements and then eliminate the air in the bag. The resin is then infused into the mold and reinforcements, which eliminates all air voids within the composite material. Other additives such as pigments and fire retardants may be added and depend on the application and characteristics desired for the final product. The final vacuum infused composites part is shipped to users.

Figure 39 displays a summary of the material inputs used to manufacture vacuum infused composites. Further information on the data sources of these material inputs are shown in Appendix B.

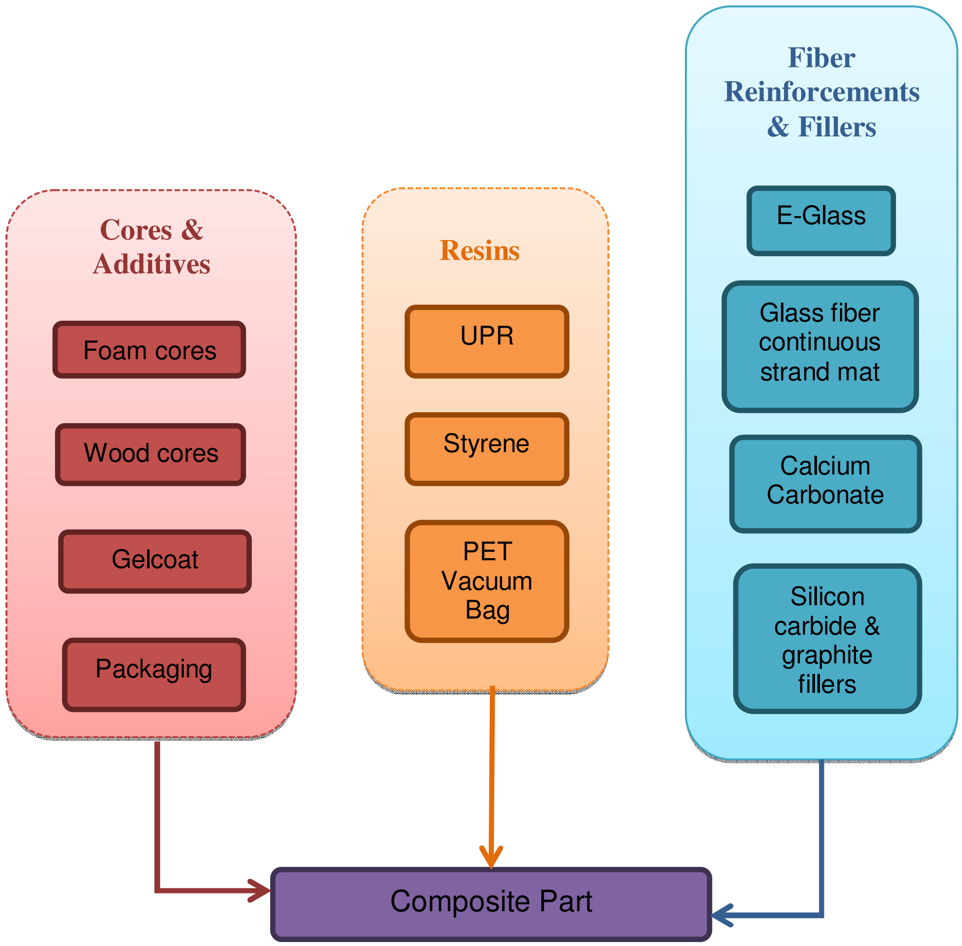

Figure 39. Summary of Material Inputs to Vacuum Infused Composite Products

Table 37 presents the complete LCI unit process data for the average industrial production of 1,000 pounds of vacuum infused composites in 2010 in the US. In terms of process energy consumption, the average vacuum infusion facility meets about two-thirds of its process energy demand with electricity. Natural gas combustion makes up a little less than a third of the total process energy, with LPG combustion used in smaller amounts to make up the remaining 2 percent of the energy.

An average of 27 pounds of solid waste is generated for every 1,000 pounds of vacuum infused composites produced: 48 percent of those solid wastes are landfilled, 4 percent are incinerated, 10 percent are incinerated with energy recovery, and almost 38 percent are sold for recycling. The solid wastes include trimmings, packaging waste, solvents, and various other process wastes. The trimmings end-of life varied between landfilling and recycling depending on the processer. The amount of water consumed for the vacuum infusion facilities were stated as zero or unavailable.

Table 37. LCI Unit Process Data for Production of Vacuum Infused Composites

	English units (Basis: 1,000 lb)			SI units (Basis: 1,000 kg)		
Outputs to Technosphere						
Vacuum infusion composite part	1,000	lb		1,000	kg	
Materials sold for recycling	10.00	lb	*	10.00	kg	*
Inputs from Technosphere (to Product)						
Core materials, wood & foam	460	lb		460	kg	
Fiberglass, continuous strand mat	250	lb		250	kg	
E-Glass	7.00	lb		7.00	kg	
Styrene	2.70	lb		2.70	kg	
Gelcoat, UPR-styrene-based	41.0	lb		41.0	kg	
Limestone	2.80	lb		2.80	kg	
PET vacuum bag	16.0	lb		16.0	kg	
Synthetic filler	2.90	lb		2.90	kg	
UPR	210	lb		210	kg	
Process Water Consumption	0	gal		0	liter	
Energy Usage						
Process Energy						
Electricity (grid)	129	kwh		284	kwh	
Natural gas	575	cu ft		35.9	cu meters	
LPG	0.42	gal		3.50	liter	
Incoming Materials Transportation Energy						
Combination truck	331	ton-miles		1,065	tonne-km	
Diesel	3.48	gal		29.0	liter	
Environmental Emissions						
Atmospheric Emissions						
Particulates, > 2.5 um, and < 10um	0.026	lb		0.026	kg	
Styrene	5.40	lb		5.40	kg	
VOCs, unspecified	2.70	lb		2.70	kg	
Solid Wastes						
Landfilled	13.0	lb		13.0	kg	
Burned	1.00	lb		1.00	kg	
Waste-to-Energy	2.70	lb		2.70	kg	

* This parameter was reported by fewer than three companies. To indicate known values while protecting the confidentiality of individual company responses, the parameter is reported only by order of magnitude.

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for Vacuum Infused Composites

For vacuum infused composites production, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs, a) UPR , b) E-Glass, and c) other materials, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For average vacuum infused composites production, material inputs include: E-Glass, continuous strand mat fiberglass, calcium carbonate, UPR, styrene, gel-coat (UPR styrene based), synthetic filler, EPS foam, plywood/lumber, and PET vacuum bag.
    a. UPR: LCI data for the production of the UPR materials are taken from the ACMA averages presented in Chapter 2.
    b. E-Glass: LCI data for the production of the E-Glass materials are taken from the ACMA averages present in Chapter 3. Also included here is the continuous strand mat. No data was available for this material; however, as this is produced in the same fashion as E-Glass, the average E-Glass data has been substituted for continuous strand mat. It should be noted that due to added material (e.g. the mat) and energy for drying that is not taken into account in this analysis, the total energy and emissions for continuous strand mat may be understated somewhat.
    c. Other Materials: The composition of the synthetic filler used to model the LCI results are based on averages of formulations for each material provided by the ACMA member companies. This synthetic filler additive represents a 50/50 silicon carbide and graphite for generic 'synthetic fillers' additives. Energy consumption and transportation in production of these materials are based on average requirements for organic chemicals per the Franklin Associates Private LCI Database. LCI data for limestone mining from the US LCI Database were used to reflect calcium carbonate material inputs. LCI data for production of styrene, EPS foam and PET are taken from the ACC resin data revised in 2011.The gel coat was based on the UPR data in Chapter 2 per information provided by the processors. The plywood data are taken from the US LCI Database.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the vacuum infusion step, as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the vacuum infusion step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of vacuum infused composites production (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the vacuum infusion composites production process itself, which is zero in this process.

5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the vacuum infusion process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the vacuum infusion process itself.

Energy Results

Cumulative energy consumption for production of vacuum infused composites is shown by energy category and process step in Table 38 and Figure 40.

Table 38. Cradle-to-Gate Cumulative Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.17	0.36	0.33	0.0057	0.28	**1.15**	**5.0%**
Coal	0.48	0.98	0.78	0.015	0.74	**2.99**	**13%**
Natural Gas	3.74	1.61	5.51	0.028	0.89	**11.8**	**51%**
Petroleum	2.86	0.18	3.14	0.58	0.12	**6.88**	**30%**
Hydro	0.020	0.042	0.030	6.6E-04	0.032	**0.13**	**<1%**
Recovered	-0.019	-1.7E-07	-0.0044	0	0	**-0.023**	**<1%**
Biomass	7.7E-04	9.6E-04	0.0053	1.4E-05	7.0E-04	**0.0077**	**<1%**
Renewables	0.0022	0.0044	0.0026	7.0E-05	0.0034	**0.013**	**<1%**
TOTAL (1)	**7.26**	**3.19**	**9.80**	**0.63**	**2.06**	**22.9**	**100%**
PERCENT TOTAL (1)	**32%**	**14%**	**43%**	**2.7%**	**9.0%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

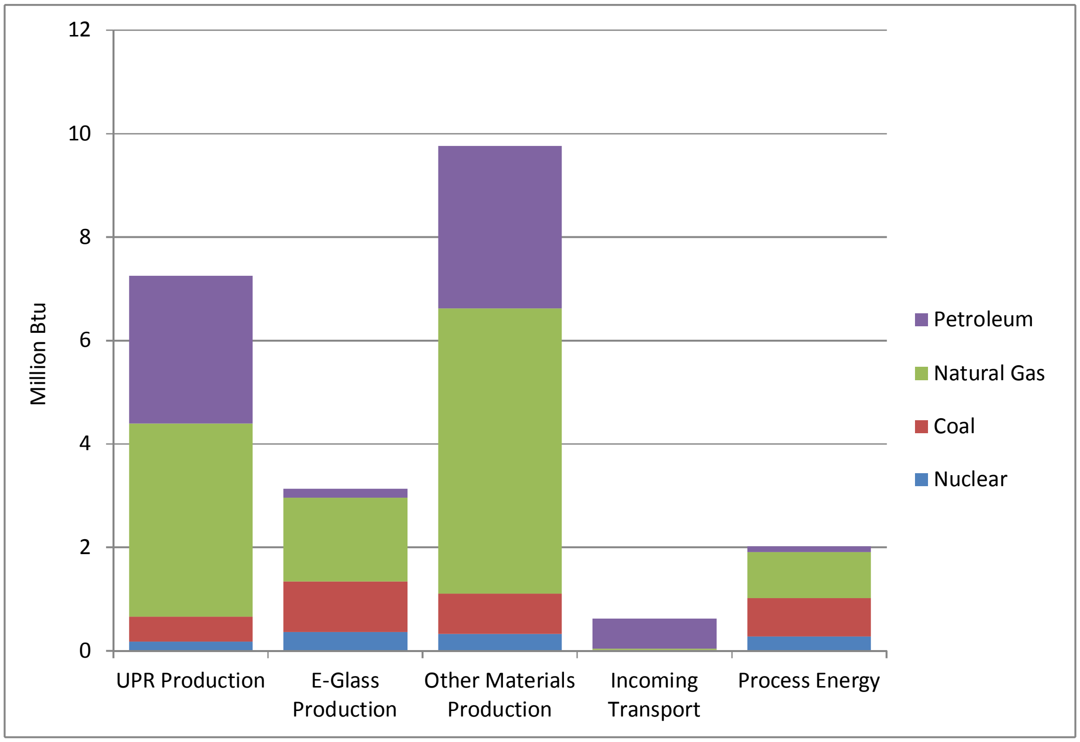

Figure 40. Cradle-to-Gate Cumulative Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

The cradle-to-gate results show that the bulk of total energy consumption for vacuum infused composites production is required by the input materials production. Of the input materials, energy demand for the other material inputs requires 43 percent of the total energy, while UPR production requires 32 percent of that total. Transport energy requirements are insignificant (<3 percent) relative to those for material production and process energy. The vacuum infusion process energy requires only 9 percent of the total energy demand. As shown in Table 39 and in Figure 41, within the vacuum infusion process facility, 67 percent of energy requirements for the gate-to-gate manufacturing step (i.e., process energy) are from electricity, with approximately one-third of the remaining energy being supplied by natural gas combustion, and only a small (2 percent) amount of LPG fuel combusted.

Table 39. Unit Process Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

	Electricity Inputs	Natural Gas Fuel	LPG Fuel	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.28	0.0017	3.9E-04	**0.28**	**14%**
Coal	0.73	0.0045	0.0010	**0.74**	**36%**
Natural Gas	0.25	0.64	0.0019	**0.89**	**43%**
Petroleum	0.077	0.0023	0.040	**0.12**	**5.8%**
Hydro	0.032	2.0E-04	4.5E-05	**0.032**	**1.6%**
Renewables	6.9E-04	4.3E-06	9.8E-07	**7.0E-04**	**<1%**
TOTAL (1)	**1.37**	**0.64**	**0.043**	**2.06**	**100%**
PERCENT TOTAL (1)	**67%**	**31%**	**2.1%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

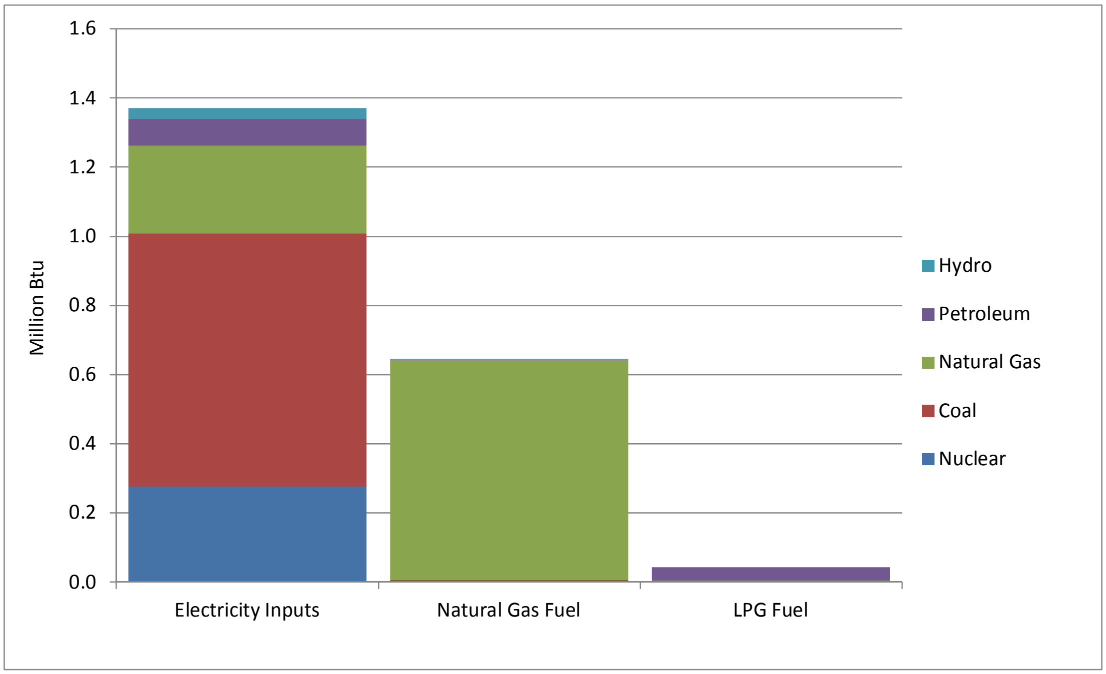

Figure 41. Unit Process Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

About a tenth of the energy demand for production of vacuum infused composite materials is from energy of material resource (EMR). EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins or corrugated fiber. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 40 and Figure 42 show the relative amounts of cradle-to-gate EMR versus expended energy demand for vacuum infused composites production. The resin amounts used in the vacuum infusion process are smaller than in other processes, which means less EMR is stored within these composites. Most of the EMR shown comes from UPR resin and the PET bag used.

Table 40. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	3.99	3.19	7.47	0.63	2.06	**13.3**	**58%**
Natural Gas EMR	1.50	0.0011	1.31	0	0	**1.31**	**6%**
Petroleum EMR	1.77	4.4E-05	1.01	0	0	**1.01**	**4%**
Biomass EMR	2.4E-16	2.2E-14	3.0E-13	0	0	**3.3E-13**	**<1%**
TOTAL (1)	**7.26**	**3.19**	**9.80**	**0.63**	**2.06**	**22.9**	**100%**
PERCENT TOTAL (1)	**32%**	**14%**	**43%**	**2.7%**	**9.0%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

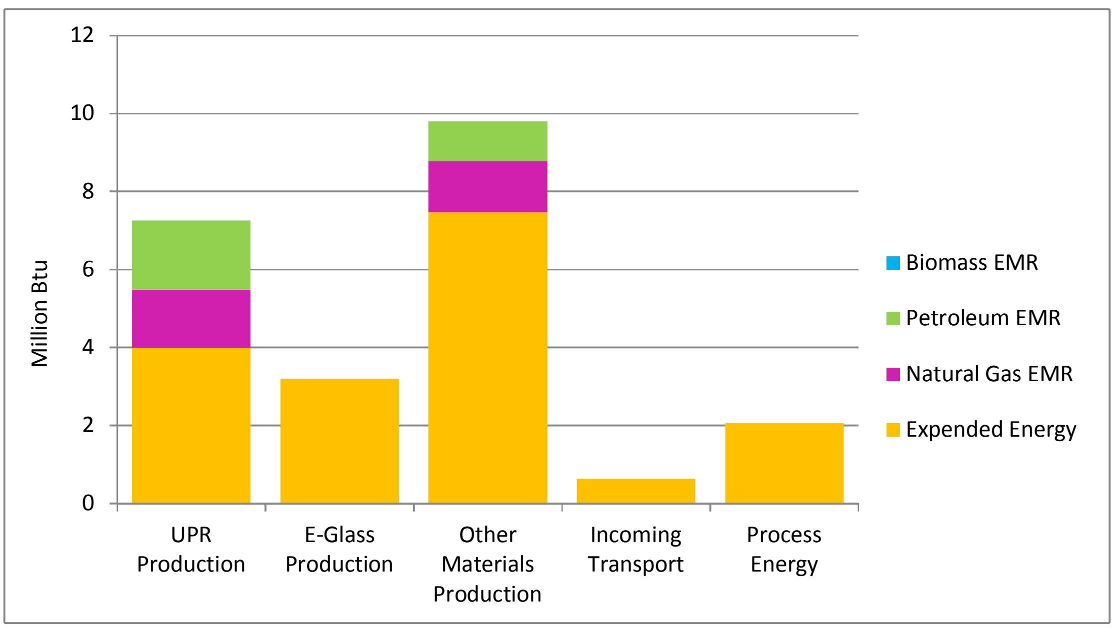

Figure 42. EMR vs. Expended Cradle-to-Gate Energy Demand for Production of Vacuum Infused Composites (Million Btu of energy per 1,000 pounds of Vacuum Infused Composites)

Water Use Results

Consumptive water use for cradle-to-gate production of vacuum infused composites is shown by life cycle phase in Table 41 and Figure 43.

Table 41. Cradle-to-Gate Water Use for Production of Vacuum Infused Composites (Gallons of water per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**
Per 1,000 lb Composite	291	510	380	22.9	227	**1,431**
% TOTAL (1)	**20%**	**36%**	**27%**	**1.6%**	**16%**	**1.00**

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

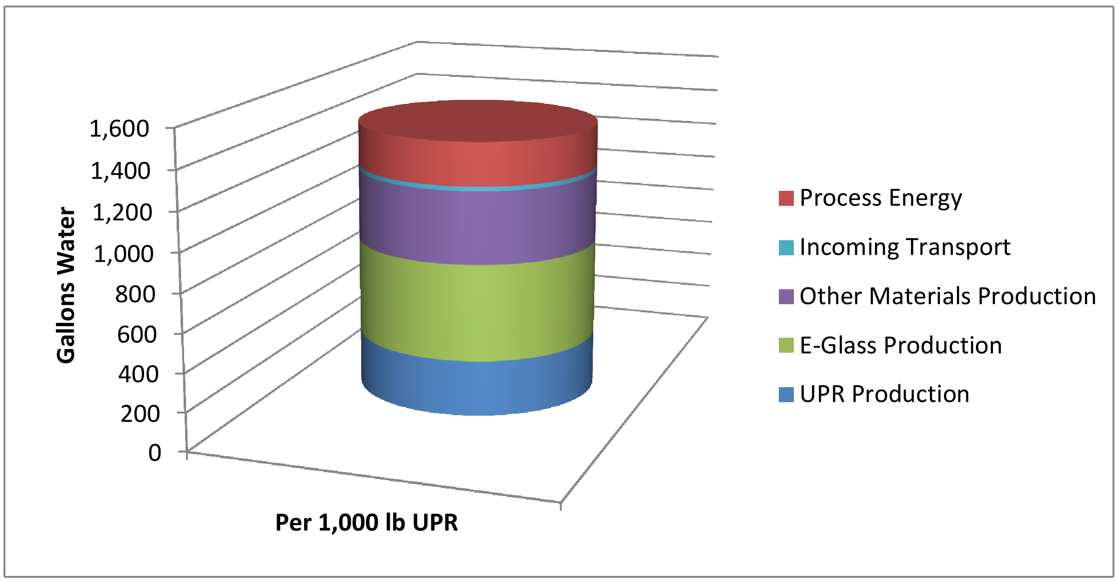

Figure 43. Cradle-to-Gate Water Use for Production of Vacuum Infused Composites (Gallons of water per 1,000 pounds of Vacuum Infused Composites)

The 'material production' results represents water consumption associated with the steps to extract and process the materials required for vacuum infused composites production. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from the vacuum infusion process. The cradle-to-gate results show that much of the total water demand is water consumed in production of the input materials used in the vacuum infusion process, with E-Glass production consuming the most water at 36 percent of the total. Water consumed during the production of the fuels and electricity used in the vacuum infusion process makes up 16 percent of the total water consumption. No water is consumed at the vacuum infusion facility itself. The remaining consumption (less than 2 percent) occurs from the production of fuels required for transporting incoming materials to the vacuum infusion facility.

Solid Waste Results

Solid waste generation for cradle-to-gate production of vacuum infused composites is shown by process step in Table 42 and Figure 44.

Table 42. Cradle-to-Gate Solid Waste Generation for Production of Vacuum Infused Composites (Pounds of solid waste per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	5.55	107	7.32	0	0	13.0	**133**	**50%**
Incinerated	0.76	0.011	1.94	0	0	1.00	**3.72**	**1.4%**
Waste-to-Energy	0.40	3.3E-06	2.33	0	0	2.70	**5.43**	**2.0%**
Fuel-Related	21.2	39.7	32.3	1.55	29.5	0	**124**	**47%**
TOTAL (1)	**27.9**	**146**	**43.8**	**1.55**	**29.5**	**16.7**	**266**	**100%**
PERCENT TOTAL (1)	**10%**	**55%**	**16%**	**<1%**	**11%**	**6.3%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

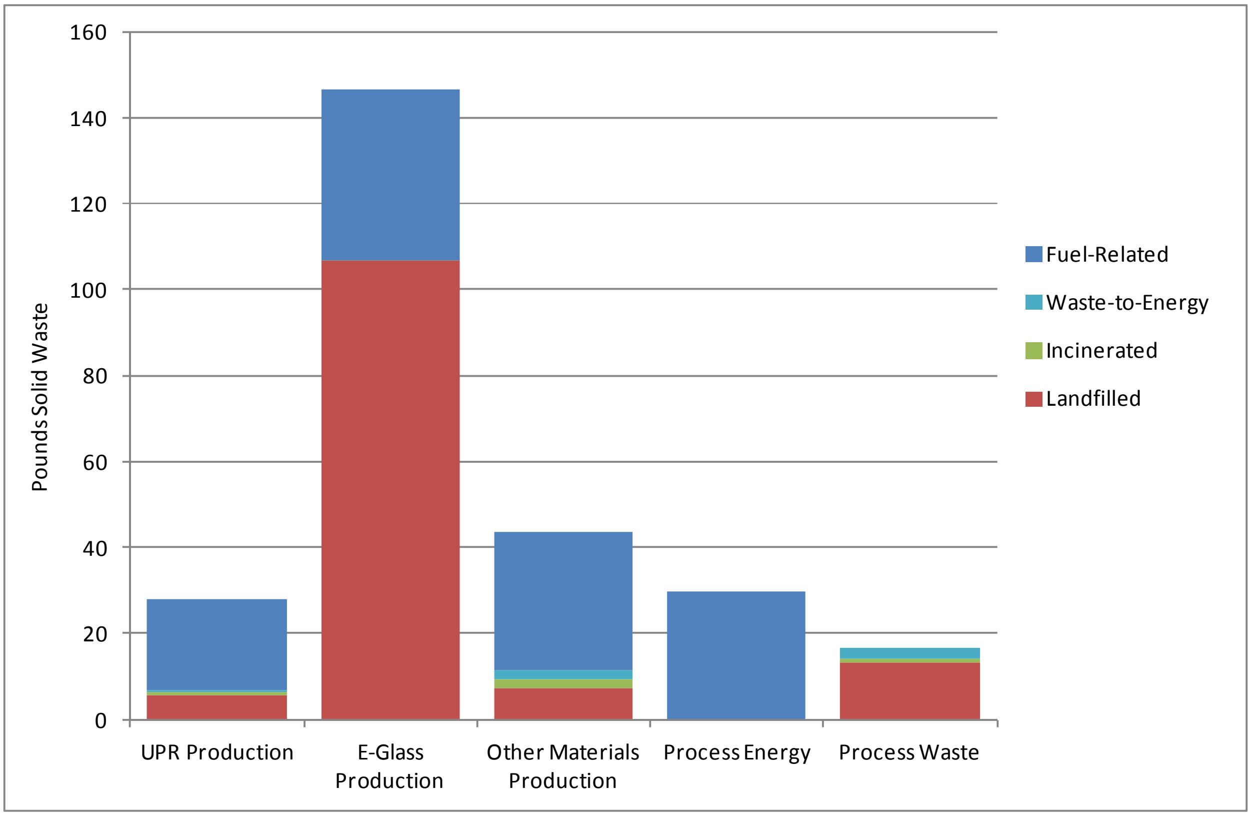

Figure 44. Cradle-to-Gate Solid Waste Generation for Production of Vacuum Infused Composites (Pounds of solid waste per 1,000 pounds of Vacuum Infused Composites)

The cradle-to-gate results for solid waste generation indicate that the bulk of generation, 55 percent, comes from the production of the E-Glass production. Other materials production generates 16 percent of the total solid wastes. The production of fuels and electricity required for vacuum infused composites production and UPR production each produce about 10 percent of the total solid waste. Solid waste generated during the vacuum infusion process is relatively small at 6 percent of the cradle-to-gate total. Waste sold for recycling is considered a co-product of the vacuum infusion process. Therefore, though the amount of solid waste sold for recycling is shown in the unit process table, this amount is not included in the total solid waste generation results presented in this report. Also, due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the vacuum infused composites) no postconsumer wastes are modeled. The disposition of the produced vacuum infused composites depends on the product application, its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate production of vacuum infused composites and include both process and fuel-related emission. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for each production of vacuum infused composites include emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the vacuum infusion facility, and from (4) the vacuum infused composites facility. Non-fuel related air emissions at the vacuum infusion facility include styrene, volatilized hydrocarbons, and particulate matter. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and 298 for nitrous oxide.[15] GHG results for production of vacuum infused composites are shown in Table 43 and Figure 45.

Table 43. Cradle-to-Gate GHGs for Production of Vacuum Infused Composites (Pounds CO2 equivalents per 1,000 pounds of Vacuum Infused Composites)

	UPR Production	E-Glass Production	Other Materials Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Fossil CO2	560	543	824	96.6	290	**2,313**	**88%**
Methane	78.8	36.4	155	4.62	22.0	**296**	**11%**
Nitrous Oxide	2.29	2.31	3.35	0.77	1.52	**10.2**	**<1%**
Others	0.69	6.35	2.03	0	0	**9.06**	**<1%**
TOTAL (1)	**642**	**588**	**984**	**102**	**313**	**2,629**	**100%**
PERCENT TOTAL (1)	**24%**	**22%**	**37%**	**3.9%**	**12%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

15 The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

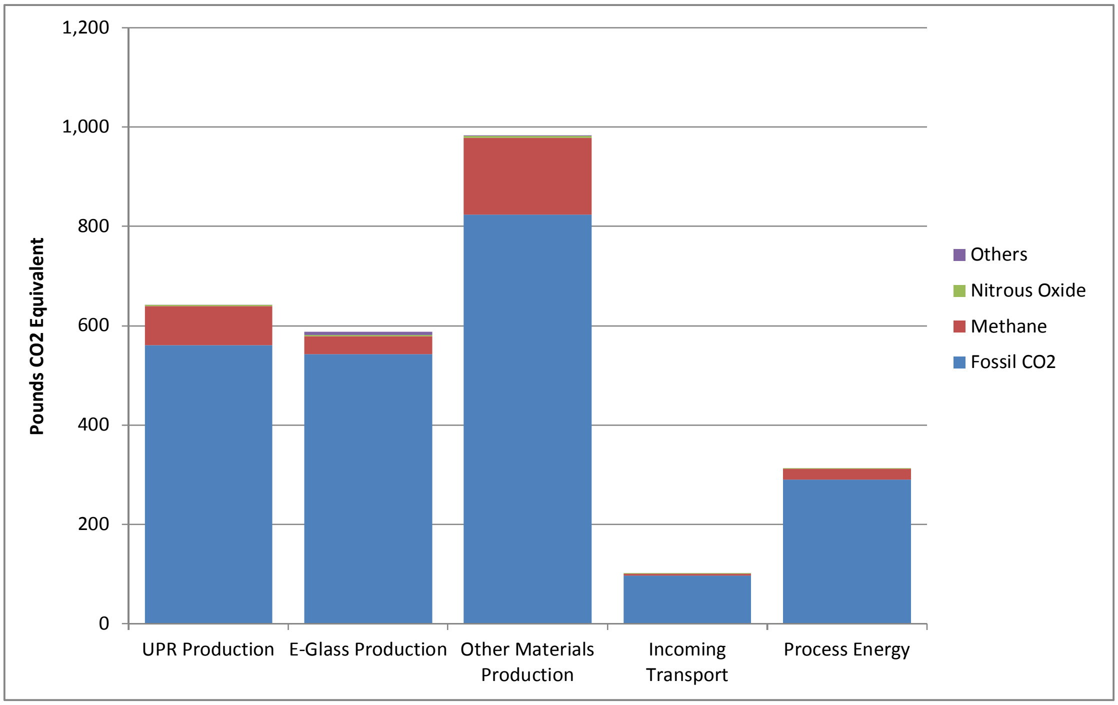

Figure 45. Cradle-to-Gate GHGs for Production of Vacuum Infused Composites (Pounds CO2 equivalents per 1,000 pounds of Vacuum Infused Composites)

As can often be the case for LCI results of product systems, the life cycle phases contributing most significantly to energy demand also contribute most significantly to GHG emissions. The results for GHG emissions for cradle-to-gate vacuum infused composites production demonstrate this correlation. The production of the other material inputs, which release 37 percent of the total GWP, requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. The production of UPR used at the vacuum infusion facility also figure significantly in total GHG emissions using 24 percent. The E-Glass production does not fit this same correlation, but releases almost as much greenhouse gases as the UPR production. This is due to the release of carbon dioxide during the burning of certain minerals used to produce E-Glass. The production of fuels and electricity used within the vacuum infusion process release 12 percent of the GWP amount. No GHG emissions are reported for the vacuum infusion process itself. Likewise, GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute less than five percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributors to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution. Nitrous oxide emissions and several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for cradle-to-gate vacuum infused composites production LCI are included in Appendix A.

CHAPTER 8. SECONDARY BONDING

INTRODUCTION

This chapter describes the secondary bonding process, presents the compiled gate-to-gate unit process LCI data for production of composites that have been joined by secondary bonding, and presents LCI results for cradle-to-gate application of 1,000 pounds of secondary bonding material in terms of cumulative energy requirements, water consumption, solid wastes, and greenhouse gases.

Gate-to-Gate LCI Data for Secondary Bonding

Secondary bonding is a processing commonly used to adhere an RFP laminate to a materials without an air-inhibited surface. A number of different adhesives can be used in this process; however, for the purpose of this analysis, only a polyurethane (PUR) based adhesive is used. Secondary bonding should not be confused with secondary lamination, which is a different process, as it uses more bond material and can be much more energy intensive.

The surface to be bonded is prepared by grinding and sanding the surface so that it is in a clean and roughened state. Any build up of glass fiber or resin sanded off should be removed from the surface as it can prevent proper secondary bonding. The surface is kept clean and dry until the lamination which should be performed within a couple of hours of the preparation. The surface is wiped with a solvent immediately before the bonding adhesive is applied. An adhesive dispenser is then used to apply the bonding adhesive to the surface. Once this adhesive is applied, the second surface to be adhered is placed on the adhesive. Weights are placed on the adhered product and the adhesive is given time to cure. Once the adhesive is set, excess adhesive is trimmed away from the product.

Figure 46 displays a summary of the material inputs used to manufacture secondary bonding composites. Further information on the data sources of these material inputs are shown in Appendix B.

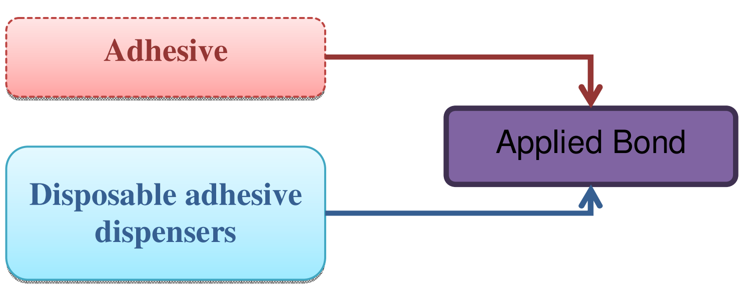

Figure 46. Summary of Material Inputs to the Secondary Bonding Process

Table 44 presents the complete LCI unit process data for the average industrial application of 1,000 pounds of secondary bonding composites in 2010 in the US. In terms of process energy consumption, the secondary bonding application meets more than 95 percent of its process energy demand with electricity. Natural gas combustion makes up a little less than 5 percent of the total process energy, which is stated as space conditioning in a number of the plants.

An average of 83 pounds of solid waste is generated for every 1,000 pounds of applied secondary bonds produced; 100 percent of those solid wastes are landfilled. The solid wastes include trimmings, waste bond, and various other process wastes. The amount of water consumed for the vacuum infusion facilities were stated as zero. Hydrotesting may be performed on final products, but this is commonly less than 1 percent of the total amount of products including a secondary bond.

Table 44. LCI Unit Process Data for Application of a Secondary Bond

	English units (Basis: 1,000 lb)			SI units (Basis: 1,000 kg)		
Outputs to Technosphere						
Secondary bonding, bond adhesive applied	1,000	lb		1,000	kg	
Inputs from Technosphere (to Product)						
Adhesive, PUR-based	1,000	lb		1,000	kg	
Disposable adhesive tube dispensers	10.0	lb	*	10.0	kg	*
Energy Usage						
Process Energy						
Electricity (grid)	41.2	kwh		90.8	kwh	
Natural gas	17.4	cu ft		1.09	cu meters	
Incoming Materials Transportation Energy						
Combination truck	331	ton-miles		1,065	tonne-km	
Diesel	3.48	gal		29.0	liter	
Environmental Emissions						
Atmospheric Emissions						
VOCs, unspecified	31.0	lb		31.0	kg	
Solid Wastes						
Landfilled	83.0	lb		83.0	kg	

* This parameter was reported by fewer than three companies. To indicate known values while protecting the confidentiality of individual company responses, the parameter is reported only by order of magnitude.

Source: Franklin Associates, A Division of ERG

Cradle-to-Gate LCI Results for Application of a Secondary Bond

For secondary bonding, the cradle-to-gate LCI results tables and figures break out results by: (1) material inputs, (2) incoming transport, (3) process energy, (4) process water, (5) process emissions, and (6) process waste. If a category is not displayed in the table, values for that category are not applicable (e.g., no energy consumption in process emissions) and/or zero. If a category is not displayed in the figure, values for that category are not applicable, zero, or less than one percent of the total.

1. **Material Inputs:** For the average secondary bonding process, material inputs include: polyurethane based adhesive and disposable adhesive tube dispensers. LCI data for the production of the PUR materials are taken from the PFL Database. Dispensing tubes are assumed to include both PVC and PET resins. LCI data for production of PVC and PET are taken from the ACC resin data revised in 2011.
2. **Incoming Transport:** Transportation requirements include the production and combustion of fuels used to deliver incoming materials to the secondary bonding step, as provided by the ACMA member companies. The production and combustion of fuels used for transportation were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
3. **Process Energy:** Process energy is the energy used to extract, refine, and deliver electricity and/or fuels for combustion required at the secondary bonding step. The production and combustion of fuels used for energy and generation of U.S. grid electricity were modeled using LCI data sets developed by Franklin for the U.S. LCI Database.
4. **Process Water:** While water consumption is inventoried at each step along the cradle-to-gate life cycle of secondary bonding (i.e., during production of input materials and energy used for transport or in the process), the process water refers specifically to water consumed in the secondary bonding process itself.
5. **Process Emissions:** As with the inventorying of water consumption, emissions are modeled along the life cycle but process emissions refer to non-fuel related emissions resulting from the secondary bonding process itself.
6. **Process Waste:** As with water and emissions inventorying, process waste refers not to cumulative solid waste generated along the cradle-to-gate life cycle but to the solid waste generated during the secondary bonding process itself.

Energy Results

Cumulative energy consumption for the application of a secondary bond is shown by energy category and process step in Table 45 and Figure 47.

