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Life Cycle Inventory of Portland Cement Concrete

(Revised March 2007)

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KEYWORDS

Concrete, energy, emission, life cycle inventory

ABSTRACT

A life cycle inventory (LCI) is a compilation of the energy and material inputs and the emissions to air, land, and water associated with the manufacture of a product, operation of a process, or provision of a service. This report is the second update of *Environmental Life Cycle Inventory of Portland Cement Concrete*, originally published in 2000 and updated in 2002. Similar to the original, this report presents the results of the LCI of three concrete products: ready mixed concrete, concrete masonry, and precast concrete. The system boundary, which defines the scope of the LCI, includes cement and slag cement manufacture; aggregate production; transportation of fuel, cement, supplementary cementitious materials, and aggregates to the concrete plant; and concrete plant operations (including truck mixer wash-out in the case of ready mixed concrete). Data on fuel and electricity use at concrete plants are from confidential life cycle inventory surveys of concrete plants conducted in 2006. The upstream profile of cement is imported from *Life Cycle Inventory of Portland Cement Manufacture*, which was also update in 2006.

The previous edition presented fuel and electricity use and emissions to air (carbon dioxide, carbon monoxide, methane, nitrogen oxides, particulate matter, sulfur dioxide, and volatile organic compounds). This update presents emissions to land, over a dozen emissions to water, and dozens more emissions to air.

Due to increases in energy efficiency, newer plants replacing older ones, and more accurate data (particularly for concrete plants and aggregate production), the present LCI results are lower for most of the flows reported in the previous edition. For example, for a typical 20-MPa (3,000-psi) concrete mix, embodied energy is 30% lower and CO_2 emissions are about 7% lower. For concrete masonry, embodied energy is about 20% lower and CO_2 emissions are about the same. For 50-MPa (7,500-psi) precast concrete, embodied energy and CO_2 are unchanged because the LCI now includes energy and emissions at the precast concrete plant.

REFERENCE

Marceau, Medgar L., Nisbet, Michael A., and VanGeem, Martha G. *Life Cycle Inventory of Portland Cement Concrete*, SN3011, Portland Cement Association, Skokie, Illinois, PCA, 2007, 112 pages.

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DEFINITIONS

Ancillary material. Material input that is used by the system producing the product but is not used directly in product formation; for example, refractory brick in cement kilns.

Data quality. Quantitative and qualitative aspects of input data and the methods by which they are measured or calculated, collected, and integrated into the LCA model. The proposed use of the LCI establishes the quality standards.

Embodied energy. Energy inputs, such as fuel and electricity, to a product or service throughout its life cycle.

Environmental impact. Consequences for human health, for the well-being of flora and fauna or for the future availability of natural resources.

Functional unit. Measure of the performance of the functional output of the product or services system; for example, in the ready mixed concrete LCI the functional unit is one cubic meter of ready mixed concrete.

Impact assessment. Understanding and evaluating the magnitude and significance of environmental impacts.

Life cycle inventory (LCI) analysis. Quantification of the inputs and outputs—in this case materials, energy, and emissions—from a given product or service throughout its life cycle.

Life cycle. Consecutive and inter-linked stages of a product or service from the extraction of natural resources to final disposal.

Life cycle assessment (LCA). A systematic method for compiling and examining the inputs and outputs of energy and materials (life cycle inventory) and the potential environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.

Middle distillates. A general classification of refined petroleum products that includes: diesel oil (Nos. 1, 2, and 4), fuel oil (Nos. 1, 2 , and 4), and kerosene.

Sensitivity analysis. Systematic procedure for estimating the effects of data uncertainties and variability on the outcome of an LCA model.

Slag cement. Ground, granulated blast furnace slag.

System boundary. Interface between the product or service system being studied and its environment or other systems. The system boundary defines the segment of the production process being studied.

Upstream profile. The resources consumed and emissions from extracting, processing, and transporting a material or energy source entering the system boundary; for example, the inputs and emissions incurred in delivering a metric ton of coal to a cement plant.

ACRONYMS AND ABBREVIATIONS

AP-42	United States Environmental Protection Agency Compilation of Air Pollution Emission Factors
CH_4	Methane
CKD	Cement kiln dust
CMU	Concrete masonry unit
CO	Carbon monoxide
CO_2	Carbon dioxide
EPA	U.S. Environmental Protection Agency
HCl	Hydrogen chloride
GJ	Gigajoule
gal	gallon
kJ	kilojoule
kWh	kilowatt-hour
L	liter (1 gallon = 3.785412 liters)
LCA	Life cycle assessment
LCI	Life cycle inventory
MBtu	Million British thermal units
MJ	Megajoule
NO_X	Nitrogen oxides
PM	Total filterable airborne particulate matter
PM-10	Particulate matter with an aerodynamic diameter of less than or equal to 10 micrometers
PM-2.5	Particulate matter with an aerodynamic diameter of less than or equal to 2.5 micrometers
SI	International System of Units
SO_2	Sulfur dioxide
VOC	Volatile organic compounds