Table 45. Cradle-to-Gate Cumulative Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

	Adhesive Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	1.31	5.8E-04	0.090	**1.40**	**3.8%**
Coal	4.14	0.0015	0.24	**4.38**	**12%**
Natural Gas	22.4	0.0029	0.10	**22.5**	**61%**
Petroleum	8.73	0.059	0.025	**8.81**	**24%**
Hydro	0.15	6.7E-05	0.010	**0.16**	**<1%**
Recovered	-0.44	0	0	**-0.44**	**<1%**
Biomass	0.011	1.5E-06	2.3E-04	**0.011**	**<1%**
Renewables	0.016	7.2E-06	0.0011	**0.017**	**<1%**
TOTAL (1)	**36.3**	**0.065**	**0.47**	**36.9**	**100%**
PERCENT TOTAL (1)	**99%**	**<1%**	**1.3%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

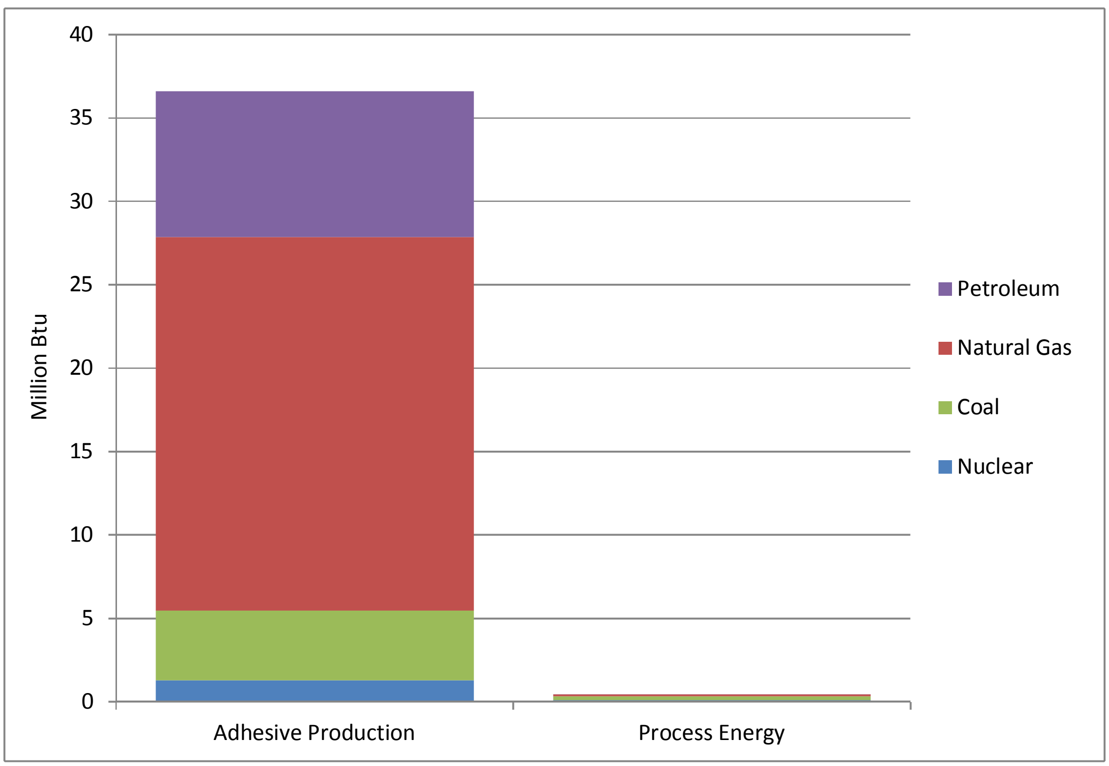

Figure 47. Cradle-to-Gate Cumulative Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

The cradle-to-gate results show that almost 99 percent of total energy consumption for applying a secondary bond is due to the manufacture of the PUR adhesive. Transport energy requirements are insignificant (<1 percent) relative to those for adhesive production. Process energy for the secondary bonding process requires only 1 percent of the cradle-to-gate total energy demand. As shown in Table 46 and in Figure 48, within the secondary bonding process, more than 95 percent of the energy requirements for the gate-to-gate process are from electricity. Less than 5 percent of the remaining energy is being supplied by natural gas combustion. Some plants state that this is actually space conditioning allocated to the bonding process.

Table 46. Unit Process Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

	Electricity Inputs	Natural Gas Fuel	**TOTAL (1)**	**PERCENT TOTAL (1)**
Nuclear	0.090	5.2E-05	**0.090**	**19%**
Coal	0.24	1.4E-04	**0.24**	**51%**
Natural Gas	0.082	0.019	**0.10**	**22%**
Petroleum	0.025	7.0E-05	**0.025**	**5.4%**
Hydro	0.010	6.0E-06	**0.010**	**2.2%**
Renewables	2.3E-04	1.3E-07	**2.3E-04**	**<1%**
TOTAL (1)	**0.45**	**0.020**	**0.47**	**100%**
PERCENT TOTAL (1)	**96%**	**4.2%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

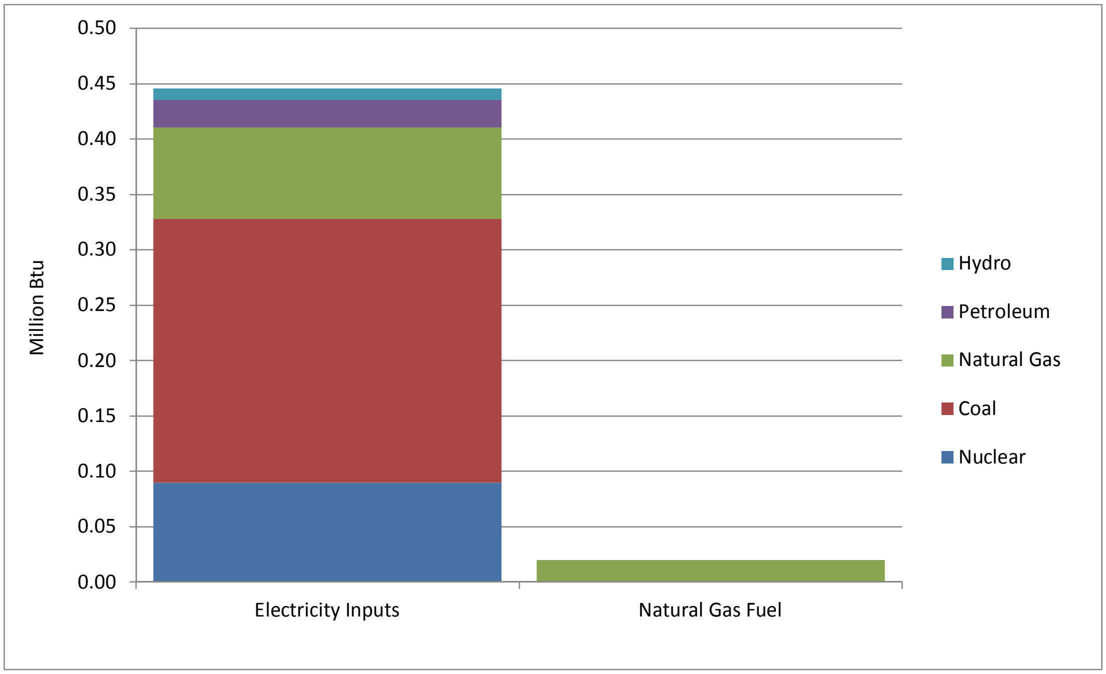

Figure 48. Unit Process Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

A little more than a third of the energy demand for the application of secondary bonds is from energy of material resource (EMR). EMR is not an expended energy but the energy value of fuel resources withdrawn from the planet's finite fossil reserves and used as material inputs for materials such as plastic resins or corrugated fiber. Use of these material resources as a material input removes them as fuel resources from the energy pool; however, some of this energy remains embodied in the material produced. A detailed description of EMR methodology can be found in Chapter 1. Study Goal & Scope/LCI Methodology. Table 47 and Figure 49 show the relative amounts of cradle-to-gate EMR versus expended energy demand for applying a secondary bond. The EMR shown for secondary bonding comes from the PUR adhesive and the plastics of the dispenser.

Table 47. EMR vs. Expended Cradle-to-Gate Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

	Adhesive Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Expended Energy	22.6	0.065	0.47	**23.16**	**62.8%**
Natural Gas EMR	8.51	0	0	**8.51**	**23.1%**
Petroleum EMR	5.18	0	0	**5.18**	**14.1%**
Biomass EMR	0.0069	0	0	**0.01**	**<1%**
TOTAL (1)	**36.3**	**0.065**	**0.47**	**36.9**	**100%**
PERCENT TOTAL (1)	**99%**	**<1%**	**1.3%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

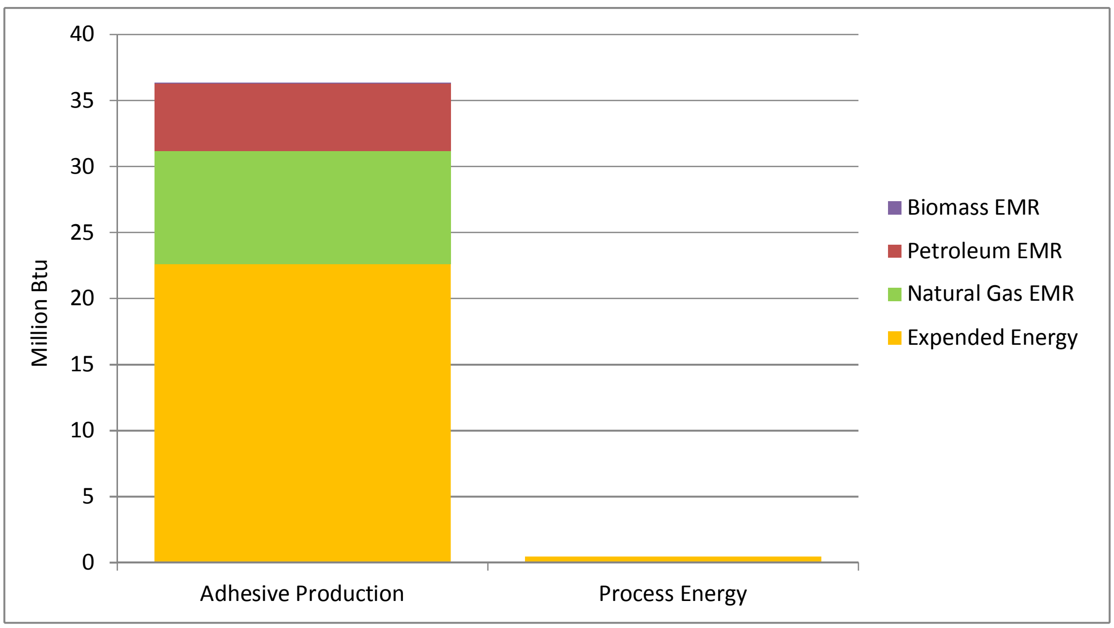

Figure 49. EMR vs. Expended Cradle-to-Gate Energy Demand for Application of a Secondary Bond (Million Btu of energy per 1,000 pounds of Secondary Bond Applied)

Water Use Results

Consumptive water use for cradle-to-gate application of a secondary bond is shown by life cycle phase in Table 48 and Figure 50.

Table 48. Cradle-to-Gate Water Use for Application of a Secondary Bond
(Gallons of water per 1,000 pounds of Secondary Bond Applied)

	Adhesive Production	Incoming Transport	Process Energy	TOTAL (1)
Per 1,000 lb Applied Bond	1,810	2.34	70.8	**1,883**
% TOTAL (1)	**96%**	**<1%**	**3.8%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

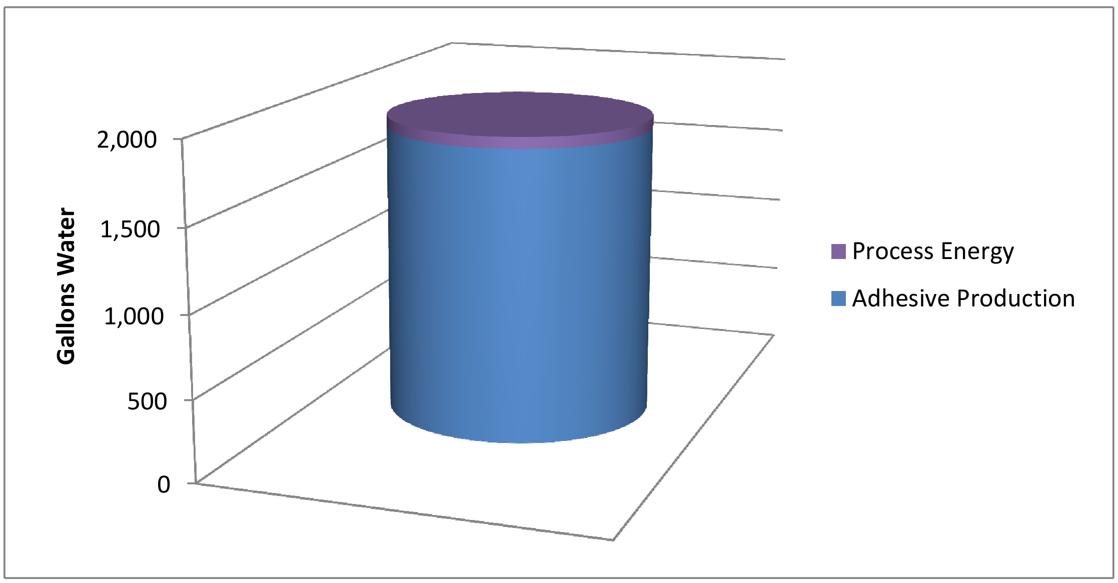

Figure 50. Cradle-to-Gate Water Use for Application of a Secondary Bond
(Gallons of water per 1,000 pounds of Secondary Bond Applied)

The 'material production' results represent water consumption associated with the steps to extract and process the materials required for the application of a secondary bond. The 'process energy' and 'incoming transport' columns show water consumption associated with the steps to extract, process, and deliver the fuels used for process and transportation steps, including water consumption associated with electricity generation. The 'process water' reflects water consumed directly from the application of a secondary bond. The cradle-to-gate results show that over 95 percent of the total water demand is water consumed in production of the PUR adhesive used in the secondary bond application. Water consumed during the production of the fuels and electricity used in the secondary bonding makes up almost 4 percent of the total water consumption. No water is consumed during the secondary bonding itself. Less than 1 percent of the total products that include secondary bonds may be hydrotested, as this percentage is so small, no water has been included for this test. The remaining consumption (less than 1 percent) occurs from the production of fuels required for transporting incoming materials to the secondary bonding facility.

Solid Waste Results

Solid waste generation for cradle-to-gate application of a secondary bond is shown by process step in Table 49 and Figure 51.

Table 49. Cradle-to-Gate Solid Waste Generation for Application of a Secondary Bond (Pounds of solid waste per 1,000 pounds of Secondary Bond Applied)

	Adhesive Production	Incoming Transport	Process Energy	Process Waste	**TOTAL (1)**	**PERCENT TOTAL (1)**
Landfilled	20.7	0	0	83.0	**104**	**35%**
Incinerated	4.18	0	0	0	**4.18**	**1.4%**
Waste-to-Energy	0.42	0	0	0	**0.42**	**<1%**
Fuel-Related	179	0.16	9.31	0	**189**	**64%**
TOTAL (1)	**205**	**0.16**	**9.31**	**83.0**	**297**	**100%**
PERCENT TOTAL (1)	**69%**	**<1%**	**3.1%**	**28%**	**100%**	

(1) Totals may not sum due to rounding.

Source: Franklin Associates, A Division of ERG

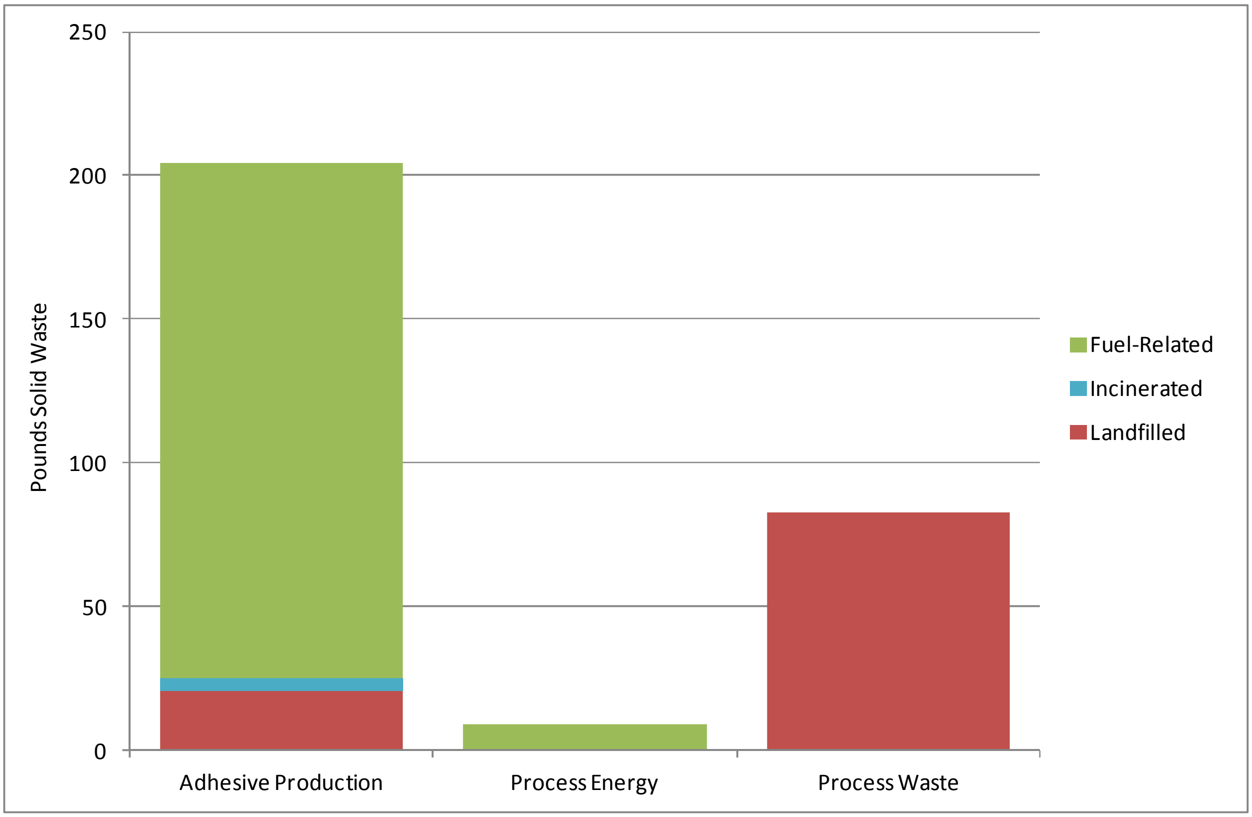

Figure 51. Cradle-to-Gate Solid Waste Generation for Application of a Secondary Bond (Pounds of solid waste per 1,000 pounds of Secondary Bond Applied)

The cradle-to-gate results for solid waste generation indicate that the bulk of generation, almost 70 percent, comes from the production of the PUR adhesive. Solid waste generated during the secondary bonding process is makes up 28 percent of the cradle-to-gate total. This solid waste is mostly waste bond and trimmed off bond. The production of fuels and electricity required for the secondary bonding process produces about 3 percent of the total solid waste, while the fuels from transporting incoming materials makes up less than 1 percent of the total solid waste. Also, due to the fact that this is a cradle-to-gate LCI analysis, (i.e., extends only through production of the secondary bonded composites) no postconsumer wastes are modeled. The disposition of the produced composites that are secondary bonded depends on the product application, its composition, access to recycling programs, and other product-specific factors that are outside the scope of a generic cradle-to-gate LCI.

Atmospheric and Waterborne Emissions

The emissions reported in this analysis include those associated with cradle-to-gate application of a secondary bond and include both process and fuel-related emission. Emissions tables in this section present emission quantities based upon the best data available. However, in the many unit processes included in the system models, some emissions data have been collected as reported from the industrial sources, some are estimated from EPA emission factors, and some have been calculated based on reaction chemistry or other information.

Atmospheric and waterborne emissions for the application of a secondary bond includes emissions from (1) production of the material inputs, (2) production and combustion of fuels during transportation of incoming materials, (3) production and combustion of required processing fuels and production of the required electricity at the secondary bonding facility, and from (4) the application of the secondary bond. Non-fuel related air emissions released during the secondary bonding process include unspecified volatilized hydrocarbons. However, atmospheric emissions are also often related to the combustion of fuels during any of these steps, particularly in the case of greenhouse gas emissions, which are the focus of this discussion.

Greenhouse Gas (GHG) Emissions. The atmospheric emissions that typically contribute the majority of the total greenhouse gas impacts for product systems are fossil fuel-derived carbon dioxide, methane, and nitrous oxide. Greenhouse gas impacts are reported as carbon dioxide equivalents (CO_2 eq). Global warming potential (GWP) factors are used to convert emissions of individual greenhouse gases to the basis of CO_2 eq. The GWP of each greenhouse gas represents the relative global warming contribution of a pound of that substance compared to a pound of carbon dioxide. For each emission at each step of the cradle-to-gate life cycle, the weight of each greenhouse gas emitted is multiplied by its GWP, then the CO_2 eq for the individual GHGs are summed to arrive at the total CO_2 eq. The tables in this report show GHG results using International Panel on Climate Change (IPCC) 2007 GWP factors, which are 25 for methane and 298 for nitrous oxide.[16] GHG results for the application of a secondary bond are shown in Table 50 and Figure 52.

Table 50. Cradle-to-Gate GHGs for Application of a Secondary Bond
(Pounds CO2 equivalents per 1,000 pounds of Secondary Bond Applied)

	Adhesive Production	Incoming Transport	Process Energy	**TOTAL (1)**	**PERCENT TOTAL (1)**
Fossil CO2	3,380	9.91	69.2	**3,459**	**88%**
Methane	462	0.47	4.19	**466**	**12%**
Nitrous Oxide	21.4	0.079	0.45	**21.9**	**<1%**
Others	0.12	0	0	**0.12**	**<1%**
TOTAL (1)	**3,863**	**10.5**	**73.8**	**3,948**	**100%**
PERCENT TOTAL (1)	**98%**	**<1%**	**1.9%**	**100%**	

(1) Totals may not sum due to rounding

Source: Franklin Associates, A Division of ERG

16 The GWP factors that are most widely used are those from the International Panel on Climate Change (IPCC) Second Assessment Report (SAR), published in 1996. The IPCC SAR 100-year global warming potentials (GWP) are 21 for methane and 310 for nitrous oxide. Two subsequent updates of the IPCC report with slightly different GWPs have been published since the SAR; however, some reporting standards that were developed at the time of the SAR continue to use the SAR GWP factors. The United Nations Framework Convention on Climate Change reporting guidelines for national inventories continue to use GWPs from the IPPC Second Assessment Report (SAR). For this reason, the U.S. EPA also uses GWPs from the IPCC SAR, as described on page ES-1 of EPA 430-R-08-005 **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006** (April 15, 2008). The total CO2 equivalents calculated using the 2007 factors as presented in this report are slightly higher than the CO2 equivalents calculated using IPCC 1996 factors.

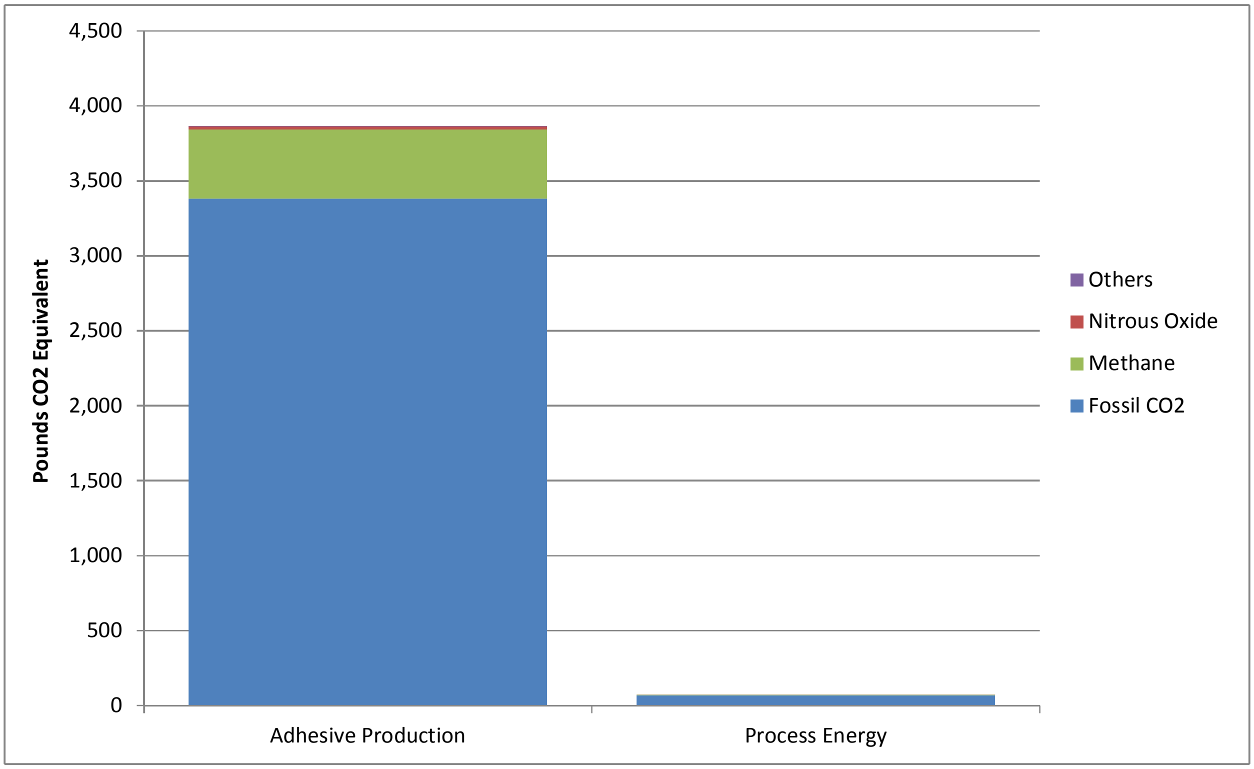

Figure 52. Cradle-to-Gate GHGs for Application of a Secondary Bond (Pounds CO2 equivalents per 1,000 pounds of Secondary Bond Applied)

As can often be the case for LCI results of product systems, the life cycle phases contributing most significantly to energy demand also contribute most significantly to GHG emissions. The results for GHG emissions for cradle-to-gate application of a secondary bond demonstrate this correlation. The production of the PUR adhesive inputs, which release 98 percent of the total GWP, requires a substantial amount of fuels production and combustion, as well as some fugitive emissions of carbon dioxide and methane released during the extraction, transport, and processing of natural gas and crude oil feedstock for the materials. The production of fuels and electricity used within the secondary bonding process release just under 2 percent of the GWP amount. No GHG emissions are reported for the secondary bonding process itself. Likewise, GHG emissions associated with the production and combustion of fuels required for incoming transport and emission released during the transport contribute less than 1 percent of the total. The breakout by GHG shows that carbon dioxide emissions are the largest contributors to the global warming potential (GWP) of the GHGs; methane emissions have the second largest contribution. Nitrous oxide emissions and several other emissions from the cradle-to-gate manufacturing systems are GHGs (e.g., sulfur hexafluoride, CFCs, and HCFCs) but their cumulative amounts and associated contribution to the overall GWP is less than one percent.

Other Atmospheric and Waterborne Emissions. Tables showing the full list of atmospheric and waterborne emissions for this cradle-to-gate secondary bonding application LCI are included in Appendix A.

APPENDIX A. CRADLE-TO-GATE EMISSIONS TABLES

This appendix section details the quantitative cradle-to-gate LCI atmospheric and waterborne emissions results for each of the materials and processes in this analysis. These tables are provided in this appendix due to their length.

- Table 51. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin.
- Table 52. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin
- Table 53. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass
- Table 54. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass
- Table 55. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products
- Table 56. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products
- Table 57. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products
- Table 58. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products
- Table 59. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products
- Table 60. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products
- Table 61. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products
- Table 62. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products
- Table 63. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond
- Table 64. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Table 51. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

1-Butanol	lb	2.4E-12
1-Pentanol	lb	5.8E-13
1-Pentene	lb	4.4E-13
1-Propanol	lb	3.7E-10
1,4-Butanediol	lb	4.3E-11
2-Aminopropanol	lb	1.1E-13
2-Butene, 2-methyl-	lb	9.7E-17
2-Chloroacetophenone	lb	4.9E-08
2-Methyl-1-propanol	lb	3.0E-12
2-Nitrobenzoic acid	lb	1.9E-13
2-Propanol	lb	5.1E-07
2,4-D	lb	1.3E-19
5-methyl Chrysene	lb	2.5E-09
Acenaphthene	lb	5.7E-08
Acenaphthylene	lb	2.8E-08
Acetaldehyde	lb	1.2E-04
Acetic acid	lb	0.0016
Acetic acid, methyl ester	lb	6.0E-04
Acetone	lb	8.1E-06
Acetonitrile	lb	8.4E-08
Acetophenone	lb	1.0E-07
Acid gases	lb	0.0034
Acidity, unspecified	lb	1.1E-13
Acids, unspecified	lb	5.3E-26
Acrolein	lb	1.3E-05
Acrylic acid	lb	1.3E-09
Actinides, radioactive, unspecified	Ci	3.9E-14
Adipate, bis(1-ethylhexyl)-	lb	7.7E-19
Aerosols, radioactive, unspecified	Ci	1.0E-12
Alachlor	lb	9.0E-20
Aldehydes, unspecified	lb	0.031
alpha-Pinene	lb	1.1E-16
Aluminium	lb	7.0E-04
Aluminum	lb	2.8E-21
Aluminum, fume or dust	lb	7.3E-19
Ammonia	lb	0.016
Ammonium carbonate	lb	8.9E-09
Ammonium chloride	lb	2.9E-04
Ammonium, ion	lb	1.6E-15

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Aniline	lb	5.4E-11
Aniline, N,N-dimethyl-	lb	1.5E-05
Anthracene	lb	2.4E-08
Anthranilic acid	lb	1.4E-13
Antimony	lb	3.4E-06
Antimony-124	Ci	4.7E-18
Antimony-125	Ci	4.9E-17
Argon-41	Ci	5.4E-10
Arsenic	lb	6.3E-05
Arsenic trioxide	lb	4.6E-18
Arsine	lb	1.6E-14
Barium	lb	2.8E-06
Barium-140	Ci	3.2E-15
Bentazone	lb	7.5E-20
Benzal chloride	lb	2.4E-16
Benzaldehyde	lb	5.2E-09
Benzene	lb	0.081
Benzene, 1-methyl-2-nitro-	lb	1.7E-13
Benzene, 1,2-dichloro-	lb	4.2E-12
Benzene, 1,3,5-trimethyl-	lb	5.6E-17
Benzene, chloro-	lb	1.5E-07
Benzene, ethyl-	lb	0.084
Benzene, hexachloro-	lb	9.4E-09
Benzene, pentachloro-	lb	7.5E-11
Benzo(a)anthracene	lb	9.0E-09
Benzo(a)pyrene	lb	2.7E-07
Benzo(b)fluoranthene	lb	1.7E-15
Benzo(b,j,k)fluoranthene	lb	1.2E-08
Benzo(ghi)perylene	lb	3.0E-09
Benzyl chloride	lb	4.9E-06
Beryllium	lb	3.0E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	4.1E-17
Biphenyl	lb	1.9E-07
Boron	lb	1.2E-04
Boron trifluoride	lb	2.1E-16
Bromine	lb	0.0030
Bromoform	lb	2.7E-07
Bromoxynil	lb	1.0E-19
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	1.7E-24
Butadiene	lb	2.4E-06
Butane	lb	0.014
Butanol	lb	2.0E-04
Butene	lb	2.0E-04
Butyrolactone	lb	8.1E-12
Cadmium	lb	2.5E-05

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Calcium	lb	9.9E-05
Carbon-14	Ci	4.2E-09
Carbon dioxide	lb	3.28
Carbon dioxide, biogenic	lb	0.41
Carbon dioxide, fossil	lb	2,668
Carbon dioxide, land transformation	lb	0.0023
Carbon disulfide	lb	5.2E-05
Carbon monoxide	lb	7.64
Carbon monoxide, biogenic	lb	6.6E-05
Carbon monoxide, fossil	lb	1.65
Carbonyl sulfide	lb	5.3E-14
Cerium-141	Ci	7.7E-16
Cesium-134	Ci	4.6E-17
Cesium-137	Ci	6.7E-16
Chloramine	lb	2.2E-12
Chloride	lb	3.6E-11
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	1.4E-26
Chlorine	lb	3.4E-04
Chloroacetic acid	lb	3.7E-10
Chloroform	lb	4.2E-07
Chlorosilane, trimethyl-	lb	4.8E-10
Chlorosulfonic acid	lb	1.3E-12
Chlorpyrifos	lb	3.3E-20
Chromium	lb	6.3E-05
Chromium-51	Ci	4.9E-17
Chromium VI	lb	9.3E-06
Chromium, ion	lb	2.6E-14
Chrysene	lb	1.1E-08
Clomazone	lb	1.7E-20
Cobalt	lb	6.6E-05
Cobalt-58	Ci	6.9E-17
Cobalt-60	Ci	6.1E-16
Copper	lb	2.4E-05
Copper compounds	lb	2.8E-19
Cumene	lb	9.4E-06
Cyanide	lb	1.8E-05
Cyanoacetic acid	lb	1.0E-12
Cyclohexane	lb	4.7E-14
D-limonene	lb	1.2E-17
Dibenz(a,h)anthracene	lb	5.3E-16
Dicyclopentadiene	lb	0.0039
Diethanolamine	lb	3.9E-20
Diethylamine	lb	2.4E-11
Dimethyl ether	lb	1.2E-15
Dimethyl malonate	lb	1.3E-12

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Dinitrogen monoxide	lb	0.037
Dioxins (unspecified)	lb	9.2E-25
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.1E-10
Dipropylamine	lb	1.5E-11
Ethane	lb	0.0032
Ethane, 1,1-difluoro-, HFC-152a	lb	1.0E-08
Ethane, 1,1,1-trichloro-, HCFC-140	lb	1.4E-07
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	8.7E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	6.3E-11
Ethane, 1,2-dibromo-	lb	8.4E-09
Ethane, 1,2-dichloro-	lb	9.7E-07
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	8.3E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	1.4E-07
Ethane, chloro-	lb	2.9E-07
Ethane, hexafluoro-, HFC-116	lb	8.3E-08
Ethanol	lb	1.2E-05
Ethene	lb	4.3E-04
Ethene, chloro-	lb	1.8E-07
Ethene, tetrachloro-	lb	5.4E-06
Ethyl acetate	lb	2.4E-06
Ethyl cellulose	lb	4.8E-09
Ethylamine	lb	1.0E-12
Ethylene diamine	lb	1.4E-11
Ethylene dibromide	lb	2.3E-06
Ethylene glycol	lb	0.0075
Ethylene oxide	lb	0.0094
Ethyne	lb	1.3E-06
Fluoranthene	lb	8.0E-08
Fluorene	lb	1.0E-07
Fluoride	lb	3.2E-04
Fluorine	lb	1.0E-05
Fluosilicic acid	lb	9.1E-08
Formaldehyde	lb	0.0037
Formamide	lb	1.1E-12
Formic acid	lb	5.7E-07
Furan	lb	1.6E-07
Glyphosate	lb	6.0E-18
Glyphosate-trimesium	lb	4.9E-19
Heat, waste	Btu	989,558
Helium	lb	3.6E-04
Heptane	lb	0.0020
Hexamethylene diamine	lb	1.1E-16
Hexane	lb	0.0043
Hydrazine, methyl-	lb	1.2E-06
Hydrocarbons, aliphatic, alkanes, cyclic	lb	1.6E-07

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Hydrocarbons, aliphatic, alkanes, unspecified	lb	4.2E-04
Hydrocarbons, aliphatic, unsaturated	lb	3.0E-05
Hydrocarbons, aromatic	lb	3.2E-04
Hydrocarbons, chlorinated	lb	8.6E-08
Hydrocarbons, unspecified	lb	0.044
Hydrogen	lb	0.0031
Hydrogen-3, Tritium	Ci	2.4E-08
Hydrogen bromide	lb	3.6E-13
Hydrogen chloride	lb	0.14
Hydrogen cyanide	lb	2.0E-14
Hydrogen fluoride	lb	0.017
Hydrogen iodide	lb	4.0E-16
Hydrogen peroxide	lb	3.3E-04
Hydrogen sulfide	lb	6.5E-05
Indeno(1,2,3-cd)pyrene	lb	6.9E-09
Iodine	lb	2.8E-05
Iodine-129	Ci	4.2E-12
Iodine-131	Ci	2.1E-10
Iodine-133	Ci	8.6E-15
Iodine-135	Ci	1.1E-14
Iron	lb	2.3E-04
Isobutyraldehyde	lb	0.0017
Isocyanic acid	lb	1.6E-07
Isophorone	lb	4.1E-06
Isoprene	lb	7.4E-09
Isopropylamine	lb	2.3E-13
Kerosene	lb	1.4E-04
Krypton-85	Ci	1.7E-09
Krypton-85m	Ci	1.2E-09
Krypton-87	Ci	3.1E-11
Krypton-88	Ci	3.0E-11
Krypton-89	Ci	7.1E-12
Lactic acid	lb	1.2E-11
Lanthanum-140	Ci	2.7E-16
Lead	lb	1.1E-04
Lead-210	Ci	2.3E-11
Lead compounds	lb	6.6E-17
m-Xylene	lb	3.6E-07
Magnesium	lb	0.0013
Maleic anhydride	lb	0.0092
Manganese	lb	8.6E-05
Manganese-54	Ci	2.5E-17
Manganese compounds	lb	2.4E-20
Mercaptans, unspecified	lb	0.0015
Mercury	lb	4.0E-05

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Metals, unspecified	lb	8.0E-11
Methacrylic acid, methyl ester	lb	1.4E-07
Methane	lb	0.84
Methane, biogenic	lb	6.5E-04
Methane, bromo-, Halon 1001	lb	1.1E-06
Methane, bromochlorodifluoro-, Halon 1211	lb	9.2E-08
Methane, bromotrifluoro-, Halon 1301	lb	5.2E-06
Methane, chlorodifluoro-, HCFC-22	lb	8.1E-07
Methane, chlorotrifluoro-, CFC-13	lb	1.2E-05
Methane, dichloro-, HCC-30	lb	7.2E-05
Methane, dichlorodifluoro-, CFC-12	lb	1.0E-09
Methane, dichlorofluoro-, HCFC-21	lb	5.5E-13
Methane, fossil	lb	14.2
Methane, monochloro-, R-40	lb	3.7E-06
Methane, tetrachloro-, CFC-10	lb	1.8E-05
Methane, tetrafluoro-, CFC-14	lb	7.0E-07
Methane, trichlorofluoro-, CFC-11	lb	1.7E-11
Methane, trifluoro-, HFC-23	lb	1.8E-10
Methanesulfonic acid	lb	1.0E-12
Methanol	lb	3.1E-04
Methyl acetate	lb	6.1E-04
Methyl acrylate	lb	1.5E-09
Methyl amine	lb	1.2E-11
Methyl borate	lb	2.2E-13
Methyl ethyl ketone	lb	5.1E-06
Methyl formate	lb	6.1E-12
Methyl lactate	lb	1.3E-11
Methyl methacrylate	lb	0.024
Metolachlor	lb	1.8E-19
Metribuzin	lb	4.3E-20
Molybdenum	lb	4.5E-06
Monoethanolamine	lb	9.9E-08
Naphthalene	lb	1.7E-05
Nickel	lb	8.0E-04
Nickel compounds	lb	5.9E-16
Niobium-95	Ci	3.0E-18
Nitrate	lb	1.8E-06
Nitric oxide	lb	5.1E-15
Nitrobenzene	lb	7.3E-11
Nitrogen	lb	1.1E-08
Nitrogen dioxide	lb	3.0E-28
Nitrogen oxides	lb	5.20
Nitrogen, total	lb	2.9E-26
Nitrous oxide	lb	3.5E-04
NMVOC, non-methane volatile organic compounds, unspecified	lb	4.11

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Noble gases, radioactive, unspecified	Ci	4.1E-05
Octane	lb	2.4E-11
Odorous sulfur	lb	1.4E-17
Organic acids	lb	1.1E-06
Organic substances, unspecified	lb	0.083
Oxygen	lb	8.2E-08
Ozone	lb	1.2E-04
PAH, polycyclic aromatic hydrocarbons	lb	1.6E-05
Palladium	lb	3.9E-20
Particulates, < 10 um	lb	1.54
Particulates, < 2.5 um	lb	0.36
Particulates, > 10 um	lb	0.020
Particulates, > 2.5 um, and < 10um	lb	0.12
Particulates, unspecified	lb	0.58
Pendimethalin	lb	9.7E-19
Pentane	lb	0.011
PFC (perfluorocarbons)	lb	5.9E-15
Phenanthrene	lb	3.0E-07
Phenol	lb	2.8E-07
Phenol, 2,4-dichloro-	lb	8.3E-12
Phenol, pentachloro-	lb	9.5E-08
Phenols, unspecified	lb	3.2E-05
Phosphate	lb	6.6E-28
Phosphine	lb	1.1E-12
Phosphorus	lb	1.4E-06
Phthalate, dioctyl-	lb	5.1E-07
Phthalic acid,branched and linear di c7-c11 alk	lb	0.013
Phthalic anhydride	lb	4.8E-04
Platinum	lb	4.9E-12
Plutonium-238	Ci	5.8E-19
Plutonium-alpha	Ci	1.3E-18
Polonium-210	Ci	4.1E-11
Polychlorinated biphenyls	lb	1.7E-08
Polycyclic organic matter, unspecified	lb	3.1E-05
Potassium	lb	1.0E-04
Potassium-40	Ci	5.2E-12
Propanal	lb	2.7E-06
Propane	lb	0.0090
Propene	lb	5.1E-04
Propionic acid	lb	7.5E-07
Propylamine	lb	3.3E-13
Propylene oxide	lb	0.19
Protactinium-234	Ci	5.7E-13
Pyrene	lb	3.7E-08
Radioactive species, other beta emitters	Ci	1.1E-11

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Radioactive species, unspecified	Ci	7.3E-05
Radionuclides (Including Radon)	lb	0.0078
Radium-226	Ci	2.5E-11
Radium-228	Ci	2.6E-12
Radon-220	Ci	2.3E-10
Radon-222	Ci	7.6E-05
Rhodium	lb	3.8E-20
Ruthenium-103	Ci	6.6E-19
Scandium	lb	5.7E-07
Selenium	lb	1.6E-04
Silicon	lb	6.4E-05
Silicon tetrafluoride	lb	1.3E-08
Silver	lb	2.5E-08
Silver-110	Ci	6.5E-18
Sodium	lb	2.0E-04
Sodium chlorate	lb	1.4E-07
Sodium dichromate	lb	4.4E-08
Sodium formate	lb	4.7E-10
Sodium hydroxide	lb	1.3E-08
Strontium	lb	2.5E-06
Styrene	lb	0.13
Sulfate	lb	5.3E-04
Sulfur dioxide	lb	5.62
Sulfur hexafluoride	lb	1.8E-06
Sulfur oxides	lb	2.64
Sulfur trioxide	lb	5.9E-10
Sulfur, total reduced	lb	8.0E-12
Sulfuric acid	lb	0.0028
Sulfuric acid, dimethyl ester	lb	3.4E-07
t-Butyl methyl ether	lb	2.5E-07
t-Butylamine	lb	9.0E-13
Tar	lb	7.5E-31
Tellurium	lb	3.4E-15
Terpenes	lb	7.0E-08
Thallium	lb	8.0E-09
Thorium	lb	3.3E-09
Thorium-228	Ci	1.1E-12
Thorium-230	Ci	2.4E-12
Thorium-232	Ci	1.7E-12
Thorium-234	Ci	5.7E-13
Tin	lb	3.6E-07
Tin oxide	lb	5.8E-18
Titanium	lb	1.1E-05
TOC, Total Organic Carbon	lb	0.0048
Toluene	lb	0.12

Source: Franklin Associates, A Division of ERG

Table 51 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Unsaturated Polyester Resin

Toluene, 2-chloro-	lb	2.2E-11
Toluene, 2,4-dinitro-	lb	2.0E-09
Trichloroethane	lb	6.1E-22
Triethyl amine	lb	1.8E-18
Trifluralin	lb	9.7E-19
Trimethylamine	lb	8.0E-14
Tungsten	lb	6.4E-08
Uranium	lb	3.1E-09
Uranium-234	Ci	6.9E-12
Uranium-235	Ci	3.2E-13
Uranium-238	Ci	1.1E-11
Uranium alpha	Ci	3.1E-11
Used air	lb	6.0E-04
Vanadium	lb	2.0E-04
Vinyl acetate	lb	5.3E-08
VOC, volatile organic compounds	lb	0.79
Water	lb	0.057
Xenon-131m	Ci	1.4E-10
Xenon-133	Ci	4.4E-09
Xenon-133m	Ci	2.0E-11
Xenon-135	Ci	1.8E-09
Xenon-135m	Ci	1.1E-09
Xenon-137	Ci	1.9E-11
Xenon-138	Ci	1.8E-10
Xylene	lb	0.073
Zinc	lb	3.7E-05
Zinc-65	Ci	1.3E-16
Zinc compounds	lb	4.9E-20
Zinc oxide	lb	1.2E-17
Zirconium	lb	1.9E-08
Zirconium-95	Ci	1.2E-16

Source: Franklin Associates, A Division of ERG

Table 52. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

1-Butanol	lb	8.7E-09
1-Pentanol	lb	1.4E-12
1-Pentene	lb	1.0E-12
1,4-Butanediol	lb	1.7E-11
2-Aminopropanol	lb	2.7E-13
2-Hexanone	lb	2.2E-06
2-Methyl-1-propanol	lb	7.2E-12
2-Methyl-2-butene	lb	2.3E-16
2-Propanol	lb	1.3E-12
2,4-D	lb	5.4E-21
4-Methyl-2-pentanone	lb	7.1E-07
Acenaphthene	lb	6.0E-08
Acenaphthylene	lb	3.7E-09
Acetaldehyde	lb	0.0099
Acetic acid	lb	2.1E-06
Acetone	lb	1.7E-06
Acetonitrile	lb	8.6E-13
Acetyl chloride	lb	1.1E-12
Acidity, unspecified	lb	0.79
Acids, unspecified	lb	0.0024
Acrylate, ion	lb	3.1E-09
Acrylonitrile	lb	6.2E-15
Actinides, radioactive, unspecified	Ci	6.9E-12
Alachlor	lb	3.9E-21
Aldehydes (unspecified)	lb	1.6E-19
Aluminium	lb	0.025
Aluminum	lb	0.033
Aluminum, ion	lb	1.0E-17
Americium-241	Ci	3.1E-17
Ammonia	lb	0.014
Ammonia, as N	lb	7.8E-17
Ammonium, ion	lb	0.027
Aniline	lb	1.3E-10
Anthracene	lb	5.3E-14
Antimony	lb	3.2E-05
Antimony-122	Ci	1.9E-15
Antimony-124	Ci	1.1E-12
Antimony-125	Ci	1.0E-12
Antimony compounds	lb	1.5E-08
AOX, Adsorbable Organic Halogen as Cl	lb	7.8E-06
Arsenic, ion	lb	1.4E-04
Barite	lb	0.035
Barium	lb	0.42
Barium-140	Ci	8.3E-15

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Bentazone	lb	3.2E-21
Benzene	lb	0.0010
Benzene, 1-methyl-4-(1-methylethyl)-	lb	1.7E-08
Benzene, 1,2-dichloro-	lb	3.8E-09
Benzene, chloro-	lb	7.8E-08
Benzene, ethyl-	lb	5.9E-04
Benzene, pentamethyl-	lb	1.3E-08
Benzenes, alkylated, unspecified	lb	6.3E-05
Benzo(a)anthracene	lb	3.8E-14
Benzo(b)fluoranthene	lb	4.1E-14
Benzoic acid	lb	3.4E-04
Beryllium	lb	2.2E-05
Biphenyl	lb	4.1E-06
BOD5, Biological Oxygen Demand	lb	13.8
Borate	lb	1.2E-10
Boron	lb	0.0016
Bromate	lb	1.6E-04
Bromide	lb	0.042
Bromine	lb	0.0068
Butene	lb	4.3E-09
Butyl acetate	lb	1.1E-08
Butyrolactone	lb	2.0E-11
Cadmium	lb	7.4E-07
Cadmium, ion	lb	2.7E-05
Calcium, ion	lb	1.26
Carbon-14	Ci	1.6E-15
Carbon disulfide	lb	6.1E-11
Carbonate	lb	1.1E-05
Carboxylic acids, unspecified	lb	0.042
Cerium-141	Ci	3.3E-15
Cerium-144	Ci	1.0E-15
Cesium	lb	9.6E-06
Cesium-134	Ci	9.4E-13
Cesium-136	Ci	5.9E-16
Cesium-137	Ci	7.9E-10
Chloramine	lb	2.0E-11
Chlorate	lb	0.0012
Chloride	lb	13.5
Chlorinated solvents, unspecified	lb	3.6E-07
Chlorine	lb	3.9E-07
Chloroacetic acid	lb	1.8E-08
Chloroacetyl chloride	lb	3.6E-13
Chloroform	lb	1.8E-10
Chlorosulfonic acid	lb	3.1E-12

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Chlorpyrifos	lb	1.4E-21
Chromium	lb	0.0033
Chromium-51	Ci	1.1E-12
Chromium VI	lb	2.9E-04
Chromium, ion	lb	2.7E-05
Chrysene	lb	2.1E-13
Clomazone	lb	7.4E-22
Cobalt	lb	3.0E-04
Cobalt-57	Ci	1.9E-14
Cobalt-58	Ci	8.6E-12
Cobalt-60	Ci	6.7E-12
COD, Chemical Oxygen Demand	lb	14.2
Copper	lb	5.4E-05
Copper, ion	lb	3.4E-04
Cresol	lb	2.4E-16
Cumene	lb	2.3E-05
Curium alpha	Ci	4.1E-17
Cyanide	lb	2.6E-05
Cyclohexane	lb	2.8E-21
Decane	lb	9.6E-06
Detergent, oil	lb	9.6E-16
Detergents, unspecified	lb	7.1E-29
Dibenzofuran	lb	3.2E-08
Dibenzothiophene	lb	3.3E-08
Dichromate	lb	1.6E-07
Diethylamine	lb	5.8E-11
Dimethylamine	lb	3.2E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.6E-22
Dipropylamine	lb	3.7E-11
Dissolved organics	lb	8.5E-06
Dissolved solids	lb	12.8
DOC, Dissolved Organic Carbon	lb	2.41
Docosane	lb	1.8E-07
Dodecane	lb	1.8E-05
Eicosane	lb	5.0E-06
Ethane, 1,2-dichloro-	lb	9.6E-08
Ethanol	lb	2.1E-08
Ethene	lb	9.4E-06
Ethene, chloro-	lb	1.5E-09
Ethyl acetate	lb	6.3E-11
Ethylamine	lb	2.5E-12
Ethylene diamine	lb	3.4E-11
Ethylene oxide	lb	1.6E-09
Fluoranthene	lb	4.5E-14

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Fluorene	lb	1.7E-06
Fluorene, 1-methyl-	lb	1.9E-08
Fluorenes, alkylated, unspecified	lb	3.6E-06
Fluoride	lb	0.0031
Fluorine	lb	3.9E-12
Fluosilicic acid	lb	1.6E-07
Formaldehyde	lb	1.2E-06
Formamide	lb	2.5E-12
Formate	lb	2.8E-10
Formic acid	lb	7.4E-13
Furan	lb	6.8E-14
Glutaraldehyde	lb	4.3E-06
Glyphosate	lb	2.6E-19
Glyphosate-trimesium	lb	2.1E-20
Heat, waste	Ci	2.2E-09
Hexadecane	lb	2.0E-05
Hexane	lb	3.0E-17
Hexanoic acid	lb	7.0E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	0.0013
Hydrocarbons, aliphatic, unsaturated	lb	1.2E-04
Hydrocarbons, aromatic	lb	0.0051
Hydrocarbons, unspecified	lb	0.072
Hydrogen-3, Tritium	Ci	1.8E-06
Hydrogen chloride	lb	4.2E-14
Hydrogen fluoride	lb	2.2E-14
Hydrogen peroxide	lb	4.1E-08
Hydrogen sulfide	lb	3.2E-05
Hydroxide	lb	1.1E-07
Hypochlorite	lb	8.0E-06
Iodide	lb	9.6E-04
Iodine-129	Ci	4.5E-15
Iodine-131	Ci	2.0E-13
Iodine-133	Ci	5.2E-15
Iron	lb	0.063
Iron-59	Ci	1.4E-15
Iron, ion	lb	0.038
Isopropylamine	lb	5.6E-13
Lactic acid	lb	2.9E-11
Lanthanum-140	Ci	8.8E-15
Lead	lb	3.1E-04
Lead-210	Ci	6.9E-11
Lead-210/kg	lb	3.4E-14
Lithium, ion	lb	0.12
m-Xylene	lb	9.7E-06

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Magnesium	lb	0.32
Manganese	lb	0.013
Manganese-54	Ci	5.3E-13
Mercury	lb	4.6E-06
Metallic ions, unspecified	lb	1.2E-04
Methane, dibromo-	lb	1.1E-17
Methane, dichloro-, HCC-30	lb	1.1E-04
Methane, monochloro-, R-40	lb	6.7E-09
Methane, trichlorofluoro-, CFC-11	lb	3.6E-15
Methanol	lb	1.3E-06
Methyl acetate	lb	1.1E-13
Methyl acrylate	lb	2.9E-08
Methyl amine	lb	2.8E-11
Methyl ethyl ketone	lb	1.3E-08
Methyl formate	lb	2.4E-12
Metolachlor	lb	7.5E-21
Metribuzin	lb	1.8E-21
Molybdenum	lb	8.0E-05
Molybdenum-99	Ci	3.0E-15
n-Hexacosane	lb	1.1E-07
Naphthalene	lb	6.0E-06
Naphthalene, 2-methyl-	lb	5.1E-06
Naphthalenes, alkylated, unspecified	lb	1.0E-06
Nickel	lb	7.9E-05
Nickel, ion	lb	0.0013
Niobium-95	Ci	8.4E-14
Nitrate	lb	0.014
Nitrate compounds	lb	6.8E-13
Nitric acid	lb	4.3E-28
Nitrite	lb	4.9E-06
Nitrobenzene	lb	2.9E-10
Nitrogen	lb	5.5E-04
Nitrogen, organic bound	lb	0.0019
Nitrogen, total	lb	1.6E-04
o-Cresol	lb	9.6E-06
o-Xylene	lb	3.6E-06
Octadecane	lb	5.0E-06
Oils, unspecified	lb	0.68
Organic substances, unspecified	lb	1.6E-28
p-Cresol	lb	1.0E-05
p-Xylene	lb	3.6E-06
PAH, polycyclic aromatic hydrocarbons	lb	5.6E-05
Particulates, < 10 um	lb	6.6E-15
Particulates, > 10 um	lb	9.4E-08

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Pendimethalin	lb	4.2E-20
Phenanthrene	lb	2.7E-07
Phenanthrenes, alkylated, unspecified	lb	4.3E-07
Phenol	lb	0.0015
Phenol, 2,4-dimethyl-	lb	9.3E-06
Phenols, unspecified	lb	0.10
Phosphate	lb	0.043
Phosphorus	lb	9.1E-05
Phosphorus compounds, unspecified	lb	1.3E-18
Plutonium-alpha	Ci	1.2E-16
Polonium-210	Ci	1.0E-10
Potassium	lb	7.3E-12
Potassium-40	Ci	2.0E-11
Potassium, ion	lb	0.12
Process solvents, unspecified	lb	6.8E-12
Propanal	lb	2.0E-12
Propane, 1,2-dichloro-	lb	8.5E-20
Propanol	lb	3.1E-12
Propene	lb	9.1E-06
Propionic acid	lb	2.0E-11
Propylamine	lb	8.0E-13
Propylene oxide	lb	0.37
Protactinium-234	Ci	1.1E-11
Radioactive species, alpha emitters	Ci	1.8E-13
Radioactive species, Nuclides, unspecified	Ci	1.2E-07
Radium-224	Ci	5.9E-09
Radium-226	Ci	1.6E-08
Radium-226/kg	lb	1.2E-11
Radium-228	Ci	1.2E-08
Radium-228/kg	lb	6.1E-14
Rubidium	lb	9.6E-05
Ruthenium-103	Ci	6.4E-16
Ruthenium-106	Ci	3.1E-17
Scandium	lb	3.0E-05
Selenium	lb	7.1E-05
Silicon	lb	0.35
Silver	lb	4.2E-04
Silver-110	Ci	6.2E-12
Silver, ion	lb	8.5E-06
Sodium-24	Ci	2.3E-14
Sodium dichromate	lb	4.0E-18
Sodium formate	lb	1.1E-09
Sodium hydroxide	lb	0.11
Sodium, ion	lb	5.06

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

Solids, inorganic	lb	0.019
Solved solids	lb	9.8E-04
Strontium	lb	0.040
Strontium-89	Ci	1.1E-13
Strontium-90	Ci	5.9E-09
Styrene	lb	3.3E-04
Sulfate	lb	1.23
Sulfide	lb	4.2E-04
Sulfite	lb	2.2E-05
Sulfur	lb	0.0026
Surfactants	lb	6.9E-05
Surfactants, unspecified	lb	1.0E-04
Suspended solids, unspecified	lb	4.20
t-Butyl methyl ether	lb	2.1E-05
t-Butylamine	lb	2.2E-12
Tar	lb	1.1E-32
Technetium-99m	Ci	7.1E-14
Tellurium-123m	Ci	1.2E-13
Tellurium-132	Ci	1.8E-16
Tetradecane	lb	7.8E-06
Thallium	lb	5.7E-06
Thorium-228	Ci	2.4E-08
Thorium-230	Ci	1.4E-09
Thorium-232	Ci	2.3E-12
Thorium-234	Ci	1.1E-11
Tin	lb	7.6E-05
Tin, ion	lb	1.2E-05
Titanium	lb	4.8E-12
Titanium, ion	lb	0.0011
TOC, Total Organic Carbon	lb	2.41
Toluene	lb	0.0016
Toluene, 2-chloro-	lb	4.5E-11
Tributyltin compounds	lb	8.4E-06
Triethylene glycol	lb	7.5E-07
Trifluralin	lb	2.5E-20
Trimethylamine	lb	1.9E-13
Tungsten	lb	1.3E-05
Uranium-234	Ci	1.3E-11
Uranium-235	Ci	2.1E-11
Uranium-238	Ci	6.7E-11
Uranium alpha	Ci	6.1E-10
Urea	lb	2.4E-12
Vanadium	lb	3.8E-05
Vanadium, ion	lb	1.4E-04

Source: Franklin Associates, A Division of ERG

Table 52 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Unsaturated Polyester Resin

VOC, volatile organic compounds, unspecified origin	lb	0.0034
Xylene	lb	0.0011
Yttrium	lb	2.2E-06
Zinc	lb	0.0019
Zinc-65	Ci	3.1E-13
Zinc, ion	lb	0.0039
Zirconium-95	Ci	3.6E-15

Source: Franklin Associates, A Division of ERG

Table 53. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

1-Butanol	lb	4.9E-16
1-Pentanol	lb	2.8E-21
1-Pentene	lb	2.1E-21
1-Propanol	lb	1.0E-13
1,4-Butanediol	lb	1.6E-13
2-Aminopropanol	lb	4.4E-22
2-Butene, 2-methyl-	lb	4.7E-25
2-Chloroacetophenone	lb	4.3E-08
2-Methyl-1-propanol	lb	5.5E-21
2-Nitrobenzoic acid	lb	7.8E-22
2-Propanol	lb	2.8E-09
2,4-D	lb	1.7E-11
5-methyl Chrysene	lb	4.2E-09
Acenaphthene	lb	9.8E-08
Acenaphthylene	lb	4.8E-08
Acetaldehyde	lb	2.1E-04
Acetic acid	lb	1.0E-09
Acetic acid, methyl ester	lb	2.5E-13
Acetone	lb	3.9E-09
Acetonitrile	lb	7.3E-18
Acetophenone	lb	9.2E-08
Acid gases	lb	2.5E-12
Acidity, unspecified	lb	1.0E-11
Acids, unspecified	lb	3.2E-21
Acrolein	lb	9.2E-05
Acrylic acid	lb	7.7E-12
Actinides, radioactive, unspecified	Ci	8.4E-23
Adipate, bis(1-ethylhexyl)-	lb	1.3E-12
Aerosols, radioactive, unspecified	Ci	1.8E-21
Alachlor	lb	1.2E-11
Aldehydes, unspecified	lb	3.2E-04
alpha-Pinene	lb	5.5E-13
Aluminium	lb	0.0023
Aluminum	lb	4.1E-17
Aluminum, fume or dust	lb	1.3E-12
Ammonia	lb	0.0018
Ammonium carbonate	lb	8.9E-14
Ammonium chloride	lb	5.2E-04
Ammonium, ion	lb	-1.9E-12

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Aniline	lb	1.6E-20
Anthracene	lb	4.1E-08
Anthranilic acid	lb	5.7E-22
Antimony	lb	3.7E-06
Antimony-124	Ci	2.2E-20
Antimony-125	Ci	1.2E-25
Argon-41	Ci	1.4E-13
Arsenic	lb	8.2E-05
Arsenic trioxide	lb	1.4E-17
Arsine	lb	1.3E-15
Barium	lb	2.5E-09
Barium-140	Ci	7.8E-24
Bentazone	lb	1.0E-11
Benzal chloride	lb	2.6E-24
Benzaldehyde	lb	1.9E-18
Benzene	lb	0.028
Benzene, 1-methyl-2-nitro-	lb	6.7E-22
Benzene, 1,2-dichloro-	lb	1.8E-20
Benzene, 1,3,5-trimethyl-	lb	1.2E-16
Benzene, chloro-	lb	1.3E-07
Benzene, ethyl-	lb	0.0035
Benzene, hexachloro-	lb	3.8E-11
Benzene, pentachloro-	lb	4.2E-11
Benzo(a)anthracene	lb	1.5E-08
Benzo(a)pyrene	lb	3.6E-07
Benzo(b)fluoranthene	lb	4.0E-15
Benzo(b,j,k)fluoranthene	lb	2.1E-08
Benzo(ghi)perylene	lb	5.2E-09
Benzyl chloride	lb	4.3E-06
Beryllium	lb	4.4E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	2.1E-13
Biphenyl	lb	3.3E-07
Boric acid	lb	2.7E-04
Boron	lb	6.9E-08
Boron trifluoride	lb	1.2E-18
Bromine	lb	4.3E-09
Bromoform	lb	2.4E-07
Bromoxynil	lb	1.4E-11
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	1.0E-19
Butadiene	lb	3.0E-06
Butane	lb	5.8E-09
Butene	lb	1.6E-14
Butyrolactone	lb	4.6E-14
Cadmium	lb	1.3E-05
Calcium	lb	2.6E-07

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Carbon-14	Ci	6.3E-14
Carbon dioxide	lb	24.6
Carbon dioxide, biogenic	lb	4.88
Carbon dioxide, fossil	lb	2,111
Carbon dioxide, land transformation	lb	6.9E-04
Carbon disulfide	lb	4.7E-06
Carbon monoxide	lb	0.63
Carbon monoxide, biogenic	lb	1.7E-05
Carbon monoxide, fossil	lb	0.32
Carbonyl sulfide	lb	3.9E-08
Cerium-141	Ci	1.9E-24
Cesium-134	Ci	1.7E-17
Cesium-137	Ci	3.5E-17
Chloramine	lb	1.1E-20
Chloride	lb	2.0E-10
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	8.3E-22
Chlorine	lb	0.0038
Chloroacetic acid	lb	3.5E-14
Chloroform	lb	3.6E-07
Chlorosilane, trimethyl-	lb	1.2E-11
Chlorosulfonic acid	lb	5.2E-21
Chlorpyrifos	lb	4.6E-12
Chromium	lb	5.5E-05
Chromium-51	Ci	1.2E-25
Chromium VI	lb	1.5E-05
Chromium, ion	lb	2.4E-12
Chrysene	lb	1.9E-08
Clomazone	lb	2.4E-12
Cobalt	lb	3.2E-05
Cobalt-58	Ci	1.1E-19
Cobalt-60	Ci	2.7E-18
Copper	lb	6.9E-07
Copper compounds	lb	4.8E-13
Cumene	lb	3.8E-08
Cyanide	lb	1.7E-05
Cyanoacetic acid	lb	4.3E-21
Cyclohexane	lb	1.2E-13
D-limonene	lb	6.1E-14
Dibenz(a,h)anthracene	lb	1.2E-15
Diethanolamine	lb	-4.7E-17
Diethylamine	lb	7.4E-21
Dimethyl ether	lb	6.9E-14
Dimethyl malonate	lb	5.3E-21
Dinitrogen monoxide	lb	0.030
Dioxins (unspecified)	lb	9.8E-18

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.7E-08
Dipropylamine	lb	4.5E-21
Ethane	lb	6.2E-08
Ethane, 1,1-difluoro-, HFC-152a	lb	2.9E-12
Ethane, 1,1,1-trichloro-, HCFC-140	lb	1.2E-07
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	1.6E-07
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	3.7E-13
Ethane, 1,2-dibromo-	lb	7.4E-09
Ethane, 1,2-dichloro-	lb	1.6E-06
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	1.6E-07
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	3.2E-11
Ethane, chloro-	lb	2.6E-07
Ethane, hexafluoro-, HFC-116	lb	9.2E-09
Ethanol	lb	1.2E-10
Ethene	lb	1.5E-08
Ethene, chloro-	lb	1.4E-06
Ethene, tetrachloro-	lb	8.5E-06
Ethyl acetate	lb	1.4E-08
Ethyl cellulose	lb	2.8E-11
Ethylamine	lb	5.6E-21
Ethylene diamine	lb	1.7E-16
Ethylene dibromide	lb	1.4E-07
Ethylene glycol	lb	1.2E-05
Ethylene oxide	lb	4.6E-06
Ethyne	lb	1.4E-11
Fluoranthene	lb	1.4E-07
Fluorene	lb	1.8E-07
Fluoride	lb	2.9E-04
Fluorine	lb	1.4E-06
Fluosilicic acid	lb	1.7E-08
Formaldehyde	lb	0.0033
Formamide	lb	5.2E-21
Formic acid	lb	1.7E-11
Furan	lb	8.4E-10
Glyphosate	lb	8.2E-10
Glyphosate-trimesium	lb	6.7E-11
Heat, waste	Btu	169,579
Helium	lb	3.2E-11
Heptane	lb	1.1E-10
Hexamethylene diamine	lb	2.3E-16
Hexane	lb	4.2E-07
Hydrazine, methyl-	lb	1.0E-06
Hydrocarbons, aliphatic, alkanes, cyclic	lb	1.4E-06
Hydrocarbons, aliphatic, alkanes, unspecified	lb	1.8E-08
Hydrocarbons, aliphatic, unsaturated	lb	5.6E-14

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Hydrocarbons, aromatic	lb	7.8E-05
Hydrocarbons, chlorinated	lb	3.1E-05
Hydrocarbons, unspecified	lb	0.0030
Hydrogen	lb	0.0090
Hydrogen-3, Tritium	Ci	2.7E-13
Hydrogen bromide	lb	7.8E-13
Hydrogen chloride	lb	0.23
Hydrogen cyanide	lb	3.2E-13
Hydrogen fluoride	lb	0.075
Hydrogen iodide	lb	8.6E-16
Hydrogen peroxide	lb	2.1E-11
Hydrogen sulfide	lb	1.3E-05
Indeno(1,2,3-cd)pyrene	lb	1.2E-08
Iodine	lb	1.5E-11
Iodine-129	Ci	1.3E-16
Iodine-131	Ci	2.0E-17
Iodine-133	Ci	1.9E-23
Iodine-135	Ci	2.1E-23
Iron	lb	6.9E-09
Isocyanic acid	lb	5.2E-16
Isophorone	lb	3.6E-06
Isoprene	lb	2.0E-18
Isopropylamine	lb	1.3E-21
Kerosene	lb	2.5E-04
Krypton-85	Ci	2.9E-18
Krypton-85m	Ci	2.3E-09
Krypton-87	Ci	6.0E-20
Krypton-88	Ci	6.1E-20
Krypton-89	Ci	1.6E-20
Lactic acid	lb	3.5E-21
Lanthanum-140	Ci	6.7E-25
Lead	lb	1.1E-04
Lead-210	Ci	1.0E-19
Lead compounds	lb	1.4E-16
m-Xylene	lb	6.7E-16
Magnesium	lb	0.0021
Manganese	lb	1.3E-04
Manganese-54	Ci	6.2E-26
Manganese compounds	lb	4.2E-14
Mercaptans, unspecified	lb	0.0013
Mercury	lb	2.7E-05
Metals, unspecified	lb	6.9E-04
Methacrylic acid, methyl ester	lb	1.2E-07
Methane	lb	1.48
Methane, biogenic	lb	0.0028

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Methane, bromo-, Halon 1001	lb	9.8E-07
Methane, bromochlorodifluoro-, Halon 1211	lb	3.5E-16
Methane, bromotrifluoro-, Halon 1301	lb	9.8E-14
Methane, chlorodifluoro-, HCFC-22	lb	3.2E-10
Methane, chlorotrifluoro-, CFC-13	lb	7.2E-07
Methane, dichloro-, HCC-30	lb	7.4E-05
Methane, dichlorodifluoro-, CFC-12	lb	7.0E-12
Methane, dichlorofluoro-, HCFC-21	lb	2.5E-15
Methane, fossil	lb	4.18
Methane, monochloro-, R-40	lb	3.3E-06
Methane, tetrachloro-, CFC-10	lb	1.1E-06
Methane, tetrafluoro-, CFC-14	lb	9.2E-08
Methane, trichlorofluoro-, CFC-11	lb	3.1E-11
Methane, trifluoro-, HFC-23	lb	7.8E-13
Methanesulfonic acid	lb	4.3E-21
Methanol	lb	0.083
Methyl acetate	lb	1.8E-22
Methyl acrylate	lb	8.8E-12
Methyl amine	lb	1.7E-14
Methyl borate	lb	5.4E-18
Methyl ethyl ketone	lb	2.4E-06
Methyl formate	lb	3.4E-14
Methyl lactate	lb	3.8E-21
Methyl methacrylate	lb	1.4E-18
Metolachlor	lb	2.4E-11
Metribuzin	lb	5.9E-12
Molybdenum	lb	7.4E-11
Monoethanolamine	lb	6.7E-10
Naphthalene	lb	1.3E-05
Nickel	lb	2.4E-04
Nickel compounds	lb	3.3E-14
Niobium-95	Ci	7.4E-27
Nitrate	lb	1.0E-07
Nitric oxide	lb	6.4E-11
Nitrobenzene	lb	2.2E-20
Nitrogen	lb	6.3E-08
Nitrogen dioxide	lb	1.8E-23
Nitrogen oxides	lb	4.06
Nitrogen, total	lb	1.8E-21
Nitrous oxide	lb	1.5E-09
NMVOC, non-methane volatile organic compounds, unspecified	lb	0.10
Noble gases, radioactive, unspecified	Ci	7.1E-14
Octane	lb	6.2E-11
Odorous sulfur	lb	3.8E-04
Organic acids	lb	1.9E-06

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Organic substances, unspecified	lb	0.068
Oxygen	lb	3.8E-06
Ozone	lb	5.1E-13
PAH, polycyclic aromatic hydrocarbons	lb	1.5E-05
Palladium	lb	7.1E-20
Particulates, < 10 um	lb	0.61
Particulates, < 2.5 um	lb	0.084
Particulates, > 10 um	lb	0.095
Particulates, > 2.5 um, and < 10um	lb	0.18
Particulates, unspecified	lb	6.55
Pendimethalin	lb	1.3E-10
Pentane	lb	3.4E-09
PFC (perfluorocarbons)	lb	3.3E-13
Phenanthrene	lb	5.2E-07
Phenol	lb	1.0E-07
Phenol, 2,4-dichloro-	lb	1.5E-21
Phenol, pentachloro-	lb	2.5E-11
Phenols, unspecified	lb	1.4E-05
Phosphate	lb	4.0E-23
Phosphine	lb	6.9E-13
Phosphorus	lb	1.6E-08
Phthalate, dioctyl-	lb	4.5E-07
Platinum	lb	1.8E-12
Plutonium-238	Ci	1.0E-27
Plutonium-alpha	Ci	1.4E-20
Polonium-210	Ci	1.4E-19
Polychlorinated biphenyls	lb	2.4E-11
Polycyclic organic matter, unspecified	lb	1.8E-06
Potassium	lb	1.2E-07
Potassium-40	Ci	1.1E-20
Propanal	lb	2.3E-06
Propane	lb	2.1E-08
Propene	lb	8.1E-05
Propionic acid	lb	3.5E-14
Propylamine	lb	1.6E-21
Propylene oxide	lb	1.2E-04
Protactinium-234	Ci	1.0E-21
Pyrene	lb	6.4E-08
Radioactive species, other beta emitters	Ci	5.0E-20
Radioactive species, unspecified	Ci	1.3E-04
Radionuclides (Including Radon)	lb	0.014
Radium-226	Ci	1.9E-19
Radium-228	Ci	1.2E-20
Radon-220	Ci	4.0E-19
Radon-222	Ci	3.4E-11

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Rhodium	lb	6.9E-20
Ruthenium-103	Ci	1.6E-27
Scandium	lb	2.6E-15
Selenium	lb	2.5E-04
Silicon	lb	6.6E-07
Silicon tetrafluoride	lb	1.1E-16
Silver	lb	6.2E-13
Silver-110	Ci	1.6E-26
Sodium	lb	1.8E-07
Sodium chlorate	lb	7.3E-17
Sodium dichromate	lb	5.1E-12
Sodium formate	lb	4.8E-18
Sodium hydroxide	lb	7.7E-11
Strontium	lb	5.2E-13
Styrene	lb	0.22
Sulfate	lb	1.4E-06
Sulfur dioxide	lb	6.24
Sulfur hexafluoride	lb	6.0E-13
Sulfur oxides	lb	0.63
Sulfur trioxide	lb	1.8E-19
Sulfur, total reduced	lb	3.1E-08
Sulfuric acid	lb	1.6E-11
Sulfuric acid, dimethyl ester	lb	2.9E-07
t-Butyl methyl ether	lb	2.1E-07
t-Butylamine	lb	4.1E-21
Tar	lb	4.6E-26
Tellurium	lb	4.0E-13
Terpenes	lb	6.1E-18
Thallium	lb	1.7E-12
Thorium	lb	2.2E-17
Thorium-228	Ci	2.5E-21
Thorium-230	Ci	1.5E-19
Thorium-232	Ci	7.4E-21
Thorium-234	Ci	1.0E-21
Tin	lb	2.1E-08
Tin oxide	lb	1.2E-17
Titanium	lb	5.0E-11
TOC, Total Organic Carbon	lb	2.4E-04
Toluene	lb	0.042
Toluene, 2-chloro-	lb	7.5E-21
Toluene, 2,4-dinitro-	lb	1.7E-09
Trichloroethane	lb	7.0E-16
Triethyl amine	lb	3.0E-12
Trifluralin	lb	1.3E-10
Trimethylamine	lb	3.2E-22

Source: Franklin Associates, A Division of ERG

Table 53 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of E-Glass

Tungsten	lb	1.1E-16
Uranium	lb	2.8E-17
Uranium-234	Ci	1.5E-16
Uranium-235	Ci	5.6E-16
Uranium-238	Ci	7.6E-16
Uranium alpha	Ci	5.5E-20
Used air	lb	0.0019
Vanadium	lb	5.1E-10
Vinyl acetate	lb	4.7E-08
VOC, volatile organic compounds	lb	0.59
Water	lb	0.10
Xenon-131m	Ci	1.9E-15
Xenon-133	Ci	3.1E-13
Xenon-133m	Ci	3.6E-20
Xenon-135	Ci	1.0E-13
Xenon-135m	Ci	2.2E-18
Xenon-137	Ci	2.7E-17
Xenon-138	Ci	3.4E-15
Xylene	lb	0.080
Zinc	lb	5.2E-07
Zinc-65	Ci	3.1E-25
Zinc compounds	lb	8.4E-14
Zinc oxide	lb	2.4E-17
Zirconium	lb	1.1E-17
Zirconium-95	Ci	3.0E-25

Source: Franklin Associates, A Division of ERG

Table 54. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

1-Butanol	lb	5.0E-11
1-Pentanol	lb	6.8E-21
1-Pentene	lb	5.1E-21
1,4-Butanediol	lb	6.4E-14
2-Aminopropanol	lb	1.1E-21
2-Hexanone	lb	5.2E-07
2-Methyl-1-propanol	lb	1.3E-20
2-Methyl-2-butene	lb	1.1E-24
2-Propanol	lb	2.3E-11
2,4-D	lb	7.4E-13
4-Methyl-2-pentanone	lb	2.1E-07
Acenaphthene	lb	4.5E-13
Acenaphthylene	lb	1.7E-13
Acetaldehyde	lb	4.8E-06
Acetic acid	lb	5.1E-10
Acetone	lb	5.2E-07
Acetonitrile	lb	3.6E-21
Acetyl chloride	lb	5.3E-21
Acidity, unspecified	lb	2.3E-08
Acids, unspecified	lb	4.4E-09
Acrylate, ion	lb	1.8E-11
Acrylonitrile	lb	1.4E-14
Actinides, radioactive, unspecified	Ci	1.2E-20
Alachlor	lb	5.3E-13
Aldehydes (unspecified)	lb	3.0E-15
Aluminium	lb	0.0067
Aluminum	lb	0.011
Aluminum, ion	lb	1.1E-10
Americium-241	Ci	6.2E-17
Ammonia	lb	0.0014
Ammonia, as N	lb	1.1E-10
Ammonium, ion	lb	3.1E-04
Aniline	lb	3.9E-20
Anthracene	lb	1.3E-13
Antimony	lb	1.8E-04
Antimony-122	Ci	4.6E-24
Antimony-124	Ci	6.4E-19
Antimony-125	Ci	4.4E-19
Antimony compounds	lb	6.0E-18
AOX, Adsorbable Organic Halogen as Cl	lb	7.3E-11
Arsenic, ion	lb	2.5E-05
Barite	lb	1.9E-12
Barium	lb	0.096
Barium-140	Ci	2.0E-23

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Bentazone	lb	4.4E-13
Benzene	lb	8.1E-05
Benzene, 1-methyl-4-(1-methylethyl)-	lb	5.0E-09
Benzene, 1,2-dichloro-	lb	2.1E-11
Benzene, chloro-	lb	4.4E-10
Benzene, ethyl-	lb	4.6E-06
Benzene, pentamethyl-	lb	3.8E-09
Benzenes, alkylated, unspecified	lb	1.5E-05
Benzo(a)anthracene	lb	1.0E-13
Benzo(b)fluoranthene	lb	1.1E-13
Benzoic acid	lb	8.0E-05
Beryllium	lb	1.3E-06
Biphenyl	lb	9.5E-07
BOD5, Biological Oxygen Demand	lb	0.055
Borate	lb	5.6E-19
Boron	lb	3.0E-04
Bromate	lb	2.0E-12
Bromide	lb	0.0094
Bromine	lb	1.5E-04
Butene	lb	2.2E-14
Butyl acetate	lb	6.5E-11
Butyrolactone	lb	1.1E-13
Cadmium	lb	1.9E-11
Cadmium, ion	lb	7.1E-06
Calcium, ion	lb	0.32
Carbon-14	Ci	3.1E-15
Carbon disulfide	lb	3.1E-19
Carbonate	lb	0.042
Carboxylic acids, unspecified	lb	1.7E-04
Cerium-141	Ci	8.1E-24
Cerium-144	Ci	2.5E-24
Cesium	lb	3.0E-16
Cesium-134	Ci	3.2E-15
Cesium-136	Ci	1.4E-24
Cesium-137	Ci	2.9E-14
Chloramine	lb	9.7E-20
Chlorate	lb	6.1E-11
Chloride	lb	4.71
Chlorinated solvents, unspecified	lb	2.0E-04
Chlorine	lb	6.7E-05
Chloroacetic acid	lb	8.7E-14
Chloroacetyl chloride	lb	1.5E-21
Chloroform	lb	1.0E-12
Chlorosulfonic acid	lb	1.3E-20

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Chlorpyrifos	lb	2.0E-13
Chromium	lb	1.9E-04
Chromium-51	Ci	2.4E-21
Chromium VI	lb	9.8E-05
Chromium, ion	lb	8.7E-09
Chrysene	lb	5.7E-13
Clomazone	lb	1.0E-13
Cobalt	lb	6.8E-06
Cobalt-57	Ci	4.6E-23
Cobalt-58	Ci	2.4E-17
Cobalt-60	Ci	1.3E-14
COD, Chemical Oxygen Demand	lb	0.20
Copper	lb	1.9E-05
Copper, ion	lb	3.5E-04
Cresol	lb	9.2E-16
Cumene	lb	1.3E-08
Curium alpha	Ci	8.2E-17
Cyanide	lb	1.6E-06
Cyclohexane	lb	4.1E-17
Decane	lb	2.3E-06
Detergent, oil	lb	1.4E-09
Detergents, unspecified	lb	4.3E-24
Dibenzofuran	lb	9.6E-09
Dibenzothiophene	lb	1.0E-08
Dichromate	lb	1.9E-11
Diethylamine	lb	1.8E-20
Dimethylamine	lb	4.1E-20
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	7.8E-19
Dipropylamine	lb	1.1E-20
Dissolved organics	lb	3.3E-12
Dissolved solids	lb	2.05
DOC, Dissolved Organic Carbon	lb	0.019
Docosane	lb	5.4E-08
Dodecane	lb	4.3E-06
Eicosane	lb	1.2E-06
Ethane, 1,2-dichloro-	lb	1.4E-06
Ethanol	lb	1.2E-10
Ethene	lb	1.3E-09
Ethene, chloro-	lb	1.4E-06
Ethyl acetate	lb	7.9E-15
Ethylamine	lb	1.3E-20
Ethylene diamine	lb	4.1E-16
Ethylene oxide	lb	9.0E-12
Fluoranthene	lb	1.2E-13

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Fluorene	lb	4.0E-07
Fluorene, 1-methyl-	lb	5.7E-09
Fluorenes, alkylated, unspecified	lb	8.5E-07
Fluoride	lb	0.0021
Fluorine	lb	2.3E-10
Fluosilicic acid	lb	3.1E-08
Formaldehyde	lb	3.7E-12
Formamide	lb	1.2E-20
Formate	lb	1.3E-18
Formic acid	lb	3.6E-21
Furan	lb	1.3E-13
Glutaraldehyde	lb	2.4E-16
Glyphosate	lb	3.5E-11
Glyphosate-trimesium	lb	2.9E-12
Heat, waste	Ci	1.8E-11
Hexadecane	lb	4.7E-06
Hexane	lb	1.1E-16
Hexanoic acid	lb	1.6E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	3.9E-14
Hydrocarbons, aliphatic, unsaturated	lb	3.6E-15
Hydrocarbons, aromatic	lb	4.9E-11
Hydrocarbons, unspecified	lb	0.016
Hydrogen-3, Tritium	Ci	9.1E-11
Hydrogen chloride	lb	4.0E-12
Hydrogen fluoride	lb	2.9E-10
Hydrogen peroxide	lb	1.1E-10
Hydrogen sulfide	lb	9.6E-06
Hydroxide	lb	6.6E-10
Hypochlorite	lb	1.4E-14
Iodide	lb	4.7E-09
Iodine-129	Ci	8.9E-15
Iodine-131	Ci	4.6E-19
Iodine-133	Ci	1.3E-23
Iron	lb	0.023
Iron-59	Ci	3.5E-24
Iron, ion	lb	9.4E-04
Isopropylamine	lb	3.0E-21
Lactic acid	lb	8.4E-21
Lanthanum-140	Ci	2.2E-23
Lead	lb	1.4E-04
Lead-210	Ci	4.2E-20
Lead-210/kg	lb	8.2E-15
Lithium, ion	lb	0.042
m-Xylene	lb	2.3E-06

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Magnesium	lb	0.034
Manganese	lb	0.0036
Manganese-54	Ci	2.1E-15
Mercury	lb	3.5E-06
Metallic ions, unspecified	lb	6.1E-11
Methane, dibromo-	lb	2.9E-17
Methane, dichloro-, HCC-30	lb	9.4E-15
Methane, monochloro-, R-40	lb	2.0E-09
Methane, trichlorofluoro-, CFC-11	lb	2.3E-11
Methanol	lb	6.1E-10
Methyl acetate	lb	4.3E-22
Methyl acrylate	lb	1.7E-10
Methyl amine	lb	4.0E-14
Methyl ethyl ketone	lb	4.1E-09
Methyl formate	lb	1.4E-14
Metolachlor	lb	1.0E-12
Metribuzin	lb	2.5E-13
Molybdenum	lb	6.3E-06
Molybdenum-99	Ci	7.5E-24
n-Hexacosane	lb	3.4E-08
Naphthalene	lb	1.4E-06
Naphthalene, 2-methyl-	lb	1.2E-06
Naphthalenes, alkylated, unspecified	lb	2.4E-07
Nickel	lb	1.8E-05
Nickel, ion	lb	5.7E-05
Niobium-95	Ci	1.5E-22
Nitrate	lb	6.3E-04
Nitrate compounds	lb	4.1E-07
Nitric acid	lb	2.6E-23
Nitrite	lb	6.6E-06
Nitrobenzene	lb	8.9E-20
Nitrogen	lb	2.8E-04
Nitrogen, organic bound	lb	1.4E-04
Nitrogen, total	lb	2.8E-04
o-Cresol	lb	2.3E-06
o-Xylene	lb	8.5E-07
Octadecane	lb	1.2E-06
Oils, unspecified	lb	0.0028
Organic substances, unspecified	lb	9.6E-24
p-Cresol	lb	2.4E-06
p-Xylene	lb	8.5E-07
PAH, polycyclic aromatic hydrocarbons	lb	4.6E-10
Particulates, < 10 um	lb	6.3E-13
Particulates, > 10 um	lb	4.4E-07

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Pendimethalin	lb	5.7E-12
Phenanthrene	lb	6.3E-08
Phenanthrenes, alkylated, unspecified	lb	9.9E-08
Phenol	lb	4.4E-05
Phenol, 2,4-dimethyl-	lb	2.2E-06
Phenols, unspecified	lb	2.1E-05
Phosphate	lb	0.0020
Phosphorus	lb	1.1E-09
Phosphorus compounds, unspecified	lb	1.7E-10
Plutonium-alpha	Ci	2.5E-16
Polonium-210	Ci	5.5E-20
Potassium	lb	1.2E-09
Potassium-40	Ci	2.5E-20
Potassium, ion	lb	0.012
Process solvents, unspecified	lb	1.3E-11
Propanal	lb	9.8E-21
Propane, 1,2-dichloro-	lb	1.9E-19
Propanol	lb	1.4E-20
Propene	lb	4.4E-09
Propionic acid	lb	6.2E-21
Propylamine	lb	3.9E-21
Propylene oxide	lb	2.1E-10
Protactinium-234	Ci	1.9E-20
Radioactive species, alpha emitters	Ci	1.1E-19
Radioactive species, Nuclides, unspecified	Ci	2.0E-07
Radium-224	Ci	1.8E-19
Radium-226	Ci	1.0E-12
Radium-226/kg	lb	2.8E-12
Radium-228	Ci	3.7E-19
Radium-228/kg	lb	1.5E-14
Rubidium	lb	3.0E-15
Ruthenium-103	Ci	1.6E-24
Ruthenium-106	Ci	6.2E-17
Scandium	lb	4.6E-07
Selenium	lb	4.3E-05
Silicon	lb	0.024
Silver	lb	9.5E-05
Silver-110	Ci	1.1E-19
Silver, ion	lb	2.6E-07
Sodium-24	Ci	5.7E-23
Sodium dichromate	lb	5.6E-13
Sodium formate	lb	1.2E-17
Sodium hydroxide	lb	7.9E-11
Sodium, ion	lb	1.52

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

Solids, inorganic	lb	1.5E-07
Solved solids	lb	0.048
Strontium	lb	0.0043
Strontium-89	Ci	2.3E-22
Strontium-90	Ci	3.0E-15
Styrene	lb	5.1E-11
Sulfate	lb	0.28
Sulfide	lb	9.2E-06
Sulfite	lb	9.6E-11
Sulfur	lb	2.0E-04
Surfactants	lb	4.2E-06
Surfactants, unspecified	lb	3.4E-05
Suspended solids, unspecified	lb	1.39
t-Butyl methyl ether	lb	1.8E-15
t-Butylamine	lb	9.8E-21
Tar	lb	6.5E-28
Technetium-99m	Ci	1.7E-22
Tellurium-123m	Ci	2.1E-22
Tellurium-132	Ci	4.3E-25
Tetradecane	lb	1.9E-06
Thallium	lb	1.0E-06
Thorium-228	Ci	7.3E-19
Thorium-230	Ci	2.5E-18
Thorium-232	Ci	4.0E-21
Thorium-234	Ci	1.9E-20
Tin	lb	1.8E-05
Tin, ion	lb	1.7E-05
Titanium	lb	1.8E-11
Titanium, ion	lb	7.2E-05
TOC, Total Organic Carbon	lb	0.019
Toluene	lb	7.5E-05
Toluene, 2-chloro-	lb	1.5E-20
Tributyltin compounds	lb	1.7E-15
Triethylene glycol	lb	3.9E-15
Trifluralin	lb	3.4E-12
Trimethylamine	lb	7.7E-22
Tungsten	lb	6.9E-07
Uranium-234	Ci	2.2E-20
Uranium-235	Ci	3.7E-20
Uranium-238	Ci	1.8E-14
Uranium alpha	Ci	1.1E-18
Urea	lb	1.2E-20
Vanadium	lb	3.9E-06
Vanadium, ion	lb	1.4E-05

Source: Franklin Associates, A Division of ERG

Table 54 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of E-Glass

VOC, volatile organic compounds, unspecified origin	lb	6.0E-12
Xylene	lb	3.5E-05
Yttrium	lb	5.3E-07
Zinc	lb	3.4E-04
Zinc-65	Ci	7.7E-22
Zinc, ion	lb	3.4E-04
Zirconium-95	Ci	8.9E-24

Source: Franklin Associates, A Division of ERG

Table 55. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

1-Butanol	lb	5.3E-13
1-Pentanol	lb	1.3E-13
1-Pentene	lb	9.5E-14
1-Propanol	lb	7.0E-11
1,4-Butanediol	lb	3.8E-11
2-Aminopropanol	lb	2.3E-14
2-Butene, 2-methyl-	lb	2.1E-17
2-Chloroacetophenone	lb	3.4E-08
2-Methyl-1-propanol	lb	0.0019
2-Nitrobenzoic acid	lb	4.1E-14
2-Propanol	lb	6.4E-07
2,4-D	lb	5.1E-12
4-Methyl-2-pentanone	lb	2.3E-05
5-methyl Chrysene	lb	6.8E-09
Acenaphthene	lb	1.6E-07
Acenaphthylene	lb	7.7E-08
Acetaldehyde	lb	9.4E-04
Acetic acid	lb	0.0020
Acetic acid, methyl ester	lb	1.1E-04
Acetone	lb	0.0018
Acetonitrile	lb	1.5E-08
Acetophenone	lb	7.3E-08
Acid gases	lb	6.0E-04
Acidity, unspecified	lb	1.6E-10
Acids, unspecified	lb	3.9E-12
Acrolein	lb	0.0029
Acrylic acid	lb	1.7E-09
Actinides, radioactive, unspecified	Ci	7.8E-15
Adipate, bis(1-ethylhexyl)-	lb	1.1E-12
Aerosols, radioactive, unspecified	Ci	1.9E-13
Alachlor	lb	3.6E-12
Aldehydes, unspecified	lb	0.0058
alpha-Pinene	lb	5.1E-04
Aluminium	lb	8.4E-04
Aluminum	lb	3.2E-15
Aluminum, fume or dust	lb	1.0E-12
Ammonia	lb	0.010
Ammonium carbonate	lb	1.7E-09
Ammonium chloride	lb	8.4E-04

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Ammonium, ion	lb	-8.6E-12
Aniline	lb	9.8E-12
Aniline, N,N-dimethyl-	lb	2.6E-06
Anthracene	lb	6.5E-08
Anthranilic acid	lb	3.0E-14
Antimony	lb	1.2E-05
Antimony-124	Ci	1.4E-18
Antimony-125	Ci	1.4E-17
Argon-41	Ci	1.0E-10
Arsenic	lb	1.5E-04
Arsenic trioxide	lb	1.3E-16
Arsine	lb	3.0E-14
Barium	lb	2.5E-06
Barium-140	Ci	8.9E-16
Bentazone	lb	3.0E-12
Benzal chloride	lb	7.4E-17
Benzaldehyde	lb	1.0E-09
Benzene	lb	0.047
Benzene, 1-methyl-2-nitro-	lb	3.6E-14
Benzene, 1,2-dichloro-	lb	9.0E-13
Benzene, 1,2,4-trichloro-	lb	1.4E-05
Benzene, 1,3,5-trimethyl-	lb	3.2E-16
Benzene, chloro-	lb	1.1E-07
Benzene, ethyl-	lb	0.018
Benzene, hexachloro-	lb	1.8E-09
Benzene, pentachloro-	lb	6.9E-11
Benzo(a)anthracene	lb	2.5E-08
Benzo(a)pyrene	lb	4.1E-07
Benzo(b)fluoranthene	lb	2.1E-14
Benzo(b,j,k)fluoranthene	lb	3.4E-08
Benzo(g,h,i)perylene	lb	4.5E-12
Benzo(ghi)perylene	lb	8.3E-09
Benzyl chloride	lb	3.4E-06
Beryllium	lb	8.9E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	3.1E-04
Biphenyl	lb	5.3E-07
Boric acid	lb	7.6E-05
Boron	lb	2.4E-05
Boron trifluoride	lb	2.7E-16
Bromine	lb	5.2E-04
Bromoform	lb	1.9E-07
Bromoxynil	lb	4.1E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	1.0E-05
Butadiene	lb	8.1E-06
Butane	lb	0.0046

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Butanol	lb	3.5E-05
Butene	lb	0.0042
Butyrolactone	lb	1.0E-11
Cadmium	lb	2.9E-05
Calcium	lb	2.1E-05
Carbon-14	Ci	7.9E-10
Carbon dioxide	lb	11.7
Carbon dioxide, biogenic	lb	241
Carbon dioxide, fossil	lb	2,925
Carbon dioxide, land transformation	lb	0.0068
Carbon disulfide	lb	2.7E-05
Carbon monoxide	lb	4.57
Carbon monoxide, biogenic	lb	5.0E-05
Carbon monoxide, fossil	lb	1.40
Carbonyl sulfide	lb	8.8E-05
Cerium-141	Ci	2.1E-16
Cesium-134	Ci	6.0E-17
Cesium-137	Ci	2.8E-16
Chloramine	lb	4.9E-13
Chloride	lb	1.3E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	9.9E-13
Chlorine	lb	0.0017
Chloroacetic acid	lb	9.2E-11
Chloroform	lb	3.5E-05
Chlorosilane, trimethyl-	lb	2.9E-10
Chlorosulfonic acid	lb	2.7E-13
Chlorpyrifos	lb	1.3E-12
Chromium	lb	1.1E-04
Chromium-51	Ci	1.4E-17
Chromium VI	lb	2.5E-05
Chromium, ion	lb	4.1E-11
Chrysene	lb	3.1E-08
Clomazone	lb	7.0E-13
Cobalt	lb	6.8E-05
Cobalt-58	Ci	1.9E-17
Cobalt-60	Ci	1.8E-16
Copper	lb	1.2E-05
Copper compounds	lb	3.8E-13
Cumene	lb	0.0092
Cyanide	lb	1.5E-05
Cyanoacetic acid	lb	2.2E-13
Cyclohexane	lb	7.6E-13
D-limonene	lb	2.3E-05
Dibenz(a,h)anthracene	lb	6.7E-15
Dicyclopentadiene	lb	6.9E-04

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Diethanolamine	lb	-2.1E-16
Diethylamine	lb	4.4E-12
Diethylene glycol	lb	0.0036
Dimethyl ether	lb	4.4E-14
Dimethyl malonate	lb	2.8E-13
Dimethyl sulfide	lb	5.0E-04
Dinitrogen monoxide	lb	0.055
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	lb	1.5E-13
Dioxins (unspecified)	lb	9.3E-18
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	1.1E-06
Dipropylamine	lb	2.8E-12
Ethane	lb	6.7E-04
Ethane, 1,1-difluoro-, HFC-152a	lb	2.0E-09
Ethane, 1,1,1-trichloro-, HCFC-140	lb	9.8E-08
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	2.4E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	8.1E-11
Ethane, 1,2-dibromo-	lb	5.9E-09
Ethane, 1,2-dichloro-	lb	7.2E-07
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	2.3E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	2.7E-08
Ethane, chloro-	lb	2.1E-07
Ethane, hexafluoro-, HFC-116	lb	4.0E-08
Ethanol	lb	2.2E-06
Ethene	lb	1.4E-04
Ethene, chloro-	lb	4.4E-07
Ethene, tetrachloro-	lb	1.4E-05
Ethyl acetate	lb	3.1E-06
Ethyl cellulose	lb	6.2E-09
Ethylamine	lb	2.4E-13
Ethylene diamine	lb	3.0E-12
Ethylene dibromide	lb	1.2E-06
Ethylene glycol	lb	0.0013
Ethylene oxide	lb	0.0017
Ethyne	lb	1.0E-06
Fluoranthene	lb	2.2E-07
Fluorene	lb	2.8E-07
Fluoride	lb	2.4E-04
Fluorine	lb	2.4E-06
Fluosilicic acid	lb	4.7E-08
Formaldehyde	lb	0.0054
Formamide	lb	2.3E-13
Formic acid	lb	1.1E-07
Furan	lb	3.0E-08
Glyphosate	lb	2.4E-10
Glyphosate-trimesium	lb	2.0E-11

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Heat, waste	Btu	493,943
Helium	lb	6.4E-05
Heptane	lb	3.6E-04
Hexamethylene diamine	lb	1.3E-15
Hexane	lb	7.7E-04
Hydrazine, methyl-	lb	8.3E-07
Hydrocarbons, aliphatic, alkanes, cyclic	lb	6.4E-07
Hydrocarbons, aliphatic, alkanes, unspecified	lb	0.0022
Hydrocarbons, aliphatic, unsaturated	lb	6.3E-06
Hydrocarbons, aromatic	lb	1.5E-04
Hydrocarbons, chlorinated	lb	8.7E-06
Hydrocarbons, unspecified	lb	0.012
Hydrogen	lb	0.0045
Hydrogen-3, Tritium	Ci	4.5E-09
Hydrogen bromide	lb	4.2E-12
Hydrogen chloride	lb	0.39
Hydrogen cyanide	lb	1.1E-12
Hydrogen fluoride	lb	0.059
Hydrogen iodide	lb	4.6E-15
Hydrogen peroxide	lb	1.4E-04
Hydrogen sulfide	lb	3.0E-05
Indeno(1,2,3-cd)pyrene	lb	1.9E-08
Iodine	lb	5.1E-06
Iodine-129	Ci	8.0E-13
Iodine-131	Ci	4.0E-11
Iodine-133	Ci	2.0E-15
Iodine-135	Ci	2.1E-15
Iron	lb	5.1E-05
Isobutyraldehyde	lb	3.0E-04
Isobutyric acid	lb	2.8E-04
Isocyanic acid	lb	3.2E-08
Isophorone	lb	2.8E-06
Isoprene	lb	4.3E-04
Isopropylamine	lb	5.4E-14
Kerosene	lb	4.0E-04
Krypton-85	Ci	3.2E-10
Krypton-85m	Ci	6.7E-09
Krypton-87	Ci	6.7E-12
Krypton-88	Ci	6.8E-12
Krypton-89	Ci	1.8E-12
Lactic acid	lb	2.2E-12
Lanthanum-140	Ci	7.6E-17
Lead	lb	2.0E-04
Lead-210	Ci	5.2E-12
Lead compounds	lb	3.8E-16

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

m-Xylene	lb	6.8E-08
Magnesium	lb	0.0034
Maleic anhydride	lb	0.0016
Manganese	lb	0.0013
Manganese-54	Ci	7.0E-18
Manganese compounds	lb	3.3E-14
Mercaptans, unspecified	lb	0.0011
Mercury	lb	4.3E-05
Metals, unspecified	lb	0.029
Methacrylic acid, methyl ester	lb	9.8E-08
Methane	lb	4.72
Methane, biogenic	lb	0.0011
Methane, bromo-, Halon 1001	lb	7.8E-07
Methane, bromochlorodifluoro-, Halon 1211	lb	4.5E-08
Methane, bromotrifluoro-, Halon 1301	lb	9.2E-07
Methane, chlorodifluoro-, HCFC-22	lb	2.8E-07
Methane, chlorotrifluoro-, CFC-13	lb	6.3E-06
Methane, dichloro-, HCC-30	lb	3.3E-04
Methane, dichlorodifluoro-, CFC-12	lb	4.0E-10
Methane, dichlorofluoro-, HCFC-21	lb	5.5E-13
Methane, fossil	lb	7.20
Methane, monochloro-, R-40	lb	2.6E-06
Methane, tetrachloro-, CFC-10	lb	3.6E-05
Methane, tetrafluoro-, CFC-14	lb	3.2E-07
Methane, trichlorofluoro-, CFC-11	lb	9.2E-11
Methane, trifluoro-, HFC-23	lb	1.8E-10
Methanesulfonic acid	lb	2.2E-13
Methanol	lb	0.027
Methyl acetate	lb	4.5E-04
Methyl acrylate	lb	1.9E-09
Methyl amine	lb	5.3E-12
Methyl borate	lb	4.9E-14
Methyl ethyl ketone	lb	5.3E-04
Methyl formate	lb	7.5E-12
Methyl lactate	lb	2.4E-12
Methyl mercaptan	lb	5.8E-05
Methyl methacrylate	lb	0.0042
Metolachlor	lb	7.1E-12
Metribuzin	lb	1.7E-12
Molybdenum	lb	8.1E-07
Monoethanolamine	lb	8.6E-08
Naphthalene	lb	8.2E-05
Nickel	lb	5.8E-04
Nickel compounds	lb	2.1E-14
Niobium-95	Ci	8.4E-19

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Nitrate	lb	3.8E-07
Nitric oxide	lb	2.0E-09
Nitrobenzene	lb	1.3E-11
Nitrogen	lb	5.80
Nitrogen dioxide	lb	5.4E-06
Nitrogen oxides	lb	9.25
Nitrogen, total	lb	7.3E-14
Nitrous oxide	lb	2.7E-04
NMVOC, non-methane volatile organic compounds, uns	lb	1.23
Noble gases, radioactive, unspecified	Ci	7.6E-06
Octane	lb	5.9E-10
Odorous sulfur	lb	0.016
Organic acids	lb	3.1E-06
Organic substances, unspecified	lb	0.035
Oxygen	lb	0.37
Ozone	lb	2.2E-05
PAH, polycyclic aromatic hydrocarbons	lb	4.5E-05
Palladium	lb	6.8E-20
Particulates, < 10 um	lb	1.21
Particulates, < 2.5 um	lb	0.32
Particulates, > 10 um	lb	0.032
Particulates, > 2.5 um, and < 10um	lb	0.46
Particulates, unspecified	lb	3.55
Pendimethalin	lb	3.9E-11
Pentane	lb	0.0019
PFC (perfluorocarbons)	lb	2.1E-13
Phenanthrene	lb	8.3E-07
Phenol	lb	0.0053
Phenol, 2,4-dichloro-	lb	1.5E-12
Phenol, pentachloro-	lb	1.8E-08
Phenols, unspecified	lb	7.1E-05
Phosphate	lb	1.3E-15
Phosphine	lb	4.6E-12
Phosphorus	lb	3.8E-07
Phthalate, dioctyl-	lb	3.6E-07
Phthalic acid,branched and linear di c7-c11 alk*	lb	0.0023
Phthalic anhydride	lb	4.7E-04
Platinum	lb	1.9E-12
Plutonium-238	Ci	1.1E-19
Plutonium-alpha	Ci	2.8E-19
Polonium-210	Ci	9.3E-12
Polychlorinated biphenyls	lb	3.1E-09
Polycyclic organic matter, unspecified	lb	1.6E-05
Potassium	lb	3.3E-04
Potassium-40	Ci	1.2E-12

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Propanal	lb	1.9E-06
Propane	lb	0.0016
Propene	lb	0.0054
Propionic acid	lb	2.7E-07
Propylamine	lb	7.2E-14
Propylene oxide	lb	0.033
Protactinium-234	Ci	1.1E-13
Pyrene	lb	1.0E-07
Radioactive species, other beta emitters	Ci	2.2E-12
Radioactive species, unspecified	Ci	2.1E-04
Radionuclides (Including Radon)	lb	0.023
Radium-226	Ci	4.9E-12
Radium-228	Ci	1.8E-12
Radon-220	Ci	4.3E-11
Radon-222	Ci	1.4E-05
Rhodium	lb	6.5E-20
Ruthenium-103	Ci	1.8E-19
Scandium	lb	1.1E-07
Selenium	lb	4.2E-04
Silicon	lb	3.9E-05
Silicon tetrafluoride	lb	2.3E-09
Silver	lb	4.8E-09
Silver-110	Ci	1.8E-18
Sodium	lb	4.4E-05
Sodium chlorate	lb	2.6E-08
Sodium dichromate	lb	8.3E-09
Sodium formate	lb	1.1E-10
Sodium hydroxide	lb	1.7E-08
Strontium	lb	7.7E-07
Styrene	lb	2.29
Sulfate	lb	9.8E-05
Sulfur dioxide	lb	10.1
Sulfur hexafluoride	lb	3.4E-07
Sulfur oxides	lb	2.53
Sulfur trioxide	lb	1.1E-10
Sulfur, total reduced	lb	0.0025
Sulfuric acid	lb	4.9E-04
Sulfuric acid, dimethyl ester	lb	2.3E-07
t-Butyl methyl ether	lb	1.7E-07
t-Butylamine	lb	2.0E-13
Tar	lb	1.5E-11
Tellurium	lb	8.1E-12
Terpenes	lb	0.0018
Thallium	lb	4.1E-09
Thorium	lb	3.6E-09

Source: Franklin Associates, A Division of ERG

Table 55 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Compression Molded Products

Thorium-228	Ci	3.1E-13
Thorium-230	Ci	4.5E-13
Thorium-232	Ci	3.8E-13
Thorium-234	Ci	1.1E-13
Tin	lb	1.4E-07
Tin oxide	lb	3.3E-17
Titanium	lb	2.7E-06
TOC, Total Organic Carbon	lb	0.0053
Toluene	lb	0.058
Toluene, 2-chloro-	lb	3.9E-12
Toluene, 2,4-dinitro-	lb	1.4E-09
Trichloroethane	lb	1.1E-14
Triethyl amine	lb	2.4E-12
Trifluralin	lb	3.9E-11
Trimethylamine	lb	1.7E-14
Tungsten	lb	1.2E-08
Uranium	lb	4.6E-09
Uranium-234	Ci	1.3E-12
Uranium-235	Ci	6.3E-14
Uranium-238	Ci	2.3E-12
Uranium alpha	Ci	5.9E-12
Used air	lb	0.024
Vanadium	lb	3.6E-05
Vinyl acetate	lb	5.7E-06
VOC, volatile organic compounds	lb	1.12
Water	lb	0.065
Xenon-131m	Ci	3.1E-11
Xenon-133	Ci	1.0E-09
Xenon-133m	Ci	3.9E-12
Xenon-135	Ci	4.1E-10
Xenon-135m	Ci	2.4E-10
Xenon-137	Ci	5.1E-12
Xenon-138	Ci	4.3E-11
Xylene	lb	0.049
Zinc	lb	0.0014
Zinc-65	Ci	3.5E-17
Zinc compounds	lb	6.6E-14
Zinc oxide	lb	6.6E-04
Zirconium	lb	3.5E-09
Zirconium-95	Ci	3.4E-17

Source: Franklin Associates, A Division of ERG

Table 56. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

1-Butanol	lb	0.0011
1-Pentanol	lb	3.0E-13
1-Pentene	lb	2.3E-13
1,4-Butanediol	lb	1.5E-11
2-Aminopropanol	lb	5.8E-14
2-Hexanone	lb	1.1E-06
2-Methyl-1-propanol	lb	0.0047
2-Methyl-2-butene	lb	5.0E-17
2-Propanol	lb	1.6E-11
2,4-D	lb	2.2E-13
4-Methyl-2-pentanone	lb	3.4E-07
Acenaphthene	lb	1.1E-08
Acenaphthylene	lb	6.6E-10
Acetaldehyde	lb	0.0035
Acetic acid	lb	0.0039
Acetone	lb	0.0080
Acetonitrile	lb	1.8E-13
Acetyl chloride	lb	2.4E-13
Acidity, unspecified	lb	0.14
Acids, unspecified	lb	0.0012
Acrylate, ion	lb	4.0E-09
Acrylonitrile	lb	7.9E-14
Actinides, radioactive, unspecified	Ci	1.3E-12
Alachlor	lb	1.6E-13
Aldehydes (unspecified)	lb	3.4E-13
Aluminium	lb	0.0081
Aluminum	lb	0.022
Aluminum, ion	lb	1.0E-10
Americium-241	Ci	1.8E-16
Ammonia	lb	0.0084
Ammonia, as N	lb	1.3E-09
Ammonium, ion	lb	0.0060
Aniline	lb	2.4E-11
Anthracene	lb	1.2E-12
Antimony	lb	8.0E-05
Antimony-122	Ci	5.3E-16
Antimony-124	Ci	2.1E-13
Antimony-125	Ci	2.0E-13
Antimony compounds	lb	2.6E-09
AOX, Adsorbable Organic Halogen as Cl	lb	1.1E-04
Arsenic	lb	6.3E-13
Arsenic, ion	lb	6.0E-05
Barite	lb	0.0063
Barium	lb	0.21

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Barium-140	Ci	2.3E-15
Bentazone	lb	1.3E-13
Benzene	lb	0.014
Benzene, 1-methyl-4-(1-methylethyl)-	lb	8.2E-09
Benzene, 1,2-dichloro-	lb	4.7E-09
Benzene, chloro-	lb	9.8E-08
Benzene, ethyl-	lb	1.7E-04
Benzene, pentamethyl-	lb	6.1E-09
Benzenes, alkylated, unspecified	lb	3.1E-05
Benzo(a)anthracene	lb	1.0E-12
Benzo(b)fluoranthene	lb	1.1E-12
Benzoic acid	lb	1.7E-04
Beryllium	lb	6.3E-06
Biphenyl	lb	2.0E-06
BOD5, Biological Oxygen Demand	lb	4.21
Borate	lb	2.5E-11
Boron	lb	7.9E-04
Bromate	lb	2.8E-05
Bromide	lb	0.021
Bromine	lb	0.0013
Butene	lb	0.010
Butyl acetate	lb	0.0014
Butyrolactone	lb	2.4E-11
Cadmium	lb	1.3E-07
Cadmium, ion	lb	1.5E-05
Calcium, ion	lb	0.51
Carbon-14	Ci	9.1E-15
Carbon disulfide	lb	1.3E-11
Carbonate	lb	0.012
Carboxylic acids, unspecified	lb	0.0074
Cerium-141	Ci	9.2E-16
Cerium-144	Ci	2.8E-16
Cesium	lb	1.7E-06
Cesium-134	Ci	1.9E-13
Cesium-136	Ci	1.6E-16
Cesium-137	Ci	1.5E-10
Chloramine	lb	4.4E-12
Chlorate	lb	2.1E-04
Chloride	lb	5.96
Chlorinated solvents, unspecified	lb	5.7E-05
Chlorine	lb	2.0E-05
Chloroacetic acid	lb	3.9E-09
Chloroacetyl chloride	lb	7.8E-14
Chloroform	lb	2.3E-10

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Chlorosulfonic acid	lb	6.7E-13
Chlorpyrifos	lb	5.7E-14
Chromium	lb	9.2E-04
Chromium-51	Ci	2.6E-13
Chromium VI	lb	9.7E-05
Chromium, ion	lb	5.0E-06
Chrysene	lb	5.7E-12
Clomazone	lb	3.0E-14
Cobalt	lb	7.2E-05
Cobalt-57	Ci	5.2E-15
Cobalt-58	Ci	1.8E-12
Cobalt-60	Ci	1.5E-12
COD, Chemical Oxygen Demand	lb	3.25
Copper	lb	2.6E-05
Copper, ion	lb	3.4E-04
Cresol	lb	7.9E-15
Cumene	lb	0.022
Curium alpha	Ci	2.4E-16
Cyanide	lb	7.5E-06
Cyclohexane	lb	3.2E-15
Decane	lb	4.8E-06
Detergent, oil	lb	6.8E-07
Detergents, unspecified	lb	5.2E-15
Dibenzofuran	lb	1.6E-08
Dibenzothiophene	lb	1.6E-08
Dichromate	lb	3.1E-08
Diethylamine	lb	1.0E-11
Diethylene glycol	lb	0.0033
Dimethylamine	lb	6.0E-12
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.9E-17
Dipropylamine	lb	6.7E-12
Dissolved organics	lb	1.8E-06
Dissolved solids	lb	6.07
DOC, Dissolved Organic Carbon	lb	0.53
Docosane	lb	8.7E-08
Dodecane	lb	9.1E-06
Eicosane	lb	2.5E-06
Ethane, 1,2-dichloro-	lb	4.1E-07
Ethanol	lb	0.0024
Ethene	lb	1.4E-04
Ethene, chloro-	lb	3.9E-07
Ethyl acetate	lb	1.3E-11
Ethylamine	lb	5.7E-13
Ethylene diamine	lb	7.3E-12

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Ethylene oxide	lb	1.9E-09
Fluoranthene	lb	1.2E-12
Fluorene	lb	8.5E-07
Fluorene, 1-methyl-	lb	9.3E-09
Fluorenes, alkylated, unspecified	lb	1.8E-06
Fluoride	lb	0.0039
Fluorine	lb	4.8E-10
Fluosilicic acid	lb	8.5E-08
Formaldehyde	lb	2.2E-07
Formamide	lb	5.5E-13
Formate	lb	6.1E-11
Formic acid	lb	1.6E-13
Furan	lb	1.9E-13
Glutaraldehyde	lb	7.8E-07
Glyphosate	lb	1.0E-11
Glyphosate-trimesium	lb	8.5E-13
Haloalkanes	lb	3.3E-14
Heat, waste	Ci	3.9E-10
Hexadecane	lb	1.0E-05
Hexane	lb	8.8E-16
Hexanoic acid	lb	3.5E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	2.2E-04
Hydrocarbons, aliphatic, unsaturated	lb	2.0E-05
Hydrocarbons, aromatic	lb	9.1E-04
Hydrocarbons, unspecified	lb	0.017
Hydrogen-3, Tritium	Ci	3.4E-07
Hydrogen chloride	lb	6.2E-11
Hydrogen fluoride	lb	9.2E-09
Hydrogen peroxide	lb	3.4E-08
Hydrogen sulfide	lb	1.7E-05
Hydroxide	lb	1.3E-07
Hypochlorite	lb	1.5E-06
Iodide	lb	1.7E-04
Iodine-129	Ci	2.6E-14
Iodine-131	Ci	4.0E-14
Iodine-133	Ci	1.4E-15
Iron	lb	0.044
Iron-59	Ci	4.0E-16
Iron, ion	lb	0.0089
Isopropylamine	lb	1.3E-13
Lactic acid	lb	5.2E-12
Lanthanum-140	Ci	2.5E-15
Lead	lb	1.6E-04
Lead-210	Ci	1.3E-11

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Lead-210/kg	lb	1.7E-14
Lead 210	lb	2.4E-22
Lithium, ion	lb	0.058
m-Xylene	lb	4.8E-06
Magnesium	lb	0.11
Manganese	lb	0.0079
Manganese-54	Ci	1.2E-13
Mercury	lb	2.2E-06
Metallic ions, unspecified	lb	2.5E-05
Methane, dibromo-	lb	1.8E-16
Methane, dichloro-, HCC-30	lb	2.0E-05
Methane, monochloro-, R-40	lb	3.3E-09
Methane, trichlorofluoro-, CFC-11	lb	1.6E-11
Methanol	lb	0.0017
Methyl acetate	lb	2.3E-14
Methyl acrylate	lb	3.8E-08
Methyl amine	lb	1.3E-11
Methyl ethyl ketone	lb	6.6E-09
Methyl formate	lb	3.0E-12
Metolachlor	lb	3.0E-13
Metribuzin	lb	7.4E-14
Molybdenum	lb	2.2E-05
Molybdenum-99	Ci	8.5E-16
n-Hexacosane	lb	5.4E-08
n-Hexadecane	lb	1.5E-15
Naphthalene	lb	3.0E-06
Naphthalene, 2-methyl-	lb	2.5E-06
Naphthalenes, alkylated, unspecified	lb	5.1E-07
Nickel	lb	3.9E-05
Nickel, ion	lb	2.8E-04
Niobium-95	Ci	1.7E-14
Nitrate	lb	0.0035
Nitrate compounds	lb	1.9E-07
Nitric acid	lb	8.3E-09
Nitrite	lb	2.8E-06
Nitrobenzene	lb	5.3E-11
Nitrogen	lb	0.011
Nitrogen, organic bound	lb	3.8E-04
Nitrogen, total	lb	4.5E-04
o-Cresol	lb	4.8E-06
o-Xylene	lb	1.8E-06
Octadecane	lb	2.5E-06
Oils, unspecified	lb	0.13
Organic substances, unspecified	lb	1.2E-14

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

p-Cresol	lb	5.2E-06
p-Xylene	lb	1.8E-06
PAH, polycyclic aromatic hydrocarbons	lb	1.0E-05
Particulates, < 10 um	lb	3.0E-12
Particulates, > 10 um	lb	6.9E-06
Pendimethalin	lb	1.7E-12
Phenanthrene	lb	1.3E-07
Phenanthrenes, alkylated, unspecified	lb	2.1E-07
Phenol	lb	0.026
Phenol, 2,4-dimethyl-	lb	4.7E-06
Phenols, unspecified	lb	0.018
Phosphate	lb	0.010
Phosphorus	lb	4.3E-05
Phosphorus compounds, unspecified	lb	5.1E-11
Plutonium-alpha	Ci	7.1E-16
Polonium-210	Ci	1.8E-11
Potassium	lb	3.8E-08
Potassium-40	Ci	3.6E-12
Potassium, ion	lb	0.028
Process solvents, unspecified	lb	1.9E-11
Propanal	lb	4.3E-13
Propane, 1,2-dichloro-	lb	1.1E-18
Propanol	lb	6.7E-13
Propene	lb	0.021
Propionic acid	lb	3.7E-12
Propylamine	lb	1.7E-13
Propylene oxide	lb	0.065
Protactinium-234	Ci	2.0E-12
Radioactive species, alpha emitters	Ci	3.2E-14
Radioactive species, Nuclides, unspecified	Ci	3.2E-07
Radium-224	Ci	1.0E-09
Radium-226	Ci	2.9E-09
Radium-226/kg	lb	6.0E-12
Radium-228	Ci	2.1E-09
Radium-228/kg	lb	3.1E-14
Rubidium	lb	1.7E-05
Ruthenium-103	Ci	1.8E-16
Ruthenium-106	Ci	1.8E-16
Scandium	lb	7.2E-06
Selenium	lb	7.8E-05
Silicon	lb	0.080
Silver	lb	2.1E-04
Silver-110	Ci	1.4E-12
Silver, ion	lb	1.8E-06

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Sodium-24	Ci	6.4E-15
Sodium dichromate	lb	4.0E-08
Sodium formate	lb	2.6E-10
Sodium hydroxide	lb	0.019
Sodium, ion	lb	2.16
Solids, inorganic	lb	0.0036
Solved solids	lb	0.045
Strontium	lb	0.013
Strontium-89	Ci	2.5E-14
Strontium-90	Ci	1.1E-09
Styrene	lb	1.2E-04
Sulfate	lb	0.64
Sulfide	lb	1.9E-04
Sulfite	lb	4.0E-06
Sulfur	lb	7.2E-04
Surfactants	lb	3.8E-05
Surfactants, unspecified	lb	4.7E-05
Suspended solids, unspecified	lb	2.45
t-Butyl methyl ether	lb	3.7E-06
t-Butylamine	lb	4.7E-13
Tar	lb	2.1E-13
Technetium-99m	Ci	2.0E-14
Tellurium-123m	Ci	2.3E-14
Tellurium-132	Ci	4.9E-17
Tetradecane	lb	3.9E-06
Thallium	lb	2.7E-06
Thorium-228	Ci	4.2E-09
Thorium-230	Ci	2.7E-10
Thorium-232	Ci	4.3E-13
Thorium-234	Ci	2.0E-12
Tin	lb	3.8E-05
Tin, ion	lb	1.1E-05
Titanium	lb	1.6E-10
Titanium, ion	lb	3.1E-04
TOC, Total Organic Carbon	lb	0.53
Toluene	lb	4.0E-04
Toluene, 2-chloro-	lb	8.2E-12
Tributyltin compounds	lb	1.5E-06
Triethylene glycol	lb	4.6E-07
Trifluralin	lb	1.0E-12
Trimethylamine	lb	4.1E-14
Tungsten	lb	7.2E-06
Uranium-234	Ci	2.4E-12
Uranium-235	Ci	4.0E-12

Source: Franklin Associates, A Division of ERG

Table 56 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Compression Molded Products

Uranium-238	Ci	1.3E-11
Uranium alpha	Ci	1.2E-10
Urea	lb	5.2E-13
Vanadium	lb	2.0E-05
Vanadium, ion	lb	3.4E-05
VOC, volatile organic compounds, unspecified origin	lb	6.0E-04
Xylene	lb	2.5E-04
Yttrium	lb	1.1E-06
Zinc	lb	8.3E-04
Zinc-65	Ci	8.7E-14
Zinc, ion	lb	0.0010
Zirconium-95	Ci	1.0E-15

Source: Franklin Associates, A Division of ERG

Table 57. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

1-Butanol	lb	1.4E-12
1-Pentanol	lb	3.5E-13
1-Pentene	lb	2.6E-13
1-Propanol	lb	2.1E-10
1,4-Butanediol	lb	3.9E-11
2-Aminopropanol	lb	6.5E-14
2-Butene, 2-methyl-	lb	5.8E-17
2-Chloroacetophenone	lb	4.9E-08
2-Methyl-1-propanol	lb	0.0025
2-Nitrobenzoic acid	lb	1.2E-13
2-Propanol	lb	5.7E-07
2,4-D	lb	3.8E-12
4-Methyl-2-pentanone	lb	1.7E-05
5-methyl Chrysene	lb	5.8E-09
Acenaphthene	lb	1.3E-07
Acenaphthylene	lb	6.6E-08
Acetaldehyde	lb	5.0E-04
Acetic acid	lb	0.0029
Acetic acid, methyl ester	lb	3.3E-04
Acetone	lb	3.4E-04
Acetonitrile	lb	4.7E-08
Acetophenone	lb	1.0E-07
Acid gases	lb	0.0019
Acidity, unspecified	lb	4.3E-12
Acids, unspecified	lb	2.9E-12
Acrolein	lb	6.0E-04
Acrylic acid	lb	1.5E-09
Actinides, radioactive, unspecified	Ci	2.3E-14
Adipate, bis(1-ethylhexyl)-	lb	1.2E-12
Aerosols, radioactive, unspecified	Ci	5.8E-13
Alachlor	lb	2.7E-12
Aldehydes, unspecified	lb	0.017
alpha-Pinene	lb	0.0036
Aluminium	lb	9.2E-04
Aluminum	lb	1.8E-17
Aluminum, fume or dust	lb	1.1E-12
Ammonia	lb	0.013
Ammonium carbonate	lb	5.0E-09
Ammonium chloride	lb	7.1E-04

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Ammonium, ion	lb	-3.9E-13
Aniline	lb	3.0E-11
Aniline, N,N-dimethyl-	lb	8.2E-06
Anthracene	lb	5.5E-08
Anthranilic acid	lb	8.4E-14
Antimony	lb	6.6E-06
Antimony-124	Ci	3.2E-18
Antimony-125	Ci	3.3E-17
Argon-41	Ci	3.0E-10
Arsenic	lb	1.2E-04
Arsenic trioxide	lb	7.1E-18
Arsine	lb	1.8E-14
Barium	lb	3.2E-06
Barium-140	Ci	2.2E-15
Bentazone	lb	2.3E-12
Benzal chloride	lb	1.7E-16
Benzaldehyde	lb	2.9E-09
Benzene	lb	0.065
Benzene, 1-methyl-2-nitro-	lb	9.9E-14
Benzene, 1,2-dichloro-	lb	2.5E-12
Benzene, 1,2,4-trichloro-	lb	1.0E-05
Benzene, 1,3,5-trimethyl-	lb	6.7E-17
Benzene, chloro-	lb	1.5E-07
Benzene, ethyl-	lb	0.048
Benzene, hexachloro-	lb	5.3E-09
Benzene, pentachloro-	lb	7.3E-11
Benzo(a)anthracene	lb	2.1E-08
Benzo(a)pyrene	lb	2.4E-07
Benzo(b)fluoranthene	lb	2.2E-15
Benzo(b,j,k)fluoranthene	lb	2.9E-08
Benzo(ghi)perylene	lb	7.1E-09
Benzyl chloride	lb	4.9E-06
Beryllium	lb	6.4E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	0.0015
Biphenyl	lb	4.5E-07
Boric acid	lb	5.7E-05
Boron	lb	7.0E-05
Boron trifluoride	lb	2.4E-16
Bromine	lb	0.0016
Bromoform	lb	2.7E-07
Bromoxynil	lb	3.1E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	2.2E-12
Butadiene	lb	3.6E-06
Butane	lb	0.010
Butanol	lb	1.1E-04

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Butene	lb	0.0056
Butyrolactone	lb	9.0E-12
Cadmium	lb	2.9E-05
Calcium	lb	5.8E-05
Carbon-14	Ci	2.4E-09
Carbon dioxide	lb	7.55
Carbon dioxide, biogenic	lb	57.4
Carbon dioxide, fossil	lb	3,172
Carbon dioxide, land transformation	lb	0.0019
Carbon disulfide	lb	3.4E-05
Carbon monoxide	lb	6.68
Carbon monoxide, biogenic	lb	7.5E-05
Carbon monoxide, fossil	lb	1.62
Carbonyl sulfide	lb	0.013
Cerium-141	Ci	5.2E-16
Cesium-134	Ci	3.5E-17
Cesium-137	Ci	4.7E-16
Chloramine	lb	1.3E-12
Chloride	lb	7.0E-11
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	7.4E-13
Chlorine	lb	0.0011
Chloroacetic acid	lb	2.4E-10
Chloroform	lb	2.6E-05
Chlorosilane, trimethyl-	lb	3.8E-10
Chlorosulfonic acid	lb	7.5E-13
Chlorpyrifos	lb	1.0E-12
Chromium	lb	9.6E-05
Chromium-51	Ci	3.4E-17
Chromium VI	lb	2.1E-05
Chromium, ion	lb	1.1E-12
Chrysene	lb	2.6E-08
Clomazone	lb	5.2E-13
Cobalt	lb	3.8E-04
Cobalt-58	Ci	4.7E-17
Cobalt-60	Ci	4.2E-16
Copper	lb	1.9E-05
Copper compounds	lb	4.3E-13
Cumene	lb	0.012
Cyanide	lb	1.8E-05
Cyanoacetic acid	lb	6.1E-13
Cyclohexane	lb	6.4E-14
D-limonene	lb	3.8E-04
Dibenz(a,h)anthracene	lb	6.8E-16
Dicyclopentadiene	lb	0.0021
Diethanolamine	lb	-9.8E-18

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Diethylamine	lb	1.3E-11
Diethylene glycol	lb	0.0047
Dimethyl ether	lb	1.7E-14
Dimethyl malonate	lb	7.7E-13
Dimethyl sulfide	lb	3.7E-04
Dinitrogen monoxide	lb	0.055
Dioxins (unspecified)	lb	2.1E-18
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	1.9E-07
Dipropylamine	lb	8.5E-12
Ethane	lb	0.0019
Ethane, 1,1-difluoro-, HFC-152a	lb	5.8E-09
Ethane, 1,1,1-trichloro-, HCFC-140	lb	1.4E-07
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	5.3E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	7.0E-11
Ethane, 1,2-dibromo-	lb	8.4E-09
Ethane, 1,2-dichloro-	lb	9.7E-07
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	5.0E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	7.8E-08
Ethane, chloro-	lb	2.9E-07
Ethane, hexafluoro-, HFC-116	lb	6.6E-08
Ethanol	lb	6.6E-06
Ethene	lb	2.5E-04
Ethene, chloro-	lb	4.1E-07
Ethene, tetrachloro-	lb	1.2E-05
Ethyl acetate	lb	2.7E-06
Ethyl cellulose	lb	5.4E-09
Ethylamine	lb	6.4E-13
Ethylene diamine	lb	8.4E-12
Ethylene dibromide	lb	1.8E-06
Ethylene glycol	lb	0.0041
Ethylene oxide	lb	0.0052
Ethyne	lb	1.7E-06
Fluoranthene	lb	1.9E-07
Fluorene	lb	2.4E-07
Fluoride	lb	3.3E-04
Fluorine	lb	6.1E-06
Fluosilicic acid	lb	7.2E-08
Formaldehyde	lb	0.0037
Formamide	lb	6.3E-13
Formic acid	lb	3.2E-07
Furan	lb	9.0E-08
Glyphosate	lb	1.8E-10
Glyphosate-trimesium	lb	1.5E-11
Heat, waste	Btu	592,612
Helium	lb	2.0E-04

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Heptane	lb	0.0011
Hexamethylene diamine	lb	1.3E-16
Hexane	lb	0.0024
Hydrazine, methyl-	lb	1.2E-06
Hydrocarbons, aliphatic, alkanes, cyclic	lb	3.8E-07
Hydrocarbons, aliphatic, alkanes, unspecified	lb	2.5E-04
Hydrocarbons, aliphatic, unsaturated	lb	1.8E-05
Hydrocarbons, aromatic	lb	2.8E-04
Hydrocarbons, chlorinated	lb	6.5E-06
Hydrocarbons, unspecified	lb	0.063
Hydrogen	lb	0.0050
Hydrogen-3, Tritium	Ci	1.4E-08
Hydrogen bromide	lb	4.4E-13
Hydrogen chloride	lb	0.32
Hydrogen cyanide	lb	3.7E-13
Hydrogen fluoride	lb	0.049
Hydrogen iodide	lb	4.8E-16
Hydrogen peroxide	lb	2.9E-04
Hydrogen sulfide	lb	5.6E-05
Indeno(1,2,3-cd)pyrene	lb	1.6E-08
Iodine	lb	1.6E-05
Iodine-129	Ci	2.4E-12
Iodine-131	Ci	1.2E-10
Iodine-133	Ci	5.4E-15
Iodine-135	Ci	6.0E-15
Iron	lb	1.4E-04
Isobutyraldehyde	lb	9.2E-04
Isobutyric acid	lb	3.6E-04
Isocyanic acid	lb	9.2E-08
Isophorone	lb	4.1E-06
Isoprene	lb	4.1E-09
Isopropylamine	lb	1.4E-13
Kerosene	lb	3.4E-04
Krypton-85	Ci	9.5E-10
Krypton-85m	Ci	1.4E-09
Krypton-87	Ci	1.9E-11
Krypton-88	Ci	1.8E-11
Krypton-89	Ci	4.7E-12
Lactic acid	lb	6.7E-12
Lanthanum-140	Ci	1.8E-16
Lead	lb	1.7E-04
Lead-210	Ci	1.4E-11
Lead compounds	lb	7.9E-17
m-Xylene	lb	2.0E-07
Magnesium	lb	0.0029

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Maleic anhydride	lb	0.0050
Manganese	lb	3.4E-04
Manganese-54	Ci	1.7E-17
Manganese compounds	lb	3.7E-14
Mercaptans, unspecified	lb	0.0015
Mercury	lb	4.6E-05
Metals, unspecified	lb	0.0048
Methacrylic acid, methyl ester	lb	1.4E-07
Methane	lb	2.00
Methane, biogenic	lb	0.0011
Methane, bromo-, Halon 1001	lb	1.1E-06
Methane, bromochlorodifluoro-, Halon 1211	lb	8.8E-08
Methane, bromotrifluoro-, Halon 1301	lb	2.9E-06
Methane, chlorodifluoro-, HCFC-22	lb	5.9E-07
Methane, chlorotrifluoro-, CFC-13	lb	9.2E-06
Methane, dichloro-, HCC-30	lb	1.5E-04
Methane, dichlorodifluoro-, CFC-12	lb	7.8E-10
Methane, dichlorofluoro-, HCFC-21	lb	5.4E-13
Methane, fossil	lb	10.9
Methane, monochloro-, R-40	lb	3.7E-06
Methane, tetrachloro-, CFC-10	lb	1.6E-05
Methane, tetrafluoro-, CFC-14	lb	5.5E-07
Methane, trichlorofluoro-, CFC-11	lb	1.9E-11
Methane, trifluoro-, HFC-23	lb	1.7E-10
Methanesulfonic acid	lb	6.2E-13
Methanol	lb	0.025
Methyl acetate	lb	7.8E-04
Methyl acrylate	lb	1.7E-09
Methyl amine	lb	8.1E-12
Methyl borate	lb	1.3E-13
Methyl ethyl ketone	lb	6.9E-04
Methyl formate	lb	6.7E-12
Methyl lactate	lb	7.3E-12
Methyl mercaptan	lb	4.3E-05
Methyl methacrylate	lb	0.17
Metolachlor	lb	5.3E-12
Metribuzin	lb	1.3E-12
Molybdenum	lb	2.5E-06
Monoethanolamine	lb	9.0E-08
Naphthalene	lb	2.9E-05
Nickel	lb	7.2E-04
Nickel compounds	lb	8.0E-15
Niobium-95	Ci	2.0E-18
Nitrate	lb	1.1E-06
Nitric oxide	lb	1.4E-11

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Nitrobenzene	lb	4.0E-11
Nitrogen	lb	2.6E-08
Nitrogen dioxide	lb	4.9E-06
Nitrogen oxides	lb	7.96
Nitrogen, total	lb	5.4E-14
Nitrous oxide	lb	3.3E-04
NMVOC, non-methane volatile organic compounds, uns	lb	2.57
Noble gases, radioactive, unspecified	Ci	2.3E-05
Octane	lb	3.1E-11
Odorous sulfur	lb	8.1E-05
Organic acids	lb	2.6E-06
Organic substances, unspecified	lb	0.061
Oxygen	lb	8.6E-07
Ozone	lb	6.7E-05
PAH, polycyclic aromatic hydrocarbons	lb	1.9E-05
Palladium	lb	4.4E-20
Particulates, < 10 um	lb	1.43
Particulates, < 2.5 um	lb	0.32
Particulates, > 10 um	lb	0.032
Particulates, > 2.5 um, and < 10um	lb	0.56
Particulates, unspecified	lb	2.43
Pendimethalin	lb	2.9E-11
Pentane	lb	0.0060
PFC (perfluorocarbons)	lb	8.0E-14
Phenanthrene	lb	7.1E-07
Phenol	lb	7.8E-05
Phenol, 2,4-dichloro-	lb	4.6E-12
Phenol, pentachloro-	lb	5.3E-08
Phenols, unspecified	lb	3.8E-05
Phosphate	lb	9.7E-16
Phosphine	lb	1.4E-12
Phosphorus	lb	9.2E-07
Phthalate, dioctyl-	lb	5.1E-07
Phthalic acid,branched and linear di c7-c11 alk*	lb	0.0071
Phthalic anhydride	lb	7.6E-04
Platinum	lb	3.2E-12
Plutonium-238	Ci	3.2E-19
Plutonium-alpha	Ci	7.5E-19
Polonium-210	Ci	2.5E-11
Polychlorinated biphenyls	lb	9.2E-09
Polycyclic organic matter, unspecified	lb	2.3E-05
Potassium	lb	2.9E-04
Potassium-40	Ci	3.2E-12
Propanal	lb	2.7E-06
Propane	lb	0.0050

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Propene	lb	0.0044
Propionic acid	lb	5.9E-07
Propylamine	lb	2.0E-13
Propylene oxide	lb	0.10
Protactinium-234	Ci	3.2E-13
Pyrene	lb	8.7E-08
Radioactive species, other beta emitters	Ci	6.3E-12
Radioactive species, unspecified	Ci	1.8E-04
Radionuclides (Including Radon)	lb	0.019
Radium-226	Ci	1.4E-11
Radium-228	Ci	3.1E-12
Radon-220	Ci	1.3E-10
Radon-222	Ci	4.3E-05
Rhodium	lb	4.3E-20
Ruthenium-103	Ci	4.5E-19
Scandium	lb	3.2E-07
Selenium	lb	3.5E-04
Silicon	lb	4.3E-04
Silicon tetrafluoride	lb	7.1E-09
Silver	lb	1.4E-08
Silver-110	Ci	4.4E-18
Sodium	lb	1.2E-04
Sodium chlorate	lb	7.9E-08
Sodium dichromate	lb	2.5E-08
Sodium formate	lb	2.9E-10
Sodium hydroxide	lb	1.5E-08
Strontium	lb	1.8E-06
Styrene	lb	37.1
Sulfate	lb	3.0E-04
Sulfur dioxide	lb	9.36
Sulfur hexafluoride	lb	1.0E-06
Sulfur oxides	lb	2.54
Sulfur trioxide	lb	3.2E-10
Sulfur, total reduced	lb	0.0018
Sulfuric acid	lb	0.0015
Sulfuric acid, dimethyl ester	lb	3.4E-07
t-Butyl methyl ether	lb	2.5E-07
t-Butylamine	lb	5.4E-13
Tar	lb	3.4E-19
Tellurium	lb	1.6E-13
Terpenes	lb	0.0013
Thallium	lb	7.8E-09
Thorium	lb	5.7E-09
Thorium-228	Ci	7.5E-13
Thorium-230	Ci	1.4E-12

Source: Franklin Associates, A Division of ERG

Table 57 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Molded Products

Thorium-232	Ci	1.0E-12
Thorium-234	Ci	3.2E-13
Tin	lb	2.4E-07
Tin oxide	lb	6.9E-18
Titanium	lb	6.9E-06
Titanium Dioxide (nano)	lb	0.0013
TOC, Total Organic Carbon	lb	0.0050
Toluene	lb	0.091
Toluene, 2-chloro-	lb	1.2E-11
Toluene, 2,4-dinitro-	lb	2.0E-09
Trichloroethane	lb	4.1E-12
Triethyl amine	lb	2.7E-12
Trifluralin	lb	2.9E-11
Trimethylamine	lb	4.8E-14
Tungsten	lb	3.6E-08
Uranium	lb	7.0E-09
Uranium-234	Ci	3.9E-12
Uranium-235	Ci	1.8E-13
Uranium-238	Ci	6.5E-12
Uranium alpha	Ci	1.8E-11
Used air	lb	8.7E-04
Vanadium	lb	1.1E-04
Vinyl acetate	lb	5.3E-08
VOC, volatile organic compounds	lb	12.9
Water	lb	0.063
Xenon-131m	Ci	8.5E-11
Xenon-133	Ci	2.7E-09
Xenon-133m	Ci	1.2E-11
Xenon-135	Ci	1.1E-09
Xenon-135m	Ci	6.6E-10
Xenon-137	Ci	1.3E-11
Xenon-138	Ci	1.1E-10
Xylene	lb	0.066
Zinc	lb	3.0E-05
Zinc-65	Ci	8.6E-17
Zinc compounds	lb	7.4E-14
Zinc oxide	lb	1.4E-17
Zirconium	lb	1.1E-08
Zirconium-95	Ci	8.4E-17

Source: Franklin Associates, A Division of ERG

Table 58. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

1-Butanol	lb	0.0014
1-Pentanol	lb	8.3E-13
1-Pentene	lb	6.3E-13
1,4-Butanediol	lb	1.6E-11
2-Aminopropanol	lb	1.6E-13
2-Hexanone	lb	1.7E-06
2-Methyl-1-propanol	lb	0.0060
2-Methyl-2-butene	lb	1.4E-16
2-Propanol	lb	5.7E-12
2,4-D	lb	1.6E-13
4-Methyl-2-pentanone	lb	5.3E-07
Acenaphthene	lb	3.3E-08
Acenaphthylene	lb	2.1E-09
Acetaldehyde	lb	0.0076
Acetic acid	lb	0.0049
Acetone	lb	1.3E-06
Acetonitrile	lb	5.1E-13
Acetyl chloride	lb	6.5E-13
Acidity, unspecified	lb	0.43
Acids, unspecified	lb	0.0023
Acrylate, ion	lb	3.5E-09
Acrylonitrile	lb	7.6E-15
Actinides, radioactive, unspecified	Ci	3.9E-12
Alachlor	lb	1.2E-13
Aldehydes (unspecified)	lb	6.5E-16
Aluminium	lb	0.017
Aluminum	lb	0.029
Aluminum, ion	lb	2.3E-11
Americium-241	Ci	3.6E-17
Ammonia	lb	0.010
Ammonia, as N	lb	6.6E-07
Ammonium, ion	lb	0.016
Aniline	lb	7.2E-11
Anthracene	lb	6.9E-14
Antimony	lb	7.6E-05
Antimony-122	Ci	1.3E-15
Antimony-124	Ci	6.3E-13
Antimony-125	Ci	5.8E-13
Antimony compounds	lb	8.0E-09
AOX, Adsorbable Organic Halogen as Cl	lb	8.5E-05
Arsenic	lb	4.6E-13
Arsenic, ion	lb	1.0E-04
Barite	lb	0.019
Barium	lb	0.32

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Barium-140	Ci	5.6E-15
Bentazone	lb	9.8E-14
Benzene	lb	0.011
Benzene, 1-methyl-4-(1-methylethyl)-	lb	1.3E-08
Benzene, 1,2-dichloro-	lb	4.2E-09
Benzene, chloro-	lb	8.6E-08
Benzene, ethyl-	lb	3.6E-04
Benzene, pentamethyl-	lb	9.5E-09
Benzenes, alkylated, unspecified	lb	4.7E-05
Benzo(a)anthracene	lb	5.0E-14
Benzo(b)fluoranthene	lb	5.6E-14
Benzoic acid	lb	2.5E-04
Beryllium	lb	1.4E-05
Biphenyl	lb	3.1E-06
BOD5, Biological Oxygen Demand	lb	8.10
Borate	lb	7.0E-11
Boron	lb	0.0012
Bromate	lb	8.6E-05
Bromide	lb	0.032
Bromine	lb	0.0038
Butene	lb	0.013
Butyl acetate	lb	0.0018
Butyrolactone	lb	2.2E-11
Cadmium	lb	4.1E-07
Cadmium, ion	lb	2.1E-05
Calcium, ion	lb	0.88
Carbon-14	Ci	1.8E-15
Carbon disulfide	lb	3.7E-11
Carbonate	lb	0.0091
Carboxylic acids, unspecified	lb	0.023
Cerium-141	Ci	2.3E-15
Cerium-144	Ci	6.9E-16
Cesium	lb	5.3E-06
Cesium-134	Ci	5.3E-13
Cesium-136	Ci	4.0E-16
Cesium-137	Ci	4.4E-10
Chloramine	lb	1.2E-11
Chlorate	lb	6.6E-04
Chloride	lb	9.78
Chlorinated solvents, unspecified	lb	4.3E-05
Chlorine	lb	1.6E-05
Chloroacetic acid	lb	1.1E-08
Chloroacetyl chloride	lb	2.2E-13
Chloroform	lb	2.0E-10

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Chlorosulfonic acid	lb	1.9E-12
Chlorpyrifos	lb	4.3E-14
Chromium	lb	0.0020
Chromium-51	Ci	6.9E-13
Chromium VI	lb	1.9E-04
Chromium, ion	lb	1.5E-05
Chrysene	lb	2.8E-13
Clomazone	lb	2.2E-14
Cobalt	lb	1.8E-04
Cobalt-57	Ci	1.3E-14
Cobalt-58	Ci	5.1E-12
Cobalt-60	Ci	4.0E-12
COD, Chemical Oxygen Demand	lb	8.20
Copper	lb	4.1E-05
Copper, ion	lb	3.8E-04
Cresol	lb	4.1E-16
Cumene	lb	0.030
Curium alpha	Ci	4.8E-17
Cyanide	lb	5.0E-05
Cyclohexane	lb	1.8E-17
Decane	lb	7.3E-06
Detergent, oil	lb	1.0E-06
Detergents, unspecified	lb	3.8E-15
Dibenzofuran	lb	2.4E-08
Dibenzothiophene	lb	2.5E-08
Dichromate	lb	9.1E-08
Diethylamine	lb	3.2E-11
Diethylene glycol	lb	0.0042
Dimethylamine	lb	1.8E-11
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.2E-19
Dipropylamine	lb	2.0E-11
Dissolved organics	lb	5.0E-06
Dissolved solids	lb	9.07
DOC, Dissolved Organic Carbon	lb	1.40
Docosane	lb	1.4E-07
Dodecane	lb	1.4E-05
Eicosane	lb	3.8E-06
Ethane, 1,2-dichloro-	lb	3.5E-07
Ethanol	lb	0.0032
Ethene	lb	5.2E-06
Ethene, chloro-	lb	2.9E-07
Ethyl acetate	lb	3.6E-11
Ethylamine	lb	1.5E-12
Ethylene diamine	lb	2.0E-11

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Ethylene oxide	lb	1.7E-09
Fluoranthene	lb	6.0E-14
Fluorene	lb	1.3E-06
Fluorene, 1-methyl-	lb	1.4E-08
Fluorenes, alkylated, unspecified	lb	2.7E-06
Fluoride	lb	0.0039
Fluorine	lb	6.5E-10
Fluosilicic acid	lb	1.3E-07
Formaldehyde	lb	6.6E-07
Formamide	lb	1.5E-12
Formate	lb	1.7E-10
Formic acid	lb	4.4E-13
Furan	lb	8.3E-14
Glutaraldehyde	lb	2.4E-06
Glyphosate	lb	7.7E-12
Glyphosate-trimesium	lb	6.3E-13
Haloalkanes	lb	2.4E-14
Heat, waste	Ci	1.2E-09
Hexadecane	lb	1.5E-05
Hexane	lb	4.9E-17
Hexanoic acid	lb	5.3E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	6.9E-04
Hydrocarbons, aliphatic, unsaturated	lb	6.4E-05
Hydrocarbons, aromatic	lb	0.0028
Hydrocarbons, unspecified	lb	0.043
Hydrogen-3, Tritium	Ci	1.0E-06
Hydrogen chloride	lb	1.7E-12
Hydrogen fluoride	lb	6.0E-11
Hydrogen peroxide	lb	4.0E-08
Hydrogen sulfide	lb	3.0E-05
Hydroxide	lb	1.2E-07
Hypochlorite	lb	4.5E-06
Iodide	lb	5.3E-04
Iodine-129	Ci	5.3E-15
Iodine-131	Ci	1.2E-13
Iodine-133	Ci	3.5E-15
Iron	lb	0.056
Iron-59	Ci	9.7E-16
Iron, ion	lb	0.022
Isopropylamine	lb	3.5E-13
Lactic acid	lb	1.6E-11
Lanthanum-140	Ci	6.0E-15
Lead	lb	2.5E-04
Lead-210	Ci	3.8E-11

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Lead-210/kg	lb	2.6E-14
Lead 210	lb	1.8E-22
Lithium, ion	lb	0.092
m-Xylene	lb	7.3E-06
Magnesium	lb	0.21
Manganese	lb	0.011
Manganese-54	Ci	3.2E-13
Mercury	lb	3.6E-06
Metallic ions, unspecified	lb	1.2E-04
Methane, dibromo-	lb	1.5E-17
Methane, dichloro-, HCC-30	lb	6.2E-05
Methane, monochloro-, R-40	lb	5.1E-09
Methane, trichlorofluoro-, CFC-11	lb	4.9E-12
Methanol	lb	0.0022
Methyl acetate	lb	6.4E-14
Methyl acrylate	lb	3.3E-08
Methyl amine	lb	1.9E-11
Methyl ethyl ketone	lb	1.0E-08
Methyl formate	lb	2.7E-12
Metolachlor	lb	2.3E-13
Metribuzin	lb	5.6E-14
Molybdenum	lb	4.9E-05
Molybdenum-99	Ci	2.1E-15
n-Hexacosane	lb	8.5E-08
n-Hexadecane	lb	1.1E-15
Naphthalene	lb	4.5E-06
Naphthalene, 2-methyl-	lb	3.8E-06
Naphthalenes, alkylated, unspecified	lb	7.7E-07
Nickel	lb	6.0E-05
Nickel, ion	lb	7.7E-04
Niobium-95	Ci	4.8E-14
Nitrate	lb	0.0087
Nitrate compounds	lb	1.2E-07
Nitric acid	lb	2.0E-16
Nitrite	lb	4.1E-06
Nitrobenzene	lb	1.6E-10
Nitrogen	lb	0.0061
Nitrogen, organic bound	lb	0.0011
Nitrogen, total	lb	3.8E-04
o-Cresol	lb	7.2E-06
o-Xylene	lb	2.7E-06
Octadecane	lb	3.7E-06
Oils, unspecified	lb	0.38
Organic substances, unspecified	lb	8.6E-15

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

p-Cresol	lb	7.8E-06
p-Xylene	lb	2.7E-06
PAH, polycyclic aromatic hydrocarbons	lb	3.1E-05
Particulates, < 10 um	lb	2.7E-13
Particulates, > 10 um	lb	2.3E-07
Pendimethalin	lb	1.3E-12
Phenanthrene	lb	2.0E-07
Phenanthrenes, alkylated, unspecified	lb	3.2E-07
Phenol	lb	9.2E-04
Phenol, 2,4-dimethyl-	lb	7.0E-06
Phenols, unspecified	lb	0.055
Phosphate	lb	0.027
Phosphorus	lb	5.2E-05
Phosphorus compounds, unspecified	lb	3.8E-11
Plutonium-alpha	Ci	1.5E-16
Polonium-210	Ci	5.6E-11
Potassium	lb	2.7E-10
Potassium-40	Ci	1.1E-11
Potassium, ion	lb	0.070
Process solvents, unspecified	lb	8.3E-12
Propanal	lb	1.2E-12
Propane, 1,2-dichloro-	lb	1.0E-19
Propanol	lb	1.8E-12
Propene	lb	0.018
Propionic acid	lb	1.1E-11
Propylamine	lb	4.8E-13
Propylene oxide	lb	0.20
Protactinium-234	Ci	6.0E-12
Radioactive species, alpha emitters	Ci	9.8E-14
Radioactive species, Nuclides, unspecified	Ci	2.7E-07
Radium-224	Ci	3.2E-09
Radium-226	Ci	8.9E-09
Radium-226/kg	lb	9.1E-12
Radium-228	Ci	6.5E-09
Radium-228/kg	lb	4.6E-14
Rubidium	lb	5.3E-05
Ruthenium-103	Ci	4.4E-16
Ruthenium-106	Ci	3.6E-17
Scandium	lb	1.8E-05
Selenium	lb	8.3E-05
Silicon	lb	0.21
Silver	lb	3.2E-04
Silver-110	Ci	3.7E-12
Silver, ion	lb	4.8E-06

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Sodium-24	Ci	1.6E-14
Sodium dichromate	lb	2.9E-08
Sodium formate	lb	7.0E-10
Sodium hydroxide	lb	0.059
Sodium, ion	lb	3.43
Solids, inorganic	lb	0.011
Solved solids	lb	0.059
Strontium	lb	0.026
Strontium-89	Ci	6.7E-14
Strontium-90	Ci	3.3E-09
Styrene	lb	2.1E-04
Sulfate	lb	0.98
Sulfide	lb	2.8E-04
Sulfite	lb	1.2E-05
Sulfur	lb	0.0016
Surfactants	lb	5.3E-05
Surfactants, unspecified	lb	7.5E-05
Suspended solids, unspecified	lb	3.23
t-Butyl methyl ether	lb	1.2E-05
t-Butylamine	lb	1.3E-12
Tar	lb	4.9E-21
Technetium-99m	Ci	4.8E-14
Tellurium-123m	Ci	6.8E-14
Tellurium-132	Ci	1.2E-16
Tetradecane	lb	5.9E-06
Thallium	lb	4.1E-06
Thorium-228	Ci	1.3E-08
Thorium-230	Ci	8.2E-10
Thorium-232	Ci	1.3E-12
Thorium-234	Ci	6.0E-12
Tin	lb	5.8E-05
Tin, ion	lb	1.2E-05
Titanium	lb	9.0E-12
Titanium, ion	lb	6.8E-04
TOC, Total Organic Carbon	lb	1.40
Toluene	lb	9.5E-04
Toluene, 2-chloro-	lb	2.5E-11
Tributyltin compounds	lb	4.6E-06
Triethylene glycol	lb	8.3E-07
Trifluralin	lb	7.6E-13
Trimethylamine	lb	1.1E-13
Tungsten	lb	8.6E-06
Uranium-234	Ci	7.2E-12
Uranium-235	Ci	1.2E-11

Source: Franklin Associates, A Division of ERG

Table 58 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Molded Products

Uranium-238	Ci	3.8E-11
Uranium alpha	Ci	3.4E-10
Urea	lb	1.4E-12
Vanadium	lb	2.9E-05
Vanadium, ion	lb	8.3E-05
VOC, volatile organic compounds, unspecified origin	lb	0.0019
Xylene	lb	6.6E-04
Yttrium	lb	1.7E-06
Zinc	lb	0.0014
Zinc-65	Ci	2.1E-13
Zinc, ion	lb	0.0023
Zirconium-95	Ci	2.5E-15

Source: Franklin Associates, A Division of ERG

Table 59. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

1-Butanol	lb	5.7E-13
1-Pentanol	lb	1.4E-13
1-Pentene	lb	1.0E-13
1-Propanol	lb	8.9E-11
1,4-Butanediol	lb	1.0E-11
2-Aminopropanol	lb	2.6E-14
2-Butene, 2-methyl-	lb	2.3E-17
2-Chloroacetophenone	lb	2.0E-08
2-Methyl-1-propanol	lb	7.1E-13
2-Nitrobenzoic acid	lb	4.6E-14
2-Propanol	lb	1.2E-07
2,4-D	lb	1.5E-18
5-methyl Chrysene	lb	2.4E-09
Acenaphthene	lb	5.6E-08
Acenaphthylene	lb	2.8E-08
Acetaldehyde	lb	2.8E-04
Acetic acid	lb	0.0011
Acetic acid, methyl ester	lb	7.0E-04
Acetone	lb	1.9E-06
Acetonitrile	lb	2.0E-08
Acetophenone	lb	4.2E-08
Acid gases	lb	8.1E-04
Acidity, unspecified	lb	3.3E-14
Acids, unspecified	lb	4.5E-25
Acrolein	lb	8.8E-04
Acrylic acid	lb	3.2E-10
Actinides, radioactive, unspecified	Ci	9.4E-15
Adipate, bis(1-ethylhexyl)-	lb	1.7E-15
Aerosols, radioactive, unspecified	Ci	2.4E-13
Alachlor	lb	1.1E-18
Aldehydes, unspecified	lb	9.7E-03
alpha-Pinene	lb	1.5E-16
Aluminium	lb	1.7E-04
Aluminum	lb	4.7E-21
Aluminum, fume or dust	lb	1.6E-15
Ammonia	lb	5.2E-03
Ammonium carbonate	lb	2.1E-09
Ammonium chloride	lb	3.0E-04
Ammonium, ion	lb	4.1E-16

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Aniline	lb	1.3E-11
Aniline, N,N-dimethyl-	lb	3.6E-06
Anthracene	lb	2.3E-08
Anthranilic acid	lb	3.4E-14
Antimony	lb	4.2E-06
Antimony-124	Ci	1.1E-18
Antimony-125	Ci	1.2E-17
Argon-41	Ci	1.3E-10
Arsenic	lb	5.6E-05
Arsenic trioxide	lb	1.2E-18
Arsine	lb	3.8E-15
Barium	lb	6.7E-07
Barium-140	Ci	7.6E-16
Bentazone	lb	8.9E-19
Benzal chloride	lb	5.7E-17
Benzaldehyde	lb	1.2E-09
Benzene	lb	0.034
Benzene, 1-methyl-2-nitro-	lb	4.0E-14
Benzene, 1,2-dichloro-	lb	1.0E-12
Benzene, 1,3,5-trimethyl-	lb	1.5E-17
Benzene, chloro-	lb	6.2E-08
Benzene, ethyl-	lb	0.021
Benzene, hexachloro-	lb	2.3E-09
Benzene, pentachloro-	lb	1.8E-11
Benzo(a)anthracene	lb	8.8E-09
Benzo(a)pyrene	lb	6.7E-08
Benzo(b)fluoranthene	lb	4.5E-16
Benzo(b,j,k)fluoranthene	lb	1.2E-08
Benzo(g,h,i)perylene	lb	1.5E-12
Benzo(ghi)perylene	lb	3.0E-09
Benzyl chloride	lb	2.0E-06
Beryllium	lb	3.1E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	5.9E-17
Biphenyl	lb	1.9E-07
Boron	lb	2.9E-05
Boron trifluoride	lb	5.0E-17
Bromine	lb	0.0018
Bromoform	lb	1.1E-07
Bromoxynil	lb	1.2E-18
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	3.4E-06
Butadiene	lb	3.1E-06
Butane	lb	0.0033
Butanol	lb	4.8E-05
Butene	lb	4.8E-05
Butyrolactone	lb	1.9E-12

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Cadmium	lb	1.3E-05
Calcium	lb	2.4E-05
Carbon-14	Ci	9.9E-10
Carbon dioxide	lb	1.61
Carbon dioxide, biogenic	lb	65.2
Carbon dioxide, fossil	lb	1,371
Carbon dioxide, land transformation	lb	5.6E-04
Carbon disulfide	lb	1.2E-05
Carbon monoxide	lb	2.98
Carbon monoxide, biogenic	lb	1.6E-05
Carbon monoxide, fossil	lb	0.72
Carbonyl sulfide	lb	0.0041
Cerium-141	Ci	1.8E-16
Cesium-134	Ci	1.1E-17
Cesium-137	Ci	1.6E-16
Chloramine	lb	5.4E-13
Chloride	lb	1.4E-11
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	1.2E-25
Chlorine	lb	2.6E-04
Chloroacetic acid	lb	8.8E-11
Chloroform	lb	1.7E-07
Chlorosilane, trimethyl-	lb	1.2E-10
Chlorosulfonic acid	lb	3.0E-13
Chlorpyrifos	lb	3.9E-19
Chromium	lb	4.4E-05
Chromium-51	Ci	1.2E-17
Chromium VI	lb	8.8E-06
Chromium, ion	lb	7.8E-15
Chrysene	lb	1.1E-08
Clomazone	lb	2.0E-19
Cobalt	lb	1.3E-04
Cobalt-58	Ci	1.6E-17
Cobalt-60	Ci	1.5E-16
Copper	lb	6.3E-06
Copper compounds	lb	6.3E-16
Cumene	lb	0.016
Cyanide	lb	7.2E-06
Cyanoacetic acid	lb	2.5E-13
Cyclohexane	lb	1.3E-14
D-limonene	lb	1.7E-17
Dibenz(a,h)anthracene	lb	1.4E-16
Dicyclopentadiene	lb	9.3E-04
Diethanolamine	lb	9.9E-21
Diethylamine	lb	5.8E-12
Dimethyl ether	lb	3.3E-16

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Dimethyl malonate	lb	3.1E-13
Dinitrogen monoxide	lb	0.024
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	lb	4.9E-14
Dioxins (unspecified)	lb	3.1E-22
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	3.6E-07
Dipropylamine	lb	3.7E-12
Ethane	lb	7.7E-04
Ethane, 1,1-difluoro-, HFC-152a	lb	2.5E-09
Ethane, 1,1,1-trichloro-, HCFC-140	lb	5.6E-08
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	2.4E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	1.5E-11
Ethane, 1,2-dibromo-	lb	3.4E-09
Ethane, 1,2-dichloro-	lb	5.8E-07
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	2.3E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	3.3E-08
Ethane, chloro-	lb	1.2E-07
Ethane, hexafluoro-, HFC-116	lb	2.0E-08
Ethanol	lb	2.9E-06
Ethene	lb	1.0E-04
Ethene, chloro-	lb	3.4E-07
Ethene, tetrachloro-	lb	5.0E-06
Ethyl acetate	lb	5.7E-07
Ethyl cellulose	lb	1.1E-09
Ethylamine	lb	2.5E-13
Ethylene diamine	lb	3.3E-12
Ethylene dibromide	lb	8.3E-07
Ethylene glycol	lb	0.0018
Ethylene oxide	lb	0.0026
Ethyne	lb	3.0E-07
Fluoranthene	lb	7.8E-08
Fluorene	lb	1.0E-07
Fluoride	lb	1.3E-04
Fluorine	lb	2.5E-06
Fluosilicic acid	lb	2.2E-08
Formaldehyde	lb	0.0026
Formamide	lb	2.5E-13
Formic acid	lb	1.4E-07
Furan	lb	3.9E-08
Glyphosate	lb	7.0E-17
Glyphosate-trimesium	lb	5.8E-18
Heat, waste	Btu	323,242
Helium	lb	8.6E-05
Heptane	lb	4.8E-04
Hexamethylene diamine	lb	2.8E-17
Hexane	lb	0.0010

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Hydrazine, methyl-	lb	4.8E-07
Hydrocarbons, aliphatic, alkanes, cyclic	lb	3.9E-08
Hydrocarbons, aliphatic, alkanes, unspecified	lb	1.0E-04
Hydrocarbons, aliphatic, unsaturated	lb	7.1E-06
Hydrocarbons, aromatic	lb	7.6E-05
Hydrocarbons, chlorinated	lb	5.1E-04
Hydrocarbons, unspecified	lb	0.013
Hydrogen	lb	9.2E-04
Hydrogen-3, Tritium	Ci	5.8E-09
Hydrogen bromide	lb	9.7E-14
Hydrogen chloride	lb	0.14
Hydrogen cyanide	lb	5.5E-15
Hydrogen fluoride	lb	0.016
Hydrogen iodide	lb	1.1E-16
Hydrogen peroxide	lb	8.0E-05
Hydrogen sulfide	lb	1.6E-05
Indeno(1,2,3-cd)pyrene	lb	6.7E-09
Iodine	lb	6.8E-06
Iodine-129	Ci	1.0E-12
Iodine-131	Ci	5.1E-11
Iodine-133	Ci	2.1E-15
Iodine-135	Ci	2.5E-15
Iron	lb	5.4E-05
Isobutyraldehyde	lb	4.0E-04
Isocyanic acid	lb	3.8E-08
Isophorone	lb	1.6E-06
Isoprene	lb	1.4E-04
Isopropylamine	lb	5.6E-14
Kerosene	lb	1.4E-04
Krypton-85	Ci	4.0E-10
Krypton-85m	Ci	3.3E-10
Krypton-87	Ci	7.4E-12
Krypton-88	Ci	7.1E-12
Krypton-89	Ci	1.7E-12
Lactic acid	lb	2.9E-12
Lanthanum-140	Ci	6.5E-17
Lead	lb	7.9E-05
Lead-210	Ci	5.5E-12
Lead compounds	lb	1.8E-17
m-Xylene	lb	8.6E-08
Magnesium	lb	0.0012
Maleic anhydride	lb	0.0022
Manganese	lb	4.1E-04
Manganese-54	Ci	6.0E-18
Manganese compounds	lb	5.5E-17

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Mercaptans, unspecified	lb	6.1E-04
Mercury	lb	2.0E-05
Metals, unspecified	lb	0.0093
Methacrylic acid, methyl ester	lb	5.6E-08
Methane	lb	1.62
Methane, biogenic	lb	1.6E-04
Methane, bromo-, Halon 1001	lb	4.5E-07
Methane, bromochlorodifluoro-, Halon 1211	lb	2.2E-08
Methane, bromotrifluoro-, Halon 1301	lb	1.2E-06
Methane, chlorodifluoro-, HCFC-22	lb	2.0E-07
Methane, chlorotrifluoro-, CFC-13	lb	4.2E-06
Methane, dichloro-, HCC-30	lb	0.15
Methane, dichlorodifluoro-, CFC-12	lb	1.0E-05
Methane, dichlorofluoro-, HCFC-21	lb	1.3E-13
Methane, fossil	lb	5.05
Methane, monochloro-, R-40	lb	1.5E-06
Methane, tetrachloro-, CFC-10	lb	1.5E-05
Methane, tetrafluoro-, CFC-14	lb	1.7E-07
Methane, trichlorofluoro-, CFC-11	lb	4.4E-12
Methane, trifluoro-, HFC-23	lb	4.2E-11
Methanesulfonic acid	lb	2.5E-13
Methanol	lb	9.5E-05
Methyl acetate	lb	1.5E-04
Methyl acrylate	lb	3.6E-10
Methyl amine	lb	2.8E-12
Methyl borate	lb	5.3E-14
Methyl ethyl ketone	lb	1.7E-06
Methyl formate	lb	1.5E-12
Methyl lactate	lb	3.2E-12
Methyl methacrylate	lb	0.0069
Metolachlor	lb	2.1E-18
Metribuzin	lb	5.1E-19
Molybdenum	lb	1.1E-06
Monoethanolamine	lb	2.4E-08
Naphthalene	lb	2.9E-05
Nickel	lb	3.3E-04
Nickel compounds	lb	1.6E-16
Niobium-95	Ci	7.2E-19
Nitrate	lb	4.4E-07
Nitric oxide	lb	4.3E-15
Nitrobenzene	lb	1.7E-11
Nitrogen	lb	2.9E-09
Nitrogen dioxide	lb	2.6E-27
Nitrogen oxides	lb	3.46
Nitrogen, total	lb	2.5E-25

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Nitrous oxide	lb	9.7E-05
NMVOC, non-methane volatile organic compounds, uns	lb	1.21
Noble gases, radioactive, unspecified	Ci	9.7E-06
Octane	lb	6.3E-12
Odorous sulfur	lb	0.0052
Organic acids	lb	1.1E-06
Organic substances, unspecified	lb	0.036
Oxygen	lb	2.2E-08
Ozone	lb	2.8E-05
PAH, polycyclic aromatic hydrocarbons	lb	1.9E-05
Palladium	lb	1.1E-20
Particulates, < 10 um	lb	0.58
Particulates, < 2.5 um	lb	0.16
Particulates, > 10 um	lb	0.0050
Particulates, > 2.5 um, and < 10um	lb	0.18
Particulates, unspecified	lb	0.63
Pendimethalin	lb	1.1E-17
Pentane	lb	0.0026
PFC (perfluorocarbons)	lb	1.6E-15
Phenanthrene	lb	3.0E-07
Phenol	lb	8.5E-08
Phenol, 2,4-dichloro-	lb	2.0E-12
Phenol, pentachloro-	lb	2.3E-08
Phenols, unspecified	lb	2.7E-05
Phosphate	lb	5.6E-27
Phosphine	lb	2.7E-13
Phosphorus	lb	3.3E-07
Phthalate, dioctyl-	lb	2.1E-07
Phthalic acid,branched and linear di c7-c11 alk*	lb	0.0031
Phthalic anhydride	lb	1.2E-04
Platinum	lb	1.2E-12
Plutonium-238	Ci	1.4E-19
Plutonium-alpha	Ci	3.2E-19
Polonium-210	Ci	9.7E-12
Polychlorinated biphenyls	lb	3.9E-09
Polycyclic organic matter, unspecified	lb	1.1E-05
Potassium	lb	2.4E-05
Potassium-40	Ci	1.2E-12
Propanal	lb	1.1E-06
Propane	lb	0.0022
Propene	lb	0.0033
Propionic acid	lb	1.8E-07
Propylamine	lb	8.0E-14
Propylene oxide	lb	0.045
Protactinium-234	Ci	1.4E-13

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Pyrene	lb	3.6E-08
Radioactive species, other beta emitters	Ci	2.6E-12
Radioactive species, unspecified	Ci	7.5E-05
Radionuclides (Including Radon)	lb	0.0080
Radium-226	Ci	5.9E-12
Radium-228	Ci	6.3E-13
Radon-220	Ci	5.5E-11
Radon-222	Ci	1.8E-05
Rhodium	lb	1.0E-20
Ruthenium-103	Ci	1.6E-19
Scandium	lb	1.4E-07
Selenium	lb	1.5E-04
Silicon	lb	1.3E-04
Silicon tetrafluoride	lb	3.1E-09
Silver	lb	6.0E-09
Silver-110	Ci	1.6E-18
Sodium	lb	4.8E-05
Sodium chlorate	lb	3.4E-08
Sodium dichromate	lb	1.0E-08
Sodium formate	lb	1.1E-10
Sodium hydroxide	lb	3.2E-09
Strontium	lb	6.0E-07
Styrene	lb	7.13
Sulfate	lb	1.3E-04
Sulfur dioxide	lb	3.97
Sulfur hexafluoride	lb	4.3E-07
Sulfur oxides	lb	1.10
Sulfur trioxide	lb	1.4E-10
Sulfur, total reduced	lb	3.1E-12
Sulfuric acid	lb	6.6E-04
Sulfuric acid, dimethyl ester	lb	1.4E-07
t-Butyl methyl ether	lb	1.0E-07
t-Butylamine	lb	2.2E-13
Tar	lb	4.8E-12
Tellurium	lb	1.0E-15
Terpenes	lb	1.7E-08
Thallium	lb	1.9E-09
Thorium	lb	7.8E-10
Thorium-228	Ci	2.6E-13
Thorium-230	Ci	5.7E-13
Thorium-232	Ci	4.0E-13
Thorium-234	Ci	1.4E-13
Tin	lb	8.6E-08
Tin oxide	lb	1.6E-18
Titanium	lb	2.6E-06

Source: Franklin Associates, A Division of ERG

Table 59 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Open Mold Cast Products

Titanium Dioxide (nano)	lb	4.0E-04
TOC, Total Organic Carbon	lb	0.0030
Toluene	lb	0.042
Toluene, 2-chloro-	lb	5.2E-12
Toluene, 2,4-dinitro-	lb	7.9E-10
Trichloroethane	lb	5.9E-20
Triethyl amine	lb	4.0E-15
Trifluralin	lb	1.1E-17
Trimethylamine	lb	1.9E-14
Tungsten	lb	1.5E-08
Uranium	lb	7.4E-10
Uranium-234	Ci	1.7E-12
Uranium-235	Ci	7.7E-14
Uranium-238	Ci	2.6E-12
Uranium alpha	Ci	7.4E-12
Used air	lb	1.6E-04
Vanadium	lb	4.8E-05
Vinyl acetate	lb	2.1E-08
VOC, volatile organic compounds	lb	0.83
Water	lb	0.015
Xenon-131m	Ci	3.3E-11
Xenon-133	Ci	1.1E-09
Xenon-133m	Ci	4.8E-12
Xenon-135	Ci	4.3E-10
Xenon-135m	Ci	2.5E-10
Xenon-137	Ci	4.6E-12
Xenon-138	Ci	4.2E-11
Xylene	lb	0.026
Zinc	lb	4.8E-04
Zinc-65	Ci	3.0E-17
Zinc compounds	lb	1.1E-16
Zinc oxide	lb	2.2E-04
Zirconium	lb	4.5E-09
Zirconium-95	Ci	2.9E-17

Source: Franklin Associates, A Division of ERG

Table 60. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

1-Butanol	lb	2.1E-09
1-Pentanol	lb	3.3E-13
1-Pentene	lb	2.5E-13
1,4-Butanediol	lb	4.1E-12
2-Aminopropanol	lb	6.5E-14
2-Hexanone	lb	7.8E-07
2-Methyl-1-propanol	lb	1.7E-12
2-Methyl-2-butene	lb	5.5E-17
2-Propanol	lb	3.1E-13
2,4-D	lb	6.3E-20
4-Methyl-2-pentanone	lb	2.5E-07
Acenaphthene	lb	1.4E-08
Acenaphthylene	lb	9.0E-10
Acetaldehyde	lb	0.0027
Acetic acid	lb	4.9E-07
Acetone	lb	6.0E-07
Acetonitrile	lb	2.1E-13
Acetyl chloride	lb	2.6E-13
Acidity, unspecified	lb	0.19
Acids, unspecified	lb	0.0011
Acrylate, ion	lb	7.5E-10
Acrylonitrile	lb	1.7E-15
Actinides, radioactive, unspecified	Ci	1.6E-12
Alachlor	lb	4.5E-20
Aldehydes (unspecified)	lb	4.4E-19
Aluminium	lb	0.0062
Aluminum	lb	0.013
Aluminum, ion	lb	3.5E-15
Americium-241	Ci	8.3E-18
Ammonia	lb	0.0062
Ammonia, as N	lb	4.5E-11
Ammonium, ion	lb	0.0065
Aniline	lb	3.1E-11
Anthracene	lb	1.4E-14
Antimony	lb	1.4E-05
Antimony-122	Ci	4.5E-16
Antimony-124	Ci	2.6E-13
Antimony-125	Ci	2.4E-13
Antimony compounds	lb	1.7E-08
AOX, Adsorbable Organic Halogen as Cl	lb	1.9E-06
Arsenic, ion	lb	4.3E-05
Barite	lb	0.0084
Barium	lb	0.15
Barium-140	Ci	2.0E-15

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Bentazone	lb	3.8E-20
Benzene	lb	0.014
Benzene, 1-methyl-4-(1-methylethyl)-	lb	5.8E-09
Benzene, 1,2-dichloro-	lb	9.1E-10
Benzene, chloro-	lb	1.9E-08
Benzene, ethyl-	lb	1.5E-04
Benzene, pentamethyl-	lb	4.4E-09
Benzenes, alkylated, unspecified	lb	2.2E-05
Benzo(a)anthracene	lb	1.0E-14
Benzo(b)fluoranthene	lb	1.1E-14
Benzoic acid	lb	1.2E-04
Beryllium	lb	5.8E-06
Biphenyl	lb	1.4E-06
BOD5, Biological Oxygen Demand	lb	3.93
Borate	lb	2.8E-11
Boron	lb	5.1E-04
Bromate	lb	3.7E-05
Bromide	lb	0.015
Bromine	lb	0.0016
Butene	lb	1.0E-09
Butyl acetate	lb	2.7E-09
Butyrolactone	lb	4.7E-12
Cadmium	lb	1.8E-07
Cadmium, ion	lb	8.3E-06
Calcium, ion	lb	0.38
Carbon-14	Ci	4.2E-16
Carbon disulfide	lb	1.5E-11
Carbonate	lb	2.7E-06
Carboxylic acids, unspecified	lb	0.010
Cerium-141	Ci	7.9E-16
Cerium-144	Ci	2.4E-16
Cesium	lb	2.3E-06
Cesium-134	Ci	2.2E-13
Cesium-136	Ci	1.4E-16
Cesium-137	Ci	1.9E-10
Chloramine	lb	4.8E-12
Chlorate	lb	2.9E-04
Chloride	lb	4.23
Chlorinated solvents, unspecified	lb	1.1E-05
Chlorine	lb	1.7E-07
Chloroacetic acid	lb	4.3E-09
Chloroacetyl chloride	lb	8.7E-14
Chloroform	lb	4.2E-11
Chlorosulfonic acid	lb	7.5E-13

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Chlorpyrifos	lb	1.7E-20
Chromium	lb	9.7E-04
Chromium-51	Ci	2.6E-13
Chromium VI	lb	7.1E-05
Chromium, ion	lb	6.4E-06
Chrysene	lb	5.7E-14
Clomazone	lb	8.7E-21
Cobalt	lb	7.2E-05
Cobalt-57	Ci	4.5E-15
Cobalt-58	Ci	2.0E-12
Cobalt-60	Ci	1.6E-12
COD, Chemical Oxygen Demand	lb	3.69
Copper	lb	1.9E-05
Copper, ion	lb	1.3E-04
Cresol	lb	6.4E-17
Cumene	lb	0.039
Curium alpha	Ci	1.1E-17
Cyanide	lb	6.3E-06
Cyclohexane	lb	4.7E-21
Decane	lb	3.4E-06
Detergent, oil	lb	6.0E-08
Detergents, unspecified	lb	6.0E-28
Dibenzofuran	lb	1.1E-08
Dibenzothiophene	lb	1.2E-08
Dichromate	lb	3.9E-08
Diethylamine	lb	1.4E-11
Dimethylamine	lb	7.6E-12
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	2.1E-22
Dipropylamine	lb	8.8E-12
Dissolved organics	lb	2.0E-06
Dissolved solids	lb	4.39
DOC, Dissolved Organic Carbon	lb	0.63
Docosane	lb	6.3E-08
Dodecane	lb	6.4E-06
Eicosane	lb	1.8E-06
Ethane, 1,2-dichloro-	lb	9.8E-08
Ethanol	lb	4.9E-09
Ethene	lb	2.2E-06
Ethene, chloro-	lb	7.5E-08
Ethyl acetate	lb	1.5E-11
Ethylamine	lb	5.9E-13
Ethylene diamine	lb	8.0E-12
Ethylene oxide	lb	3.8E-10
Fluoranthene	lb	1.2E-14

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Fluorene	lb	6.0E-07
Fluorene, 1-methyl-	lb	6.7E-09
Fluorenes, alkylated, unspecified	lb	1.3E-06
Fluoride	lb	0.0015
Fluorine	lb	4.5E-11
Fluosilicic acid	lb	3.9E-08
Formaldehyde	lb	2.8E-07
Formamide	lb	6.1E-13
Formate	lb	6.6E-11
Formic acid	lb	1.8E-13
Furan	lb	1.8E-14
Glutaraldehyde	lb	1.0E-06
Glyphosate	lb	3.0E-18
Glyphosate-trimesium	lb	2.5E-19
Heat, waste	Ci	5.1E-10
Hexadecane	lb	7.0E-06
Hexane	lb	8.1E-18
Hexanoic acid	lb	2.5E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	3.0E-04
Hydrocarbons, aliphatic, unsaturated	lb	2.8E-05
Hydrocarbons, aromatic	lb	0.0012
Hydrocarbons, unspecified	lb	0.017
Hydrogen-3, Tritium	Ci	4.3E-07
Hydrogen chloride	lb	1.3E-14
Hydrogen fluoride	lb	1.9E-14
Hydrogen peroxide	lb	9.8E-09
Hydrogen sulfide	lb	7.7E-06
Hydroxide	lb	2.6E-08
Hypochlorite	lb	1.9E-06
Iodide	lb	2.3E-04
Iodine-129	Ci	1.2E-15
Iodine-131	Ci	4.8E-14
Iodine-133	Ci	1.2E-15
Iron	lb	0.026
Iron-59	Ci	3.4E-16
Iron, ion	lb	0.0092
Isopropylamine	lb	1.3E-13
Lactic acid	lb	6.9E-12
Lanthanum-140	Ci	2.1E-15
Lead	lb	1.0E-04
Lead-210	Ci	1.7E-11
Lead-210/kg	lb	1.2E-14
Lithium, ion	lb	0.042
m-Xylene	lb	3.4E-06

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Magnesium	lb	0.092
Manganese	lb	0.0045
Manganese-54	Ci	1.3E-13
Mercury	lb	1.3E-06
Metallic ions, unspecified	lb	4.3E-05
Methane, dibromo-	lb	3.0E-18
Methane, dichloro-, HCC-30	lb	2.7E-05
Methane, monochloro-, R-40	lb	2.4E-09
Methane, trichlorofluoro-, CFC-11	lb	9.9E-16
Methanol	lb	3.1E-07
Methyl acetate	lb	2.6E-14
Methyl acrylate	lb	7.0E-09
Methyl amine	lb	6.7E-12
Methyl ethyl ketone	lb	4.7E-09
Methyl formate	lb	5.8E-13
Metolachlor	lb	8.9E-20
Metribuzin	lb	2.2E-20
Molybdenum	lb	2.0E-05
Molybdenum-99	Ci	7.3E-16
n-Hexacosane	lb	3.9E-08
Naphthalene	lb	2.1E-06
Naphthalene, 2-methyl-	lb	1.8E-06
Naphthalenes, alkylated, unspecified	lb	3.6E-07
Nickel	lb	2.8E-05
Nickel, ion	lb	3.2E-04
Niobium-95	Ci	2.0E-14
Nitrate	lb	0.0034
Nitrate compounds	lb	9.6E-09
Nitric acid	lb	2.7E-09
Nitrite	lb	1.2E-06
Nitrobenzene	lb	7.0E-11
Nitrogen	lb	0.0035
Nitrogen, organic bound	lb	4.6E-04
Nitrogen, total	lb	1.6E-04
o-Cresol	lb	3.4E-06
o-Xylene	lb	1.3E-06
Octadecane	lb	1.7E-06
Oils, unspecified	lb	0.17
Organic substances, unspecified	lb	1.4E-27
p-Cresol	lb	3.6E-06
p-Xylene	lb	1.3E-06
PAH, polycyclic aromatic hydrocarbons	lb	1.3E-05
Particulates, < 10 um	lb	2.1E-15
Particulates, > 10 um	lb	2.5E-08

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Pendimethalin	lb	4.9E-19
Phenanthrene	lb	9.4E-08
Phenanthrenes, alkylated, unspecified	lb	1.5E-07
Phenol	lb	4.0E-04
Phenol, 2,4-dimethyl-	lb	3.3E-06
Phenols, unspecified	lb	0.024
Phosphate	lb	0.010
Phosphorus	lb	2.2E-05
Phosphorus compounds, unspecified	lb	1.5E-17
Plutonium-alpha	Ci	3.3E-17
Polonium-210	Ci	2.4E-11
Potassium	lb	2.0E-12
Potassium-40	Ci	4.7E-12
Potassium, ion	lb	0.028
Process solvents, unspecified	lb	1.8E-12
Propanal	lb	4.8E-13
Propane, 1,2-dichloro-	lb	2.3E-20
Propanol	lb	7.4E-13
Propene	lb	0.0072
Propionic acid	lb	4.9E-12
Propylamine	lb	1.9E-13
Propylene oxide	lb	0.088
Protactinium-234	Ci	2.5E-12
Radioactive species, alpha emitters	Ci	4.2E-14
Radioactive species, Nuclides, unspecified	Ci	1.1E-07
Radium-224	Ci	1.4E-09
Radium-226	Ci	3.8E-09
Radium-226/kg	lb	4.2E-12
Radium-228	Ci	2.8E-09
Radium-228/kg	lb	2.2E-14
Rubidium	lb	2.3E-05
Ruthenium-103	Ci	1.5E-16
Ruthenium-106	Ci	8.3E-18
Scandium	lb	7.3E-06
Selenium	lb	3.5E-05
Silicon	lb	0.083
Silver	lb	1.5E-04
Silver-110	Ci	1.5E-12
Silver, ion	lb	2.0E-06
Sodium-24	Ci	5.5E-15
Sodium dichromate	lb	2.2E-15
Sodium formate	lb	2.7E-10
Sodium hydroxide	lb	0.026
Sodium, ion	lb	1.52

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

Solids, inorganic	lb	0.0046
Solved solids	lb	0.0031
Strontium	lb	0.012
Strontium-89	Ci	2.6E-14
Strontium-90	Ci	1.4E-09
Styrene	lb	8.9E-05
Sulfate	lb	0.40
Sulfide	lb	1.3E-04
Sulfite	lb	5.2E-06
Sulfur	lb	7.1E-04
Surfactants	lb	2.5E-05
Surfactants, unspecified	lb	3.5E-05
Suspended solids, unspecified	lb	1.51
t-Butyl methyl ether	lb	5.0E-06
t-Butylamine	lb	5.2E-13
Tar	lb	6.9E-14
Technetium-99m	Ci	1.7E-14
Tellurium-123m	Ci	2.9E-14
Tellurium-132	Ci	4.2E-17
Tetradecane	lb	2.7E-06
Thallium	lb	1.8E-06
Thorium-228	Ci	5.6E-09
Thorium-230	Ci	3.4E-10
Thorium-232	Ci	5.5E-13
Thorium-234	Ci	2.5E-12
Tin	lb	2.7E-05
Tin, ion	lb	3.1E-06
Titanium	lb	1.3E-12
Titanium, ion	lb	2.9E-04
TOC, Total Organic Carbon	lb	0.63
Toluene	lb	4.2E-04
Toluene, 2-chloro-	lb	1.1E-11
Tributyltin compounds	lb	2.0E-06
Triethylene glycol	lb	1.8E-07
Trifluralin	lb	3.0E-19
Trimethylamine	lb	4.6E-14
Tungsten	lb	3.1E-06
Uranium-234	Ci	3.0E-12
Uranium-235	Ci	5.0E-12
Uranium-238	Ci	1.6E-11
Uranium alpha	Ci	1.5E-10
Urea	lb	5.7E-13
Vanadium	lb	1.4E-05
Vanadium, ion	lb	3.3E-05

Source: Franklin Associates, A Division of ERG

Table 60 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Open Mold Cast Products

VOC, volatile organic compounds, unspecified origin	lb	8.1E-04
Xylene	lb	2.9E-04
Yttrium	lb	7.9E-07
Zinc	lb	7.2E-04
Zinc-65	Ci	7.4E-14
Zinc, ion	lb	9.4E-04
Zirconium-95	Ci	8.6E-16

Source: Franklin Associates, A Division of ERG

Table 61. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

1-Butanol	lb	5.5E-13
1-Pentanol	lb	1.3E-13
1-Pentene	lb	9.8E-14
1-Propanol	lb	8.4E-11
1,4-Butanediol	lb	1.3E-11
2-Aminopropanol	lb	2.4E-14
2-Butene, 2-methyl-	lb	2.2E-17
2-Chloroacetophenone	lb	4.5E-08
2-Methyl-1-propanol	lb	6.7E-13
2-Nitrobenzoic acid	lb	4.3E-14
2-Propanol	lb	1.7E-07
2,4-D	lb	4.6E-12
5-methyl Chrysene	lb	3.2E-09
Acenaphthene	lb	7.3E-08
Acenaphthylene	lb	3.6E-08
Acetaldehyde	lb	0.0014
Acetic acid	lb	0.0023
Acetic acid, methyl ester	lb	0.0017
Acetone	lb	0.0013
Acetonitrile	lb	1.9E-08
Acetophenone	lb	9.6E-08
Acid gases	lb	7.6E-04
Acidity, unspecified	lb	4.5E-11
Acids, unspecified	lb	7.0E-20
Acrolein	lb	0.0019
Acrylic acid	lb	4.4E-10
Actinides, radioactive, unspecified	Ci	8.9E-15
Adipate, bis(1-ethylhexyl)-	lb	2.3E-12
Aerosols, radioactive, unspecified	Ci	2.3E-13
Alachlor	lb	3.3E-12
Aldehydes, unspecified	lb	0.014
alpha-Pinene	lb	0.019
Aluminium	lb	7.8E-04
Aluminum	lb	5.5E-16
Aluminum, fume or dust	lb	2.1E-12
Ammonia	lb	0.0076
Ammonium carbonate	lb	2.0E-09
Ammonium chloride	lb	3.8E-04
Ammonium, ion	lb	-1.8E-12

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Aniline	lb	1.2E-11
Aniline, N,N-dimethyl-	lb	3.4E-06
Anthracene	lb	3.0E-08
Anthranilic acid	lb	3.2E-14
Antimony	lb	6.8E-06
Antimony-124	Ci	1.6E-18
Antimony-125	Ci	1.1E-17
Argon-41	Ci	1.3E-10
Arsenic	lb	7.7E-05
Arsenic trioxide	lb	2.7E-16
Arsine	lb	2.8E-14
Barium	lb	7.0E-07
Barium-140	Ci	7.1E-16
Bentazone	lb	2.7E-12
Benzal chloride	lb	5.4E-17
Benzaldehyde	lb	1.2E-09
Benzene	lb	0.046
Benzene, 1-methyl-2-nitro-	lb	3.7E-14
Benzene, 1,2-dichloro-	lb	9.5E-13
Benzene, 1,3,5-trimethyl-	lb	3.1E-15
Benzene, chloro-	lb	1.4E-07
Benzene, ethyl-	lb	0.022
Benzene, hexachloro-	lb	3.7E-09
Benzene, pentachloro-	lb	4.0E-09
Benzo(a)anthracene	lb	1.2E-08
Benzo(a)pyrene	lb	2.2E-07
Benzo(b)fluoranthene	lb	9.5E-14
Benzo(b,j,k)fluoranthene	lb	1.6E-08
Benzo(ghi)perylene	lb	3.9E-09
Benzyl chloride	lb	4.5E-06
Beryllium	lb	4.1E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	0.0075
Biphenyl	lb	2.5E-07
Boric acid	lb	7.0E-05
Boron	lb	5.0E-05
Boron trifluoride	lb	7.1E-17
Bromine	lb	0.0037
Bromoform	lb	2.5E-07
Bromoxynil	lb	3.7E-12
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	2.3E-18
Butadiene	lb	2.6E-06
Butane	lb	0.0031
Butanol	lb	4.5E-05
Butene	lb	4.5E-05
Butyrolactone	lb	2.7E-12

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Cadmium	lb	1.8E-05
Calcium	lb	4.6E-05
Carbon-14	Ci	9.4E-10
Carbon dioxide	lb	8.70
Carbon dioxide, biogenic	lb	92.1
Carbon dioxide, fossil	lb	2,313
Carbon dioxide, land transformation	lb	0.057
Carbon disulfide	lb	1.6E-05
Carbon monoxide	lb	3.76
Carbon monoxide, biogenic	lb	6.8E-04
Carbon monoxide, fossil	lb	1.37
Carbonyl sulfide	lb	0.0066
Cerium-141	Ci	1.7E-16
Cesium-134	Ci	4.8E-16
Cesium-137	Ci	1.1E-15
Chloramine	lb	5.0E-13
Chloride	lb	2.2E-09
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	1.8E-20
Chlorine	lb	0.019
Chloroacetic acid	lb	8.3E-11
Chloroform	lb	3.8E-07
Chlorosilane, trimethyl-	lb	1.3E-10
Chlorosulfonic acid	lb	2.8E-13
Chlorpyrifos	lb	1.2E-12
Chromium	lb	1.9E-04
Chromium-51	Ci	1.1E-17
Chromium VI	lb	1.1E-05
Chromium, ion	lb	1.1E-11
Chrysene	lb	1.4E-08
Clomazone	lb	6.3E-13
Cobalt	lb	2.0E-04
Cobalt-58	Ci	1.8E-17
Cobalt-60	Ci	2.1E-16
Copper	lb	1.5E-05
Copper compounds	lb	8.2E-13
Cumene	lb	2.2E-06
Cyanide	lb	1.9E-04
Cyanoacetic acid	lb	2.3E-13
Cyclohexane	lb	2.7E-12
D-limonene	lb	0.0022
Dibenz(a,h)anthracene	lb	3.0E-14
Dicyclopentadiene	lb	8.7E-04
Diethanolamine	lb	-4.4E-17
Diethylamine	lb	5.4E-12
Dimethyl ether	lb	8.7E-14

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Dimethyl malonate	lb	2.9E-13
Dinitrogen monoxide	lb	0.034
Dioxins (unspecified)	lb	4.1E-18
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	7.7E-07
Dipropylamine	lb	3.5E-12
Ethane	lb	7.2E-04
Ethane, 1,1-difluoro-, HFC-152a	lb	2.3E-09
Ethane, 1,1,1-trichloro-, HCFC-140	lb	1.3E-07
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	8.5E-06
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	2.1E-11
Ethane, 1,2-dibromo-	lb	7.7E-09
Ethane, 1,2-dichloro-	lb	8.7E-07
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	8.4E-06
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	3.2E-08
Ethane, chloro-	lb	2.7E-07
Ethane, hexafluoro-, HFC-116	lb	2.3E-08
Ethanol	lb	2.7E-06
Ethene	lb	5.6E-04
Ethene, chloro-	lb	0.0040
Ethene, tetrachloro-	lb	6.5E-06
Ethyl acetate	lb	8.0E-07
Ethyl cellulose	lb	1.6E-09
Ethylamine	lb	2.3E-13
Ethylene diamine	lb	3.1E-12
Ethylene dibromide	lb	9.7E-07
Ethylene glycol	lb	0.0017
Ethylene oxide	lb	0.0030
Ethyne	lb	2.8E-07
Fluoranthene	lb	1.0E-07
Fluorene	lb	1.3E-07
Fluoride	lb	2.9E-04
Fluorine	lb	4.8E-06
Fluosilicic acid	lb	2.8E-08
Formaldehyde	lb	0.0048
Formamide	lb	2.4E-13
Formic acid	lb	1.3E-07
Furan	lb	3.7E-08
Glyphosate	lb	2.2E-10
Glyphosate-trimesium	lb	1.8E-11
Heat, waste	Btu	2,334,473
Helium	lb	8.1E-05
Heptane	lb	4.5E-04
Hexamethylene diamine	lb	5.9E-15
Hexane	lb	9.7E-04
Hydrazine, methyl-	lb	1.1E-06

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Hydrocarbons, aliphatic, alkanes, cyclic	lb	2.3E-04
Hydrocarbons, aliphatic, alkanes, unspecified	lb	9.5E-05
Hydrocarbons, aliphatic, unsaturated	lb	6.6E-06
Hydrocarbons, aromatic	lb	0.0059
Hydrocarbons, chlorinated	lb	8.5E-05
Hydrocarbons, unspecified	lb	0.016
Hydrogen	lb	0.0077
Hydrogen-3, Tritium	Ci	5.4E-09
Hydrogen bromide	lb	2.0E-11
Hydrogen chloride	lb	0.19
Hydrogen cyanide	lb	1.7E-12
Hydrogen fluoride	lb	0.033
Hydrogen iodide	lb	2.2E-14
Hydrogen peroxide	lb	7.5E-05
Hydrogen sulfide	lb	3.1E-05
Indeno(1,2,3-cd)pyrene	lb	8.8E-09
Iodine	lb	6.4E-06
Iodine-129	Ci	9.5E-13
Iodine-131	Ci	4.8E-11
Iodine-133	Ci	1.9E-15
Iodine-135	Ci	2.4E-15
Iron	lb	5.1E-05
Isobutyraldehyde	lb	3.8E-04
Isocyanic acid	lb	3.6E-08
Isophorone	lb	3.7E-06
Isoprene	lb	1.7E-09
Isopropylamine	lb	5.2E-14
Kerosene	lb	1.8E-04
Krypton-85	Ci	3.8E-10
Krypton-85m	Ci	6.3E-08
Krypton-87	Ci	6.9E-12
Krypton-88	Ci	6.6E-12
Krypton-89	Ci	1.6E-12
Lactic acid	lb	2.7E-12
Lanthanum-140	Ci	6.1E-17
Lead	lb	1.3E-04
Lead-210	Ci	5.2E-12
Lead compounds	lb	3.6E-15
m-Xylene	lb	8.1E-08
Magnesium	lb	0.0016
Maleic anhydride	lb	0.0021
Manganese	lb	8.2E-04
Manganese-54	Ci	5.7E-18
Manganese compounds	lb	7.2E-14
Mercaptans, unspecified	lb	0.0014

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Mercury	lb	3.2E-05
Metals, unspecified	lb	0.020
Methacrylic acid, methyl ester	lb	1.3E-07
Methane	lb	1.10
Methane, biogenic	lb	0.0045
Methane, bromo-, Halon 1001	lb	1.0E-06
Methane, bromochlorodifluoro-, Halon 1211	lb	2.1E-08
Methane, bromotrifluoro-, Halon 1301	lb	1.2E-06
Methane, chlorodifluoro-, HCFC-22	lb	1.0E-04
Methane, chlorotrifluoro-, CFC-13	lb	5.0E-06
Methane, dichloro-, HCC-30	lb	2.0E-04
Methane, dichlorodifluoro-, CFC-12	lb	4.2E-10
Methane, dichlorofluoro-, HCFC-21	lb	1.7E-13
Methane, fossil	lb	10.8
Methane, monochloro-, R-40	lb	3.4E-06
Methane, tetrachloro-, CFC-10	lb	3.9E-05
Methane, tetrafluoro-, CFC-14	lb	2.0E-07
Methane, trichlorofluoro-, CFC-11	lb	8.6E-10
Methane, trifluoro-, HFC-23	lb	5.4E-11
Methanesulfonic acid	lb	2.3E-13
Methanol	lb	0.049
Methyl acetate	lb	1.4E-04
Methyl acrylate	lb	5.0E-10
Methyl amine	lb	2.9E-12
Methyl borate	lb	5.0E-14
Methyl ethyl ketone	lb	1.4E-04
Methyl formate	lb	2.0E-12
Methyl lactate	lb	3.0E-12
Methyl methacrylate	lb	0.0054
Metolachlor	lb	6.4E-12
Metribuzin	lb	1.6E-12
Molybdenum	lb	1.0E-06
Monoethanolamine	lb	2.9E-08
Naphthalene	lb	5.6E-05
Nickel	lb	6.3E-04
Nickel compounds	lb	4.2E-14
Niobium-95	Ci	6.7E-19
Nitrate	lb	4.4E-07
Nitric oxide	lb	3.5E-10
Nitrobenzene	lb	1.6E-11
Nitrogen	lb	7.4E-07
Nitrogen dioxide	lb	4.5E-09
Nitrogen oxides	lb	4.83
Nitrogen, total	lb	3.8E-20
Nitrous oxide	lb	9.6E-05

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

NMVOC, non-methane volatile organic compounds, uns	lb	1.75
Noble gases, radioactive, unspecified	Ci	9.1E-06
Octane	lb	1.4E-09
Odorous sulfur	lb	9.9E-05
Organic acids	lb	1.4E-06
Organic substances, unspecified	lb	0.085
Oxygen	lb	2.5E-05
Ozone	lb	2.6E-05
PAH, polycyclic aromatic hydrocarbons	lb	1.3E-05
Palladium	lb	2.1E-18
Particulates, < 10 um	lb	1.46
Particulates, < 2.5 um	lb	0.21
Particulates, > 10 um	lb	0.066
Particulates, > 2.5 um, and < 10um	lb	0.42
Particulates, unspecified	lb	2.20
Pendimethalin	lb	3.5E-11
Pentane	lb	0.0025
PFC (perfluorocarbons)	lb	4.2E-13
Phenanthrene	lb	3.9E-07
Phenol	lb	3.4E-04
Phenol, 2,4-dichloro-	lb	1.9E-12
Phenol, pentachloro-	lb	2.2E-08
Phenols, unspecified	lb	4.2E-05
Phosphate	lb	8.7E-22
Phosphine	lb	1.1E-12
Phosphorus	lb	4.0E-05
Phthalate, dioctyl-	lb	4.7E-07
Phthalic acid,branched and linear di c7-c11 alk*	lb	0.0029
Phthalic anhydride	lb	1.1E-04
Platinum	lb	5.8E-12
Plutonium-238	Ci	1.3E-19
Plutonium-alpha	Ci	3.8E-19
Polonium-210	Ci	9.1E-12
Polychlorinated biphenyls	lb	3.7E-09
Polycyclic organic matter, unspecified	lb	1.3E-05
Potassium	lb	3.2E-05
Potassium-40	Ci	1.2E-12
Propanal	lb	2.4E-06
Propane	lb	0.0020
Propene	lb	5.5E-04
Propionic acid	lb	1.7E-07
Propylamine	lb	7.5E-14
Propylene oxide	lb	0.043
Protactinium-234	Ci	1.3E-13
Pyrene	lb	4.7E-08

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

Radioactive species, other beta emitters	Ci	2.4E-12
Radioactive species, unspecified	Ci	9.5E-05
Radionuclides (Including Radon)	lb	0.010
Radium-226	Ci	5.5E-12
Radium-228	Ci	5.9E-13
Radon-220	Ci	5.2E-11
Radon-222	Ci	1.7E-05
Rhodium	lb	2.0E-18
Ruthenium-103	Ci	1.5E-19
Scandium	lb	1.3E-07
Selenium	lb	1.9E-04
Silicon	lb	0.0049
Silicon tetrafluoride	lb	2.9E-09
Silver	lb	5.4E-08
Silver-110	Ci	1.5E-18
Sodium	lb	6.0E-05
Sodium chlorate	lb	3.2E-08
Sodium dichromate	lb	1.0E-08
Sodium formate	lb	1.0E-10
Sodium hydroxide	lb	4.5E-09
Strontium	lb	5.6E-07
Styrene	lb	5.49
Sulfate	lb	1.2E-04
Sulfur dioxide	lb	5.80
Sulfur hexafluoride	lb	4.0E-07
Sulfur oxides	lb	1.25
Sulfur trioxide	lb	1.3E-10
Sulfur, total reduced	lb	1.0E-08
Sulfuric acid	lb	6.2E-04
Sulfuric acid, dimethyl ester	lb	3.1E-07
t-Butyl methyl ether	lb	2.3E-07
t-Butylamine	lb	2.0E-13
Tar	lb	1.0E-24
Tellurium	lb	1.9E-12
Terpenes	lb	1.6E-08
Thallium	lb	1.8E-09
Thorium	lb	7.4E-10
Thorium-228	Ci	2.4E-13
Thorium-230	Ci	5.4E-13
Thorium-232	Ci	3.7E-13
Thorium-234	Ci	1.3E-13
Tin	lb	2.2E-07
Tin oxide	lb	3.2E-16
Titanium	lb	2.4E-06
Titanium Dioxide (nano)	lb	6.6E-04

Source: Franklin Associates, A Division of ERG

Table 61 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Vacuum Infused Products

TOC, Total Organic Carbon	lb	0.0066
Toluene	lb	0.066
Toluene, 2-chloro-	lb	4.9E-12
Toluene, 2,4-dinitro-	lb	1.8E-09
Trichloroethane	lb	7.9E-15
Triethyl amine	lb	5.2E-12
Trifluralin	lb	3.5E-11
Trimethylamine	lb	1.8E-14
Tungsten	lb	1.4E-08
Uranium	lb	7.0E-10
Uranium-234	Ci	1.6E-12
Uranium-235	Ci	8.8E-14
Uranium-238	Ci	2.5E-12
Uranium alpha	Ci	7.0E-12
Used air	lb	0.036
Vanadium	lb	4.5E-05
Vinyl acetate	lb	4.9E-08
VOC, volatile organic compounds	lb	3.37
Water	lb	3.02
Xenon-131m	Ci	3.2E-11
Xenon-133	Ci	1.0E-09
Xenon-133m	Ci	4.5E-12
Xenon-135	Ci	4.1E-10
Xenon-135m	Ci	2.4E-10
Xenon-137	Ci	4.4E-12
Xenon-138	Ci	3.9E-11
Xylene	lb	0.055
Zinc	lb	5.3E-05
Zinc-65	Ci	2.8E-17
Zinc compounds	lb	1.4E-13
Zinc oxide	lb	6.3E-16
Zirconium	lb	4.2E-09
Zirconium-95	Ci	2.8E-17

Source: Franklin Associates, A Division of ERG

Table 62. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

1-Butanol	lb	2.9E-09
1-Pentanol	lb	3.1E-13
1-Pentene	lb	2.4E-13
1,4-Butanediol	lb	5.1E-12
2-Aminopropanol	lb	6.1E-14
2-Hexanone	lb	1.1E-06
2-Methyl-1-propanol	lb	1.6E-12
2-Methyl-2-butene	lb	5.2E-17
2-Propanol	lb	8.1E-12
2,4-D	lb	2.0E-13
4-Methyl-2-pentanone	lb	3.7E-07
Acenaphthene	lb	1.3E-08
Acenaphthylene	lb	8.4E-10
Acetaldehyde	lb	0.0032
Acetic acid	lb	4.7E-07
Acetone	lb	9.0E-07
Acetonitrile	lb	1.9E-13
Acetyl chloride	lb	2.4E-13
Acidity, unspecified	lb	0.18
Acids, unspecified	lb	0.0019
Acrylate, ion	lb	1.1E-09
Acrylonitrile	lb	3.5E-13
Actinides, radioactive, unspecified	Ci	1.5E-12
Alachlor	lb	1.4E-13
Aldehydes (unspecified)	lb	5.8E-14
Aluminium	lb	0.088
Aluminum	lb	0.018
Aluminum, ion	lb	4.5E-11
Americium-241	Ci	1.7E-15
Ammonia	lb	0.010
Ammonia, as N	lb	1.2E-09
Ammonium, ion	lb	0.042
Aniline	lb	2.9E-11
Anthracene	lb	3.1E-12
Antimony	lb	0.0012
Antimony-122	Ci	4.2E-16
Antimony-124	Ci	2.5E-13
Antimony-125	Ci	2.3E-13
Antimony compounds	lb	4.1E-08
AOX, Adsorbable Organic Halogen as Cl	lb	1.8E-06
Arsenic, ion	lb	1.0E-04
Barite	lb	0.0079
Barium	lb	0.21
Barium-140	Ci	1.9E-15

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Bentazone	lb	1.2E-13
Benzene	lb	3.8E-04
Benzene, 1-methyl-4-(1-methylethyl)-	lb	8.8E-09
Benzene, 1,2-dichloro-	lb	1.3E-09
Benzene, chloro-	lb	2.6E-08
Benzene, ethyl-	lb	1.6E-04
Benzene, pentamethyl-	lb	6.6E-09
Benzenes, alkylated, unspecified	lb	3.1E-05
Benzo(a)anthracene	lb	2.2E-12
Benzo(b)fluoranthene	lb	2.4E-12
Benzoic acid	lb	1.7E-04
Beryllium	lb	7.4E-06
Biphenyl	lb	2.0E-06
BOD5, Biological Oxygen Demand	lb	4.30
Borate	lb	2.6E-11
Boron	lb	0.0010
Bromate	lb	3.5E-05
Bromide	lb	0.021
Bromine	lb	0.0025
Butene	lb	9.6E-10
Butyl acetate	lb	3.8E-09
Butyrolactone	lb	6.5E-12
Cadmium	lb	1.7E-07
Cadmium, ion	lb	1.9E-05
Calcium, ion	lb	0.71
Carbon-14	Ci	8.6E-14
Carbon disulfide	lb	1.4E-11
Carbonate	lb	0.026
Carboxylic acids, unspecified	lb	0.0094
Cerium-141	Ci	7.4E-16
Cerium-144	Ci	2.3E-16
Cesium	lb	2.2E-06
Cesium-134	Ci	3.0E-13
Cesium-136	Ci	1.3E-16
Cesium-137	Ci	1.8E-10
Chloramine	lb	4.5E-12
Chlorate	lb	3.2E-04
Chloride	lb	8.80
Chlorinated solvents, unspecified	lb	5.5E-05
Chlorine	lb	1.9E-05
Chloroacetic acid	lb	4.1E-09
Chloroacetyl chloride	lb	8.1E-14
Chloroform	lb	5.9E-11
Chlorosulfonic acid	lb	7.0E-13

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Chlorpyrifos	lb	5.2E-14
Chromium	lb	0.0012
Chromium-51	Ci	2.5E-13
Chromium VI	lb	0.0015
Chromium, ion	lb	6.3E-06
Chrysene	lb	1.2E-11
Clomazone	lb	2.7E-14
Cobalt	lb	0.0019
Cobalt-57	Ci	4.2E-15
Cobalt-58	Ci	1.9E-12
Cobalt-60	Ci	1.9E-12
COD, Chemical Oxygen Demand	lb	3.84
Copper	lb	2.9E-05
Copper, ion	lb	0.0029
Cresol	lb	1.4E-14
Cumene	lb	5.2E-06
Curium alpha	Ci	2.2E-15
Cyanide	lb	0.0016
Cyclohexane	lb	5.5E-16
Decane	lb	4.8E-06
Detergent, oil	lb	1.4E-08
Detergents, unspecified	lb	9.4E-23
Dibenzofuran	lb	1.7E-08
Dibenzothiophene	lb	1.7E-08
Dichromate	lb	3.8E-08
Diethylamine	lb	1.3E-11
Dimethylamine	lb	7.1E-12
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	3.0E-11
Dipropylamine	lb	8.3E-12
Dissolved organics	lb	1.9E-06
Dissolved solids	lb	8.40
DOC, Dissolved Organic Carbon	lb	0.69
Docosane	lb	9.4E-08
Dodecane	lb	9.1E-06
Eicosane	lb	2.5E-06
Ethane, 1,2-dichloro-	lb	3.8E-07
Ethanol	lb	6.8E-09
Ethene	lb	2.1E-06
Ethene, chloro-	lb	1.0E-04
Ethyl acetate	lb	1.4E-11
Ethylamine	lb	5.6E-13
Ethylene diamine	lb	7.6E-12
Ethylene oxide	lb	5.2E-10
Fluoranthene	lb	2.6E-12

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Fluorene	lb	8.4E-07
Fluorene, 1-methyl-	lb	1.0E-08
Fluorenes, alkylated, unspecified	lb	1.8E-06
Fluoride	lb	0.11
Fluorine	lb	7.0E-10
Fluosilicic acid	lb	5.0E-08
Formaldehyde	lb	2.7E-07
Formamide	lb	5.7E-13
Formate	lb	6.2E-11
Formic acid	lb	1.7E-13
Furan	lb	3.3E-12
Glutaraldehyde	lb	9.8E-07
Glyphosate	lb	9.3E-12
Glyphosate-trimesium	lb	7.6E-13
Heat, waste	Ci	1.3E-09
Hexadecane	lb	9.9E-06
Hexane	lb	1.8E-15
Hexanoic acid	lb	3.5E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	2.8E-04
Hydrocarbons, aliphatic, unsaturated	lb	2.6E-05
Hydrocarbons, aromatic	lb	0.0012
Hydrocarbons, unspecified	lb	0.023
Hydrogen-3, Tritium	Ci	4.1E-07
Hydrogen chloride	lb	1.7E-11
Hydrogen fluoride	lb	1.6E-09
Hydrogen peroxide	lb	1.1E-08
Hydrogen sulfide	lb	9.3E-05
Hydroxide	lb	3.6E-08
Hypochlorite	lb	1.8E-06
Iodide	lb	2.2E-04
Iodine-129	Ci	2.4E-13
Iodine-131	Ci	4.5E-14
Iodine-133	Ci	1.2E-15
Iron	lb	0.035
Iron-59	Ci	3.2E-16
Iron, ion	lb	0.029
Isopropylamine	lb	1.3E-13
Lactic acid	lb	6.5E-12
Lanthanum-140	Ci	2.0E-15
Lead	lb	6.7E-04
Lead-210	Ci	1.6E-11
Lead-210/kg	lb	1.7E-14
Lithium, ion	lb	0.066
m-Xylene	lb	4.8E-06

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Magnesium	lb	0.12
Manganese	lb	0.0060
Manganese-54	Ci	1.8E-13
Mercury	lb	4.1E-05
Metallic ions, unspecified	lb	8.9E-05
Methane, dibromo-	lb	6.3E-16
Methane, dichloro-, HCC-30	lb	2.5E-05
Methane, monochloro-, R-40	lb	3.5E-09
Methane, trichlorofluoro-, CFC-11	lb	7.8E-12
Methanol	lb	3.1E-07
Methyl acetate	lb	2.4E-14
Methyl acrylate	lb	9.9E-09
Methyl amine	lb	7.1E-12
Methyl ethyl ketone	lb	7.1E-09
Methyl formate	lb	8.1E-13
Metolachlor	lb	2.7E-13
Metribuzin	lb	6.7E-14
Molybdenum	lb	4.9E-05
Molybdenum-99	Ci	6.8E-16
n-Hexacosane	lb	5.8E-08
Naphthalene	lb	3.0E-06
Naphthalene, 2-methyl-	lb	2.5E-06
Naphthalenes, alkylated, unspecified	lb	5.1E-07
Nickel	lb	3.9E-05
Nickel, ion	lb	0.0023
Niobium-95	Ci	1.9E-14
Nitrate	lb	0.015
Nitrate compounds	lb	1.5E-05
Nitric acid	lb	5.7E-22
Nitrite	lb	2.8E-06
Nitrobenzene	lb	6.5E-11
Nitrogen	lb	0.014
Nitrogen, organic bound	lb	4.7E-04
Nitrogen, total	lb	2.0E-04
o-Cresol	lb	4.8E-06
o-Xylene	lb	1.8E-06
Octadecane	lb	2.5E-06
Oils, unspecified	lb	0.16
Organic substances, unspecified	lb	2.1E-22
p-Cresol	lb	5.1E-06
p-Xylene	lb	1.8E-06
PAH, polycyclic aromatic hydrocarbons	lb	1.3E-05
Particulates, < 10 um	lb	2.0E-12
Particulates, > 10 um	lb	1.2E-05

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Pendimethalin	lb	1.5E-12
Phenanthrene	lb	1.3E-07
Phenanthrenes, alkylated, unspecified	lb	2.1E-07
Phenol	lb	5.1E-04
Phenol, 2,4-dimethyl-	lb	4.6E-06
Phenols, unspecified	lb	0.023
Phosphate	lb	0.059
Phosphorus	lb	5.6E-05
Phosphorus compounds, unspecified	lb	4.6E-11
Plutonium-alpha	Ci	6.7E-15
Polonium-210	Ci	2.3E-11
Potassium	lb	7.1E-09
Potassium-40	Ci	4.4E-12
Potassium, ion	lb	0.091
Process solvents, unspecified	lb	3.3E-10
Propanal	lb	4.5E-13
Propane, 1,2-dichloro-	lb	4.7E-18
Propanol	lb	6.9E-13
Propene	lb	2.1E-06
Propionic acid	lb	4.6E-12
Propylamine	lb	1.8E-13
Propylene oxide	lb	0.083
Protactinium-234	Ci	2.4E-12
Radioactive species, alpha emitters	Ci	4.0E-14
Radioactive species, Nuclides, unspecified	Ci	1.5E-07
Radium-224	Ci	1.3E-09
Radium-226	Ci	3.6E-09
Radium-226/kg	lb	6.0E-12
Radium-228	Ci	2.7E-09
Radium-228/kg	lb	3.0E-14
Rubidium	lb	2.2E-05
Ruthenium-103	Ci	1.4E-16
Ruthenium-106	Ci	1.7E-15
Scandium	lb	8.4E-06
Selenium	lb	6.1E-05
Silicon	lb	2.58
Silver	lb	2.1E-04
Silver-110	Ci	1.4E-12
Silver, ion	lb	3.6E-06
Sodium-24	Ci	5.2E-15
Sodium dichromate	lb	4.4E-10
Sodium formate	lb	2.5E-10
Sodium hydroxide	lb	0.024
Sodium, ion	lb	2.06

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

Solids, inorganic	lb	0.016
Solved solids	lb	0.088
Strontium	lb	0.014
Strontium-89	Ci	2.4E-14
Strontium-90	Ci	1.3E-09
Styrene	lb	9.3E-05
Sulfate	lb	3.16
Sulfide	lb	1.4E-04
Sulfite	lb	4.9E-06
Sulfur	lb	8.1E-04
Surfactants	lb	2.9E-05
Surfactants, unspecified	lb	5.4E-05
Suspended solids, unspecified	lb	2.08
t-Butyl methyl ether	lb	4.7E-06
t-Butylamine	lb	4.9E-13
Tar	lb	1.4E-26
Technetium-99m	Ci	1.6E-14
Tellurium-123m	Ci	2.7E-14
Tellurium-132	Ci	3.9E-17
Tetradecane	lb	3.9E-06
Thallium	lb	3.0E-06
Thorium-228	Ci	5.3E-09
Thorium-230	Ci	3.2E-10
Thorium-232	Ci	5.2E-13
Thorium-234	Ci	2.4E-12
Tin	lb	3.8E-05
Tin, ion	lb	1.2E-04
Titanium	lb	2.9E-10
Titanium, ion	lb	3.3E-04
TOC, Total Organic Carbon	lb	0.73
Toluene	lb	4.5E-04
Toluene, 2-chloro-	lb	1.0E-11
Tributyltin compounds	lb	1.9E-06
Triethylene glycol	lb	1.7E-07
Trifluralin	lb	9.1E-13
Trimethylamine	lb	4.3E-14
Tungsten	lb	3.7E-06
Uranium-234	Ci	2.8E-12
Uranium-235	Ci	4.7E-12
Uranium-238	Ci	1.6E-11
Uranium alpha	Ci	1.4E-10
Urea	lb	5.4E-13
Vanadium	lb	1.7E-05
Vanadium, ion	lb	2.1E-04

Source: Franklin Associates, A Division of ERG

Table 62 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Vacuum Infused Products

VOC, volatile organic compounds, unspecified origin	lb	7.6E-04
Xylene	lb	3.0E-04
Yttrium	lb	1.1E-06
Zinc	lb	0.0010
Zinc-65	Ci	7.0E-14
Zinc, ion	lb	0.0041
Zirconium-95	Ci	8.1E-16

Source: Franklin Associates, A Division of ERG

Table 63. Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

1-Butanol	lb	2.9E-19
1-Pentanol	lb	2.4E-19
1-Pentene	lb	1.8E-19
1-Propanol	lb	3.2E-17
1,4-Butanediol	lb	6.3E-18
2-Aminopropanol	lb	2.0E-19
2-Butene, 2-methyl-	lb	4.0E-23
2-Chloroacetophenone	lb	2.4E-07
2-Methyl-1-propanol	lb	6.5E-19
2-Nitrobenzoic acid	lb	3.5E-19
2-Propanol	lb	0.0010
2,4-D	lb	8.5E-15
4-Methyl-2-pentanone	lb	8.3E-07
5-methyl Chrysene	lb	4.9E-09
Acenaphthene	lb	1.1E-07
Acenaphthylene	lb	5.5E-08
Acetaldehyde	lb	4.3E-04
Acetic acid	lb	2.5E-04
Acetic acid, methyl ester	lb	2.0E-04
Acetone	lb	6.0E-06
Acetonitrile	lb	1.8E-15
Acetophenone	lb	5.0E-07
Acid gases	lb	0.020
Acidity, unspecified	lb	3.3E-14
Acids, unspecified	lb	1.4E-13
Acrolein	lb	2.5E-05
Acrylic acid	lb	2.5E-16
Actinides, radioactive, unspecified	Ci	4.5E-21
Aerosols, radioactive, unspecified	Ci	5.1E-20
Alachlor	lb	6.1E-15
Alcohols, c12-14, ethoxylated	lb	0.0010
Aldehydes, unspecified	lb	0.0011
alpha-Pinene	lb	1.9E-05
Aluminium	lb	2.1E-10
Aluminum	lb	4.5E-19
Ammonia	lb	0.15
Ammonium carbonate	lb	1.2E-15
Ammonium chloride	lb	5.2E-04
Ammonium, ion	lb	1.2E-18

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Aniline	lb	2.8E-18
Anthracene	lb	4.6E-08
Anthranilic acid	lb	2.6E-19
Antimony	lb	4.9E-06
Antimony-124	Ci	6.7E-24
Antimony-125	Ci	4.3E-23
Argon-41	Ci	3.5E-17
Arsenic	lb	1.1E-04
Arsenic trioxide	lb	3.6E-21
Arsine	lb	3.0E-19
Barium	lb	6.5E-08
Barium-140	Ci	2.8E-21
Bentazone	lb	5.1E-15
Benzal chloride	lb	3.1E-22
Benzaldehyde	lb	8.6E-16
Benzene	lb	0.10
Benzene, 1-methyl-2-nitro-	lb	3.0E-19
Benzene, 1,2-dichloro-	lb	6.5E-18
Benzene, 1,2,4-trichloro-	lb	5.1E-07
Benzene, 1,3,5-trimethyl-	lb	7.7E-21
Benzene, chloro-	lb	7.4E-07
Benzene, ethyl-	lb	0.45
Benzene, hexachloro-	lb	2.5E-14
Benzene, pentachloro-	lb	4.6E-16
Benzo(a)anthracene	lb	1.8E-08
Benzo(a)pyrene	lb	8.8E-09
Benzo(b)fluoranthene	lb	4.5E-19
Benzo(b,j,k)fluoranthene	lb	2.4E-08
Benzo(ghi)perylene	lb	6.0E-09
Benzyl chloride	lb	2.4E-05
Beryllium	lb	5.8E-06
Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-	lb	1.1E-05
Biphenyl	lb	3.8E-07
Boron	lb	4.4E-12
Boron trifluoride	lb	4.1E-23
Bromine	lb	3.9E-04
Bromoform	lb	1.3E-06
Bromoxynil	lb	6.9E-15
BTEX (Benzene, Toluene, Ethylbenzene, and Xylene), unspe	lb	1.1E-13
Butadiene	lb	1.7E-05
Butane	lb	6.4E-11
Butene	lb	1.3E-12
Butyrolactone	lb	1.5E-18
Cadmium	lb	2.9E-05
Calcium	lb	7.8E-12

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Carbon-14	Ci	3.4E-16
Carbon dioxide	lb	0.0013
Carbon dioxide, biogenic	lb	1.53
Carbon dioxide, fossil	lb	3,459
Carbon dioxide, land transformation	lb	2.0E-05
Carbon disulfide	lb	4.4E-06
Carbon monoxide	lb	6.79
Carbon monoxide, biogenic	lb	2.8E-11
Carbon monoxide, fossil	lb	1.82
Carbonyl sulfide	lb	3.4E-13
Cerium-141	Ci	6.7E-22
Cesium-134	Ci	2.1E-21
Cesium-137	Ci	4.8E-21
Chloramine	lb	1.2E-18
Chloride	lb	1.9E-14
Chlorinated fluorocarbons and hydrochlorinated fluorocarbons, unspecified	lb	3.6E-14
Chlorine	lb	0.0025
Chloroacetic acid	lb	8.1E-16
Chloroform	lb	3.3E-06
Chlorosilane, trimethyl-	lb	3.6E-13
Chlorosulfonic acid	lb	2.4E-18
Chlorpyrifos	lb	2.3E-15
Chromium	lb	8.0E-05
Chromium-51	Ci	4.3E-23
Chromium VI	lb	1.7E-05
Chromium, ion	lb	1.3E-14
Chrysene	lb	2.2E-08
Clomazone	lb	1.2E-15
Cobalt	lb	9.2E-05
Cobalt-58	Ci	7.3E-23
Cobalt-60	Ci	8.6E-22
Copper	lb	2.1E-05
Cumene	lb	1.8E-07
Cyanide	lb	8.4E-05
Cyanoacetic acid	lb	2.0E-18
Cyclohexane	lb	4.4E-17
D-limonene	lb	8.5E-07
Dibenz(a,h)anthracene	lb	1.4E-19
Diethanolamine	lb	3.0E-23
Diethylamine	lb	1.3E-18
Dimethyl ether	lb	4.0E-04
Dimethyl malonate	lb	2.5E-18
Dimethyl sulfide	lb	1.8E-05
Dinitrogen monoxide	lb	0.074
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	1.2E-09

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Dipropylamine	lb	7.3E-19
Ethane	lb	1.1E-10
Ethane, 1,1-difluoro-, HFC-152a	lb	5.7E-16
Ethane, 1,1,1-trichloro-, HCFC-140	lb	6.7E-07
Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	lb	7.1E-05
Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	lb	1.2E-17
Ethane, 1,2-dibromo-	lb	4.0E-08
Ethane, 1,2-dichloro-	lb	1.3E-06
Ethane, 1,2-dichloro-1,1,2-trifluoro-, HCFC-123	lb	7.1E-05
Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	lb	1.7E-14
Ethane, chloro-	lb	1.4E-06
Ethane, hexafluoro-, HFC-116	lb	9.5E-12
Ethanol	lb	0.010
Ethene	lb	7.1E-12
Ethene, chloro-	lb	1.9E-04
Ethene, tetrachloro-	lb	1.0E-05
Ethers, unspecified	lb	0.12
Ethyl acetate	lb	0.0010
Ethyl cellulose	lb	9.2E-16
Ethylamine	lb	7.9E-19
Ethylene diamine	lb	3.4E-18
Ethylene dibromide	lb	1.9E-06
Ethylene oxide	lb	1.2E-04
Ethyne	lb	3.8E-13
Fluoranthene	lb	1.6E-07
Fluorene	lb	2.0E-07
Fluoride	lb	0.0015
Fluorine	lb	3.7E-10
Fluosilicic acid	lb	1.8E-11
Formaldehyde	lb	0.0035
Formamide	lb	4.4E-19
Formic acid	lb	1.3E-14
Furan	lb	8.4E-10
Glyphosate	lb	4.1E-13
Glyphosate-trimesium	lb	3.3E-14
Heat, waste	Btu	7,802
Helium	lb	5.1E-12
Heptane	lb	1.3E-11
Hexamethylene diamine	lb	6.9E-20
Hexane	lb	2.3E-06
Hydrazine, methyl-	lb	5.7E-06
Hydrocarbons, aliphatic, alkanes, cyclic	lb	7.4E-15
Hydrocarbons, aliphatic, alkanes, unspecified	lb	1.6E-10
Hydrocarbons, aliphatic, unsaturated	lb	2.5E-11
Hydrocarbons, aromatic	lb	1.2E-10

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Hydrocarbons, chlorinated	lb	9.2E-14
Hydrocarbons, unspecified	lb	0.0035
Hydrogen	lb	0.0021
Hydrogen-3, Tritium	Ci	1.4E-15
Hydrogen bromide	lb	2.3E-16
Hydrogen chloride	lb	0.26
Hydrogen cyanide	lb	1.1E-14
Hydrogen fluoride	lb	0.032
Hydrogen iodide	lb	2.5E-19
Hydrogen peroxide	lb	6.9E-16
Hydrogen sulfide	lb	7.1E-10
Indeno(1,2,3-cd)pyrene	lb	1.3E-08
Iodine	lb	2.4E-13
Iodine-129	Ci	2.8E-19
Iodine-131	Ci	6.7E-18
Iodine-133	Ci	3.8E-21
Iodine-135	Ci	9.9E-22
Iron	lb	6.5E-08
Isocyanic acid	lb	0.080
Isophorone	lb	1.9E-05
Isoprene	lb	5.0E-13
Isopropylamine	lb	3.1E-19
Kerosene	lb	2.5E-04
Krypton-85	Ci	5.9E-17
Krypton-85m	Ci	2.8E-13
Krypton-87	Ci	9.5E-18
Krypton-88	Ci	1.2E-17
Krypton-89	Ci	5.0E-18
Lactic acid	lb	5.8E-19
Lanthanum-140	Ci	2.4E-22
Lead	lb	2.3E-04
Lead-210	Ci	1.3E-18
Lead compounds	lb	9.0E-21
m-Xylene	lb	9.9E-06
Magnesium	lb	0.0024
Manganese	lb	1.4E-04
Manganese-54	Ci	2.2E-23
Mercaptans, unspecified	lb	0.0073
Mercury	lb	2.0E-04
Metals, unspecified	lb	2.2E-05
Methacrylic acid, methyl ester	lb	6.7E-07
Methane	lb	1.64
Methane, biogenic	lb	3.4E-11
Methane, bromo-, Halon 1001	lb	5.4E-06
Methane, bromochlorodifluoro-, Halon 1211	lb	8.8E-15

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Methane, bromotrifluoro-, Halon 1301	lb	4.0E-14
Methane, chlorodifluoro-, HCFC-22	lb	2.0E-04
Methane, chlorotrifluoro-, CFC-13	lb	9.8E-06
Methane, dichloro-, HCC-30	lb	1.4E-04
Methane, dichlorodifluoro-, CFC-12	lb	2.8E-11
Methane, dichlorofluoro-, HCFC-21	lb	8.8E-20
Methane, fossil	lb	17.0
Methane, monochloro-, R-40	lb	1.8E-05
Methane, tetrachloro-, CFC-10	lb	1.5E-04
Methane, tetrafluoro-, CFC-14	lb	9.5E-11
Methane, trichlorofluoro-, CFC-11	lb	3.8E-15
Methane, trifluoro-, HFC-23	lb	2.8E-17
Methanesulfonic acid	lb	2.0E-18
Methanol	lb	0.052
Methyl acetate	lb	8.1E-20
Methyl acrylate	lb	2.9E-16
Methyl amine	lb	1.4E-18
Methyl borate	lb	1.0E-19
Methyl ethyl ketone	lb	0.0010
Methyl formate	lb	1.2E-18
Methyl lactate	lb	6.3E-19
Methyl mercaptan	lb	2.1E-06
Methyl methacrylate	lb	1.8E-18
Metolachlor	lb	1.2E-14
Metribuzin	lb	2.9E-15
Molybdenum	lb	2.9E-13
Monoethanolamine	lb	1.6E-11
Naphthalene	lb	2.5E-05
Nickel	lb	0.0011
Nickel compounds	lb	1.9E-04
Niobium-95	Ci	2.6E-24
Nitrate	lb	1.5E-13
Nitric oxide	lb	1.6E-15
Nitrobenzene	lb	4.0E-18
Nitrogen	lb	2.2E-11
Nitrogen dioxide	lb	2.0E-07
Nitrogen oxides	lb	6.92
Nitrogen, total	lb	2.7E-15
Nitrous oxide	lb	2.5E-04
NMVOC, non-methane volatile organic compounds, unspecified	lb	4.04
Noble gases, radioactive, unspecified	Ci	2.5E-12
o-Xylene	lb	9.9E-07
Octane	lb	2.0E-14
Odorous sulfur	lb	4.2E-16
Organic acids	lb	1.9E-06

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Organic substances, unspecified	lb	0.11
Oxygen	lb	1.2E-10
Ozone	lb	9.0E-12
p-Xylene	lb	9.9E-07
PAH, polycyclic aromatic hydrocarbons	lb	7.3E-05
Palladium	lb	2.0E-25
Particulates, < 10 um	lb	1.45
Particulates, < 2.5 um	lb	0.39
Particulates, > 10 um	lb	9.0E-09
Particulates, > 2.5 um, and < 10um	lb	0.29
Particulates, unspecified	lb	0.76
Pendimethalin	lb	6.6E-14
Pentane	lb	8.2E-11
PFC (perfluorocarbons)	lb	0.0019
Phenanthrene	lb	6.0E-07
Phenol	lb	1.6E-06
Phenol, 2,4-dichloro-	lb	5.2E-19
Phenol, pentachloro-	lb	6.5E-13
Phenols, unspecified	lb	5.2E-05
Phosphate	lb	4.8E-17
Phosphine	lb	2.3E-19
Phosphorus	lb	3.4E-12
Phthalate, dioctyl-	lb	2.5E-06
Platinum	lb	3.4E-19
Plutonium-238	Ci	3.6E-26
Plutonium-alpha	Ci	8.4E-25
Polonium-210	Ci	2.2E-18
Polychlorinated biphenyls	lb	3.0E-14
Polycyclic organic matter, unspecified	lb	2.5E-05
Potassium	lb	1.2E-05
Potassium-40	Ci	2.7E-19
Propanal	lb	1.3E-05
Propane	lb	9.9E-06
Propene	lb	0.0010
Propionic acid	lb	9.9E-14
Propylamine	lb	1.4E-19
Propylene oxide	lb	0.21
Protactinium-234	Ci	4.4E-20
Pyrene	lb	7.3E-08
Radioactive species, other beta emitters	Ci	1.7E-18
Radioactive species, unspecified	Ci	1.3E-04
Radionuclides (Including Radon)	lb	0.014
Radium-226	Ci	1.7E-18
Radium-228	Ci	5.7E-19
Radon-220	Ci	7.7E-18

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Radon-222	Ci	5.8E-12
Rhodium	lb	1.9E-25
Ruthenium-103	Ci	5.7E-25
Scandium	lb	4.4E-14
Selenium	lb	3.0E-04
Silicon	lb	2.3E-11
Silicon tetrafluoride	lb	2.4E-16
Silver	lb	2.0E-15
Silver-110	Ci	5.7E-24
Sodium	lb	2.7E-07
Sodium chlorate	lb	2.8E-15
Sodium dichromate	lb	3.1E-15
Sodium formate	lb	2.7E-16
Sodium hydroxide	lb	2.6E-15
Strontium	lb	2.3E-13
Styrene	lb	1.3E-06
Sulfate	lb	6.6E-11
Sulfur dioxide	lb	8.54
Sulfur hexafluoride	lb	7.6E-14
Sulfur oxides	lb	2.26
Sulfur trioxide	lb	3.4E-17
Sulfur, total reduced	lb	9.1E-05
Sulfuric acid	lb	1.9E-06
Sulfuric acid, dimethyl ester	lb	1.6E-06
t-Butyl methyl ether	lb	1.2E-06
t-Butylamine	lb	1.6E-18
Tar	lb	1.7E-20
Tellurium	lb	1.7E-15
Terpenes	lb	6.6E-05
Thallium	lb	1.6E-14
Thorium	lb	1.4E-15
Thorium-228	Ci	7.7E-20
Thorium-230	Ci	1.7E-19
Thorium-232	Ci	8.1E-20
Thorium-234	Ci	4.4E-20
Tin	lb	1.1E-12
Tin oxide	lb	7.9E-22
Titanium	lb	2.2E-12
TOC, Total Organic Carbon	lb	0.30
Toluene	lb	0.15
Toluene, 2-chloro-	lb	1.6E-18
Toluene, 2,4-dinitro-	lb	9.4E-09
Trichloroethane	lb	2.4E-11
Trifluralin	lb	6.6E-14
Trimethylamine	lb	0.0029

Source: Franklin Associates, A Division of ERG

Table 63 (Cont). Cradle-to-Gate LCI Results-Atmospheric Emissions for 1,000 pounds of Applied Secondary Bond

Tungsten	lb	4.9E-15
Uranium	lb	1.7E-15
Uranium-234	Ci	5.3E-19
Uranium-235	Ci	9.3E-20
Uranium-238	Ci	8.1E-19
Uranium alpha	Ci	2.4E-18
Used air	lb	2.7E-07
Vanadium	lb	2.0E-12
Vinyl acetate	lb	2.6E-07
VOC, volatile organic compounds	lb	32.0
Water	lb	1.5E-07
Xenon-131m	Ci	4.9E-17
Xenon-133	Ci	1.8E-15
Xenon-133m	Ci	2.2E-18
Xenon-135	Ci	7.3E-16
Xenon-135m	Ci	4.5E-16
Xenon-137	Ci	1.4E-17
Xenon-138	Ci	1.0E-16
Xylene	lb	0.089
Zinc	lb	1.3E-06
Zinc-65	Ci	1.1E-22
Zinc oxide	lb	1.6E-21
Zirconium	lb	1.9E-15
Zirconium-95	Ci	1.1E-22

Source: Franklin Associates, A Division of ERG

Table 64. Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

1-Butanol	lb	1.7E-15
1-Pentanol	lb	5.7E-19
1-Pentene	lb	4.3E-19
1,4-Butanediol	lb	2.5E-18
2-Aminopropanol	lb	4.9E-19
2-Hexanone	lb	2.4E-06
2-Methyl-1-propanol	lb	1.6E-18
2-Methyl-2-butene	lb	9.6E-23
2-Propanol	lb	4.6E-15
2,4-D	lb	3.7E-16
4-Methyl-2-pentanone	lb	8.6E-07
Acenaphthene	lb	4.9E-16
Acenaphthylene	lb	7.8E-17
Acetaldehyde	lb	1.3E-04
Acetic acid	lb	1.4E-13
Acetone	lb	2.1E-06
Acetonitrile	lb	1.7E-18
Acetyl chloride	lb	4.5E-19
Acidity, unspecified	lb	4.56
Acids, unspecified	lb	1.8E-04
Acrylate, ion	lb	6.0E-16
Acrylonitrile	lb	4.1E-18
Actinides, radioactive, unspecified	Ci	4.2E-19
Alachlor	lb	2.6E-16
Aldehydes (unspecified)	lb	2.2E-21
Aluminium	lb	1.2E-08
Aluminum	lb	0.037
Americium-241	Ci	7.5E-21
Ammonia	lb	0.026
Ammonia, as N	lb	3.8E-06
Ammonium, ion	lb	0.070
Aniline	lb	6.8E-18
Anthracene	lb	3.9E-17
Antimony	lb	2.0E-05
Antimony-122	Ci	1.6E-21
Antimony-124	Ci	1.3E-19
Antimony-125	Ci	1.2E-19
Antimony compounds	lb	4.8E-09
AOX, Adsorbable Organic Halogen as Cl	lb	4.0E-06
Arsenic	lb	2.3E-14
Arsenic, ion	lb	7.3E-05
Barite	lb	1.8E-10
Barium	lb	0.45
Barium-140	Ci	7.2E-21

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Bentazone	lb	2.2E-16
Benzene	lb	4.0E-04
Benzene, 1-methyl-4-(1-methylethyl)-	lb	2.0E-08
Benzene, 1,2-dichloro-	lb	7.5E-16
Benzene, chloro-	lb	1.5E-14
Benzene, ethyl-	lb	2.6E-05
Benzene, pentamethyl-	lb	1.5E-08
Benzenes, alkylated, unspecified	lb	6.8E-05
Benzo(a)anthracene	lb	3.3E-17
Benzo(b)fluoranthene	lb	3.7E-17
Benzoic acid	lb	3.7E-04
Beryllium	lb	4.4E-06
Biphenyl	lb	4.4E-06
BOD5, Biological Oxygen Demand	lb	0.67
Borate	lb	6.3E-17
Boron	lb	0.0011
Bromate	lb	2.9E-12
Bromide	lb	0.046
Bromine	lb	4.5E-11
Butene	lb	4.7E-16
Butyl acetate	lb	2.2E-15
Butyrolactone	lb	3.7E-18
Cadmium	lb	1.7E-13
Cadmium, ion	lb	1.3E-05
Calcium, ion	lb	0.76
Carbon-14	Ci	3.8E-19
Carbon disulfide	lb	1.6E-17
Carbonate	lb	8.8E-12
Carboxylic acids, unspecified	lb	2.3E-10
Cerium-141	Ci	2.9E-21
Cerium-144	Ci	8.8E-22
Cesium	lb	5.5E-14
Cesium-134	Ci	4.4E-19
Cesium-136	Ci	5.1E-22
Cesium-137	Ci	5.3E-17
Chloramine	lb	1.1E-17
Chlorate	lb	2.3E-11
Chloride	lb	9.33
Chlorinated solvents, unspecified	lb	1.3E-14
Chlorine	lb	7.6E-13
Chloroacetic acid	lb	3.5E-14
Chloroacetyl chloride	lb	6.6E-19
Chloroform	lb	4.0E-07
Chlorosulfonic acid	lb	6.0E-18

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Chlorpyrifos	lb	9.7E-17
Chromium	lb	9.2E-04
Chromium-51	Ci	5.5E-19
Chromium VI	lb	9.6E-09
Chromium, ion	lb	1.6E-06
Chrysene	lb	1.9E-16
Clomazone	lb	5.1E-17
Cobalt	lb	8.1E-06
Cobalt-57	Ci	1.6E-20
Cobalt-58	Ci	2.5E-18
Cobalt-60	Ci	3.8E-18
COD, Chemical Oxygen Demand	lb	2.32
Copper	lb	6.9E-05
Copper, ion	lb	1.4E-04
Cresol	lb	2.1E-19
Cumene	lb	1.5E-10
Curium alpha	Ci	1.0E-20
Cyanide	lb	4.2E-07
Cyclohexane	lb	4.5E-19
Decane	lb	1.1E-05
Detergent, oil	lb	3.9E-06
Detergents, unspecified	lb	1.9E-16
Dibenzofuran	lb	3.9E-08
Dibenzothiophene	lb	4.1E-08
Dichromate	lb	1.1E-14
Diethylamine	lb	3.2E-18
Dimethylamine	lb	1.7E-17
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	lb	1.4E-12
Dipropylamine	lb	1.8E-18
Dissolved organics	lb	2.7E-19
Dissolved solids	lb	48.0
DOC, Dissolved Organic Carbon	lb	0.046
Docosane	lb	2.2E-07
Dodecane	lb	2.0E-05
Eicosane	lb	5.5E-06
Ethane, 1,2-dichloro-	lb	3.5E-15
Ethanol	lb	4.3E-15
Ethene	lb	4.0E-13
Ethene, chloro-	lb	5.0E-06
Ethyl acetate	lb	3.7E-18
Ethylamine	lb	1.9E-18
Ethylene diamine	lb	8.3E-18
Ethylene oxide	lb	2.4E-14
Fluoranthene	lb	3.9E-17

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Fluorene	lb	1.8E-06
Fluorene, 1-methyl-	lb	2.3E-08
Fluorenes, alkylated, unspecified	lb	3.9E-06
Fluoride	lb	0.0018
Fluorine	lb	2.4E-09
Fluosilicic acid	lb	3.2E-11
Formaldehyde	lb	6.4E-13
Formamide	lb	1.0E-18
Formate	lb	4.9E-16
Formic acid	lb	3.0E-19
Furan	lb	1.4E-18
Glutaraldehyde	lb	2.2E-14
Glyphosate	lb	1.7E-14
Glyphosate-trimesium	lb	1.4E-15
Haloalkanes	lb	1.2E-15
Heat, waste	Ci	4.0E-16
Hexadecane	lb	2.2E-05
Hexane	lb	2.4E-20
Hexanoic acid	lb	7.7E-05
Hydrocarbons, aliphatic, alkanes, unspecified	lb	7.1E-12
Hydrocarbons, aliphatic, unsaturated	lb	6.6E-13
Hydrocarbons, aromatic	lb	2.9E-11
Hydrocarbons, unspecified	lb	0.48
Hydrogen-3, Tritium	Ci	1.2E-13
Hydrogen chloride	lb	1.3E-14
Hydrogen fluoride	lb	3.1E-17
Hydrogen peroxide	lb	7.4E-15
Hydrogen sulfide	lb	2.8E-11
Hydroxide	lb	3.7E-13
Hypochlorite	lb	2.8E-13
Iodide	lb	5.5E-12
Iodine-129	Ci	1.1E-18
Iodine-131	Ci	3.0E-20
Iodine-133	Ci	4.5E-21
Iron	lb	0.072
Iron-59	Ci	1.2E-21
Iron, ion	lb	3.6E-08
Isopropylamine	lb	7.3E-19
Lactic acid	lb	1.4E-18
Lanthanum-140	Ci	7.7E-21
Lead	lb	2.0E-04
Lead-210	Ci	1.5E-18
Lead-210/kg	lb	3.8E-14
Lead 210	lb	8.8E-24

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Lithium, ion	lb	0.16
m-Xylene	lb	1.1E-05
Magnesium	lb	0.15
Manganese	lb	0.0038
Manganese-54	Ci	4.0E-19
Mercury	lb	2.5E-06
Metallic ions, unspecified	lb	0.60
Methane, dibromo-	lb	1.0E-20
Methane, dichloro-, HCC-30	lb	5.9E-13
Methane, monochloro-, R-40	lb	8.2E-09
Methane, trichlorofluoro-, CFC-11	lb	4.6E-15
Methanol	lb	0.12
Methyl acetate	lb	2.0E-19
Methyl acrylate	lb	5.6E-15
Methyl amine	lb	3.4E-18
Methyl ethyl ketone	lb	1.6E-08
Methyl formate	lb	4.9E-19
Metolachlor	lb	5.1E-16
Metribuzin	lb	1.3E-16
Molybdenum	lb	8.4E-06
Molybdenum-99	Ci	2.6E-21
n-Hexacosane	lb	1.4E-07
n-Hexadecane	lb	5.6E-17
Naphthalene	lb	6.6E-06
Naphthalene, 2-methyl-	lb	5.6E-06
Naphthalenes, alkylated, unspecified	lb	1.1E-06
Nickel	lb	8.9E-05
Nickel, ion	lb	1.2E-09
Niobium-95	Ci	1.2E-20
Nitrate	lb	0.16
Nitrate compounds	lb	0.60
Nitric acid	lb	9.7E-18
Nitrite	lb	1.5E-12
Nitrobenzene	lb	1.6E-17
Nitrogen	lb	1.5E-05
Nitrogen, organic bound	lb	5.3E-11
Nitrogen, total	lb	2.8E-04
o-Cresol	lb	1.1E-05
o-Xylene	lb	3.9E-06
Octadecane	lb	5.4E-06
Oils, unspecified	lb	0.021
Organic substances, unspecified	lb	4.2E-16
p-Cresol	lb	1.1E-05
p-Xylene	lb	3.9E-06

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

PAH, polycyclic aromatic hydrocarbons	lb	8.0E-13
Particulates, < 10 um	lb	1.6E-16
Particulates, > 10 um	lb	2.7E-09
Pendimethalin	lb	2.8E-15
Phenanthrene	lb	2.9E-07
Phenanthrenes, alkylated, unspecified	lb	4.6E-07
Phenol	lb	5.5E-04
Phenol, 2,4-dimethyl-	lb	1.0E-05
Phenols, unspecified	lb	0.59
Phosphate	lb	0.0028
Phosphorus	lb	1.6E-12
Phosphorus compounds, unspecified	lb	8.6E-14
Plutonium-alpha	Ci	3.0E-20
Polonium-210	Ci	2.0E-18
Potassium	lb	6.8E-14
Potassium-40	Ci	5.6E-19
Potassium, ion	lb	7.8E-09
Process solvents, unspecified	lb	1.4E-16
Propanal	lb	8.3E-19
Propane, 1,2-dichloro-	lb	5.6E-23
Propanol	lb	3.2E-18
Propene	lb	5.4E-11
Propionic acid	lb	2.4E-18
Propylamine	lb	3.3E-19
Propylene oxide	lb	6.6E-14
Protactinium-234	Ci	8.0E-19
Radioactive species, alpha emitters	Ci	3.5E-21
Radioactive species, Nuclides, unspecified	Ci	2.0E-07
Radium-224	Ci	3.4E-17
Radium-226	Ci	6.8E-16
Radium-226/kg	lb	1.3E-11
Radium-228	Ci	6.7E-17
Radium-228/kg	lb	6.7E-14
Rubidium	lb	5.5E-13
Ruthenium-103	Ci	5.6E-22
Ruthenium-106	Ci	7.5E-21
Scandium	lb	4.0E-12
Selenium	lb	4.4E-05
Silicon	lb	1.5E-07
Silver	lb	4.6E-04
Silver-110	Ci	2.1E-18
Silver, ion	lb	5.1E-13
Sodium-24	Ci	2.0E-20
Sodium dichromate	lb	1.4E-09

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Sodium formate	lb	6.5E-16
Sodium hydroxide	lb	0.64
Sodium, ion	lb	2.17
Solids, inorganic	lb	1.8E-09
Solved solids	lb	0.18
Strontium	lb	0.020
Strontium-89	Ci	4.7E-20
Strontium-90	Ci	1.9E-16
Styrene	lb	4.1E-07
Sulfate	lb	0.24
Sulfide	lb	2.9E-04
Sulfite	lb	8.0E-13
Sulfur	lb	9.1E-04
Surfactants	lb	5.5E-05
Surfactants, unspecified	lb	1.3E-04
Suspended solids, unspecified	lb	3.81
t-Butyl methyl ether	lb	3.3E-13
t-Butylamine	lb	3.8E-18
Tar	lb	2.4E-22
Technetium-99m	Ci	6.1E-20
Tellurium-123m	Ci	8.4E-21
Tellurium-132	Ci	1.5E-22
Tetradecane	lb	8.6E-06
Thallium	lb	4.4E-06
Thorium-228	Ci	1.3E-16
Thorium-230	Ci	1.1E-16
Thorium-232	Ci	7.9E-20
Thorium-234	Ci	8.0E-19
Tin	lb	8.3E-05
Tin, ion	lb	5.9E-11
Titanium	lb	2.8E-14
Titanium, ion	lb	3.2E-04
TOC, Total Organic Carbon	lb	0.063
Toluene	lb	4.0E-04
Toluene, 2-chloro-	lb	2.9E-18
Tributyltin compounds	lb	6.4E-14
Triethylene glycol	lb	9.7E-14
Trifluralin	lb	1.7E-15
Trimethylamine	lb	3.5E-19
Tungsten	lb	1.1E-11
Uranium-234	Ci	9.6E-19
Uranium-235	Ci	1.6E-18
Uranium-238	Ci	5.5E-18
Uranium alpha	Ci	4.6E-17

Source: Franklin Associates, A Division of ERG

Table 64 (Cont). Cradle-to-Gate LCI Results-Waterborne Emissions for 1,000 pounds of Applied Secondary Bond

Urea	lb	1.1E-18
Vanadium	lb	3.4E-05
Vanadium, ion	lb	1.2E-10
VOC, volatile organic compounds, unspecified origin	lb	1.9E-11
Xylene	lb	1.7E-04
Yttrium	lb	2.4E-06
Zinc	lb	9.7E-04
Zinc-65	Ci	2.7E-19
Zinc, ion	lb	9.1E-10
Zirconium-95	Ci	3.1E-21

Source: Franklin Associates, A Division of ERG

APPENDIX B. DATA SOURCES FOR UPSTREAM PROCESSES

This appendix includes a data source tables for upstream materials/processes associated with each composite material and composite manufacturing process examined in this study. Each table in this appendix lists the data source(s) for all input materials necessary to develop the cradle-to-gate unit processes, as well as detailed comments regarding data development for each upstream input material. The unit process data sources for the final material or process are each discussed in the corresponding chapter within this report. The temporal, geographic and technological considerations are summarized in Table 1 of the Study Goal and Scope chapter.

Average datasets for primary data were compiled using a combination of sources including ACMA data providers, research, and material data sheets. For data that were not available through public or private sources, LCI data were estimated using literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database.

The data sources tables for the following input materials are included in this appendix:

- Table 65. Data Sources for Unsaturated Polyester Resin (UPR)
- Table 66. Data Sources for General Grade Fiberglass (E-Glass)

The data sources tables for the following composites manufacturing processes are included in this appendix:

- Table 67. Data Sources for Compression Molded Composites
- Table 68. Data Sources for Open Molded Composites
- Table 69. Data Sources for Open Mold Cast Composites
- Table 70. Data Sources for Vacuum Infused Composites
- Table 71. Data Sources for Application of a Secondary Bond

Data Sources Tables

Table 65. Data Sources for Unsaturated Polyester Resin (UPR)

Input Material	Data Sources	Comments
Dicyclopentadiene (DCPD)	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	Ethylene is used as proxy for DCPD as they are co-produced with steam cracking of naphtha & gas to ethylene.
Diethylene Glycol	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	Ethylene glycol is used as proxy for diethylene glycol as they are co-produced. The energy and emissions data for ethylene glycol production is from a confidential source and is not shown within the ACC resins report to protect its confidentiality.
Dipropylene Glycol	Ecoinvent Database	Propylene glycol is used as proxy for dipropylene glycol as they are co-produced and is adapted from ecoinvent.
Ethylene Glycol	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	The energy and emissions data for ethylene glycol production is from a confidential source and is not shown within the ACC resins report to protect its confidentiality.
Maleic Anhydride	Ecoinvent Database	Adapted from ecoinvent to reflect use of energy and material inputs for the U.S. context.
Neopentyl Glycol	Franklin Associates Private LCI Database	Estimated using literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database. The production of neopentyl glycol is based on an aldol addition from formaldehyde & isobutyraldehyde.
Phthalic Anhydride	Ecoinvent Database	Adapted from ecoinvent to reflect use of energy and material inputs for the U.S. context.
Polyethylene Terephthalate (PET)	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	None

Propylene Glycol	Ecoinvent Database	Adapted from ecoinvent to reflect use of energy and material inputs for the U.S. context.
Isophthalic Acid	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	PTA used as a proxy for isophthalic acid.
Purified terephthalic acid (PTA)	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	Confidential process aggregated within production of PET resin.
Styrene	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database.	None
Tetrabromophthalic Anyhdride (TBPA)	Franklin Associates Private LCI Database	Estimated using literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database. The production of TBPA is based on bromination of phthalic anhydride with sulfuric acid (H_2SO_4)via an iodine catalyst; This chemical was less than1% of total environmental impacts but greater than1% mass for PUR production.

Table 66. Data Sources for General Grade Fiberglass (E-Glass) Production

Input Material	Data Sources	Comments
Clay	Franklin Associates Private LCI Database	Average of four datasets from the 1990s.
Limestone (Calcium Carbonate)	U.S. LCI Database from Franklin Associates	None
Silicon Dioxide (Silica)	U.S. LCI Database from Franklin Associates	Glass mining process with silica inputs from nature added.
Flint	U.S. LCI Database from Franklin Associates	Limestone is used as a surrogate for flint with quartz inputs from nature.
Ulexite	Franklin Associates Private LCI Database	Adapted using soda powder from trona mining as a proxy because ulexite is associated with trona deposits and is found in CA and NV.
Calcium Oxide (Burnt Lime)	U.S. LCI Database from Franklin Associates	None
Borax	Ecoinvent Database	Adapted from ecoinvent to reflect use of energy and material inputs for the U.S. context.
Boric Acid	U.S. LCI Database from Franklin Associates; Ecoinvent Database Swiss Centre for Life Cycle Inventories	Data compiled for ACMA project; processing, HCl, and various reactants from Franklin Associates Private Library and borax adapted from ecoinvent.
Magnesite	U.S. LCI Database from Franklin Associates	Data compiled for ACMA project; Limestone mining is used to approximate energy and emissions.
Dolomite	U.S. LCI Database from Franklin Associates	Limestone is used as a surrogate for dolomite.
Colemanite	Ecoinvent Database	Adapted from ecoinvent to reflect use of energy and material inputs for the U.S. context. Borates processing used as proxy as colemanite is a borate mineral: $CaB_3O_4(OH)_3 \cdot H_2O$.

Epoxy Resin	Ecoinvent Database	Diglycidyl ether of bisphenol-A (DGEBA) is a typical epoxy resin and is used to reflect energy and material inputs for the U.S. context. A DGEBA Epoxy resin is produced from a reaction between epichlorohydrin and bisphenol-A, though the latter may be replaced by similar chemicals.
Ethylene Glycol Monostearate	Franklin Associates Private LCI Database	Estimated using literature, MSDS formulation, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database.

Table 67. Data Sources for Compression Molded Composites

Input Material	Data Sources	Comments
Aluminum Trihydrate (ATH)	Ecoinvent Database	Ecoinvent data was adapted to U.S. context. Transportation data for ATH was compiled from ACMA members for this project.
Corrugated boxes	Corrugated Packaging Alliance (CPA)	None
Co-Resin, UPR & Styrene Based	ACMA; Franklin Associates Private LCI Database; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database; Ecoinvent Database	The average formulation for the co-resin is 41% styrene, 40% UPR and 19% water and was provided by ACMA data collected. Energy consumption and transportation in the production of the co-resin are based on average requirements for organic chemicals per Franklin Associates Private LCI Database. Styrene data was updated in 2011 for the ACC resins. UPR data were compiled for the ACMA project. Data sources for UPR are presented in Table B-1. Water data is adapted from ecoinvent.
E-Glass	ACMA	Averaged datasets compiled for the ACMA project. See data sources for E-Glass in Table B-2.
Styrene	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	Styrene data was updated in 2011 for the ACC resins.

In-Mold coating (IMC), styrene based	ACMA; Franklin Associates Private LCI Database; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database; Ecoinvent Database	The formulation for the IMC is 26 % styrene, 0.26% vinyl acetate, 1% hydroxymethyl methacrylate, 33% ethoxylated bisphenol A diacrylate, 8% proprietary acrylate oligomer, 0.13% quartz, 16% talc, 12% barium sulfate, and 4% carbon black. The average formulation of the IMC was provided by ACMA collected data. Energy consumption and transportation in the production of the IMC are based on average requirements for organic chemicals per Franklin Associates Private LCI Database. Styrene data was updated in 2011 for the ACC resins. Silica from Franklin Associates Private LCI Database was used as a proxy for quartz,. Data for Talc was developed for the ACMA study using limestone mining from Franklin Associates Private LCI Database with malusil input from nature per ecoinvent weight factors. All other materials were adapted from ecoinvent.
Limestone (Calcium Carbonate)	U.S. LCI Database from Franklin Associates	None
Low Profile Additive (LPA)	ACMA; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database; Franklin Associates Private LCI Database	The formulation for the LPA is 99.75% styrene and .25% vinyl acetate. The average formulation of the LPA was provided by ACMA Styrene data was updated in 2011 for the ACC resins.
Methyl Ethyl Ketone Peroxide (MEKP) Initiator	ACMA; Franklin Associates Private LCI Database; Ecoinvent Database	The formulation for the initiator is 33% methyl ethyl ketone peroxide, 1 % hydrogen peroxide, 1% methyl ethyl ketone, 21% dimethyl phthalate, 42% 2,2,4-trimethyl-1,3-pentanediol diisobutyrate, and 1 % water. The average formulation of the MEKP-initiator was provided by ACMA data providers. Energy consumption and transportation for the production of the initiator are based on average requirements for organic chemicals per Franklin Associates Private LCI Database. Methyl Ethyl Ketone and water data were adapted from ecoinvent. Hydrogen peroxide data from the Franklin Associates Private LCI Database was used. Data for all other components were developed for the ACMA study using a combination

		of ecoinvent and Franklin Associates Private LCI Database.
Pigment	Franklin Associates Private LCI Database; Ecoinvent Database	50% titanium dioxide, and 50% carbon black is used as a proxy for the pigment. Titanium dioxide is from Franklin Associates Private LCI Database and carbon black is adapted from the ecoinvent database.
Thickener	Franklin Associates Private LCI Database; U.S. LCI Database	A 50:50 split of magnesium hydroxide and calcium hydroxide used as a proxy for the production of the thickener. Clay mining data from the Franklin Associates Private LCI Database was used as a proxy for the extraction of magnesium hydroxide. Hydrated lime data from the U.S. LCI Database is used as a proxy for calcium hydroxide.
UPR	ACMA	Averaged datasets compiled for the ACMA project. See data sources for UPR in Table B-1.
Mold Release Agent	ACMA; Ecoinvent Database	The composition of the mold release agent is based on averages provided by ACMA. The mold release agent is produced from zinc oxide and stearic acid. Stearic acid data was compiled for the ACMA project based on the commercial production from palm kernel oil. Zinc oxide data was adapted from Ecoinvent.

Table 68. Data Sources for Open Molded Composites

Input Material	Data Sources	Comments
Acetone	Ecoinvent Database	None
Basic Oxygen Furnace (BOF) Steel	U.S. LCI Database	None
Corrugated Boxes and Packaging	Corrugated Packaging Alliance (CPA)	None
E-Glass	ACMA	Averaged datasets compiled for the ACMA project. See data sources for E-Glass in Table B-2.
Fiberglass, Continuous Strand Mat	ACMA	No data was available for continuous strand mat fiberglass. Therefore, averaged datasets for E-glass compiled for the ACMA project were used. See data sources for E-Glass in Table B-2.
Gelcoat, UPR and Styrene Based	ACMA; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	Primary components of the gelcoat, provided by ACMA, are UPR and styrene. Averaged datasets for UPR were compiled for the ACMA project. See data sources for UPR in Table B-1. Styrene data was updated in 2011 for the ACC resins.
Barrier Coat, UPR and Styrene Based	ACMA; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	The Gelcoat was used as a proxy for the barrier coat, as they each have similar components. See data sources for UPR in Table B-1. Styrene data was updated in 2011 for the ACC resins.
Limestone (Calcium Carbonate)	U.S. LCI Database from Franklin Associates	None

Methyl Ethyl Ketone Peroxide (MEKP) Initiator	ACMA; Franklin Associates Private LCI Database; Ecoinvent Database	The formulation for the initiator is 33% methyl ethyl ketone peroxide, 1 % hydrogen peroxide, 1% methyl ethyl ketone, 21% dimethyl phthalate, 42% 2,2,4-trimethyl-1,3-pentanediol diisobutyrate, and 1 % water. The average formulation of the MEKP-initiator was provided by ACMA. Energy consumption and transportation for the production of the initiator are based on average requirements for organic chemicals per Franklin Associates Private LCI Database. Methyl Ethyl Ketone and water data were adapted from ecoinvent. Hydrogen peroxide data from the Franklin Associates Private LCI Database was used. Data for all other components were developed for the ACMA study using a combination of ecoinvent and Franklin Associates Private LCI Database.
Plywood	U.S. LCI Database	None
Softwood Lumber	U.S. LCI Database	None
UPR	ACMA	Averaged datasets compiled for the ACMA project. See data sources for UPR in Table B-1.

Table 69. Data Sources for Open Mold Cast Composites

Input Material	Data Sources	Comments
Acetone	Ecoinvent Database	None
Aluminium trihydrate	Ecoinvent Database	Ecoinvent data was adapted to U.S. context. Transportation data for ATH was compiled from ACMA members for this project.
Dichloromethane	Ecoinvent Database	None
Gelcoat, UPR and Styrene Based	ACMA; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	Primary components of the gelcoat, provided by ACMA, are UPR and styrene. Averaged datasets for UPR were compiled for the ACMA project. See data sources for UPR in Table B-1. Styrene data was updated in 2011 for the ACC resins.
Limestone (Calcium Carbonate)	U.S. LCI Database from Franklin Associates	None
Pigment	Franklin Associates Private LCI Database; Ecoinvent Database	50% titanium dioxide, and 50% carbon black is used as a proxy for the pigment. Titanium dioxide is from Franklin Associates Private LCI Database and carbon black is adapted from the ecoinvent database.
Polyethylene Terephthalate (PET)	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	None
UPR	ACMA	Averaged datasets compiled for the ACMA project. See data sources for UPR in Table B-1.

Mold Release Agent	ACMA; Ecoinvent Database	The composition of the mold release agent is based on averages provided by ACMA member companies. The mold release agent is produced from zinc oxide and stearic acid. Stearic acid data was compiled for the ACMA project based on the commercial production from palm kernel oil. Zinc oxide data was adapted from Ecoinvent.

Table 70. Data Sources for Vacuum Infused Composites

Input Material	Data Sources	Comments
Plywood (core material)	U.S. LCI Database	None
EPS foam (core material)	U.S. LCI Database	None
E-Glass	ACMA	Averaged datasets compiled for the ACMA project. See data sources for E-Glass in Table B-2.
Fiberglass, Continuous Strand Mat	ACMA	No data was available for continuous strand mat fiberglass. Therefore, averaged datasets for e-glass compiled for the ACMA project were used. See data sources for E-Glass in Table B-2.
Gelcoat, UPR and Styrene Based	ACMA; Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	Primary components of the gelcoat, provided by ACMA, are UPR and styrene. Averaged datasets for UPR were compiled for the ACMA project. See data sources for UPR in Table B-1. Styrene data was updated in 2011 for the ACC resins.
Limestone (Calcium Carbonate)	U.S. LCI Database from Franklin Associates	None
Polyethylene Terephthalate (PET)	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates and publicly available through the U.S. LCI Database	None
Synthetic Filler	U.S. LCI Database	The composition of the synthetic filler is based on averages provided by ACMA member companies. The filler additive represents 50:50 silicon carbide and graphite. Graphite data is from the Franklin Associates Private Database and silicon carbide data was adapted from ecoinvent. Energy consumption and transportation in the production of the filler materials are based on average requirements for organic chemicals per the Franklin Associates Private Database.
UPR	ACMA	Averaged datasets compiled for the ACMA project. See data sources for UPR in Table B-1.

Table 71. Data Sources for Application of Secondary Bond

Input Material	Data Sources	Comments
Adhesive, PUR-based	ACMA; Franklin Associates Private LCI Database	The data for the adhesive was compiled for the ACMA project and was based on technical literature, stoichiometry, and average requirements for organic chemicals production per the Franklin Associates Private LCI Database.
Disposable adhesive tube dispensers	Virgin resin data compiled for the American Chemistry Council (ACC) by Franklin Associates; Public adhesive tube dispensers manufacturing websites	Estimated tube dispensers are comprised of 50:50 PVC and PET resins. Data for PVC and PET are from updated ACC resins data. The composition and material ratio were estimated based on producers' public websites.