Life Cycle Inventory of Portland Cement Concrete

by Medgar L. Marceau, Michael A. Nisbet, and Martha G. VanGeem*

INTRODUCTION

This report is an update of *Environmental Life Cycle Inventory of Portland Cement Concrete* (Nisbet, Marceau, and VanGeem 2002). Similar to the original, this report presents the results of the life cycle inventory (LCI) of three concrete products: ready mixed concrete, concrete masonry, and precast concrete. The purpose of this update is to present recent data, better quality data, and new data. Recent data, such as data from the recently updated *Life Cycle Inventory of Portland Cement Manufacture* (Marceau, Nisbet, and VanGeem 2006), reflect improvements in energy efficiency and better environmental controls. Better quality data from censuses and surveys (such as data from surveys of ready mixed concrete plants, concrete masonry plants, and precast concrete plants) replace plant-specific data with more representative average data. New data (such as data on water usage, fuel and raw material consumption, and transportation modes and distances) fill in data gaps identified in the previous version of this report.

The first section of this report is a brief introduction to the concept of an LCI. The second section defines the goal and scope of the work. The third section presents the upstream profiles. In the last three sections, the LCI of each concrete product is presented, each product in its own section. The product section contains: (1) a description of the production process, (2) LCI results and analysis, and (3) sensitivity analysis.

Life Cycle Inventory

A life cycle inventory (LCI) is a compilation of the energy and material inputs and the emissions to air, land, and water associated with the manufacture of a product, operation of a process, or provision of a service. An LCI is the second step—after goal and scope definition—of a life cycle assessment (LCA). During the assessment phase, the social, economic, and environmental aspects are evaluated. The results can be used to choose among competing alternatives the one that has the most favorable attributes. For example, LCA has been used to show that insulating concrete form homes have fewer negative impacts than identically sized wood-framed homes (Marceau and VanGeem 2002a).

Intended Use of LCI Data

The Portland Cement Association is involved in on-going collection, analysis, and dissemination of LCI data for portland cement, ready mixed concrete, concrete masonry, and precast concrete. The data from earlier versions of this report have been used with commercially available LCA software to compare homes made of concrete walls with homes made from competing materials

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(Marceau and VanGeem 2006, 2002a, 2002b, 2002c). The data have also been disseminated to the National Institute of Standards and Technology and incorporated into the BEES life cycle assessment tool (NIST 2003). It is the objective of the PCA to ensure that life cycle data on portland cement manufacture and concrete production is publicly available, up-to-date, accurate, and unbiased. The data will be available for incorporation into LCA models and software tools as well as LCI databases, such as the U.S. Life Cycle Inventory Database (NREL on-going). Information on the target audience of this report and other related project reports is presented in Appendix A.

DEFINITION OF GOAL AND SCOPE

The LCI described in this report follows the guidelines proposed by the International Organization for Standardization in ISO 14040, *Environmental Management - Life Cycle Assessment - Principles and Framework* (ISO 2006a), ISO 14041, *Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis* (ISO 1998), and ISO 14044, *Environmental Management - Life Cycle Assessment – Requirements and Guidelines* (ISO 2006b).

Goal

The goal of this LCI is to present the most accurate data on the inputs and emissions associated with three concrete products: ready mixed concrete, concrete masonry, and precast concrete. The LCI of these products can be used in turn to conduct LCAs of concrete structures and other structures containing concrete.

Scope

The scope of an LCI is defined by product function, functional unit, and system boundary. The three products considered here are (1) ready mixed concrete exiting the plant gate, (2) concrete masonry exiting the manufacturing plant, and (3) precast concrete exiting the plant gate. Because there is a vast number of possible mix designs for each product, select mix designs are presented. The mix designs are presented under the respective product sections.

Product Function. After water, portland cement concrete is the mostly widely used construction material on earth (WBCSD 2002). It is used to make all types of structures including: bridges, buildings, dams, foundations, pipes, roads, sidewalks, and storage tanks. Concrete is basically a mixture of two components: aggregate and paste. The paste, comprised of portland cement and water, binds the aggregate (usually sand and gravel or crushed stone) into a rock-like mass as the paste hardens because of the chemical reaction of the cement and water. Supplementary cementitious materials and chemical admixtures may also be included in the paste. Cement constitutes 7 to 15 percent of concrete's total mass by weight, so cement LCI data used (incorrectly) as concrete LCI data is a serious error.

Throughout this report, "cement" refers to portland cement; "slag cement" refers to ground granulated blast furnace slag; "supplementary cementitious material" (SCM) refers to fly ash, slag cement, or silica fume; "concrete" refers to portland cement concrete with or without

SCM; and “concrete plant” refers to ready mixed concrete plant, concrete masonry plant, and precast concrete plant.

Functional Unit. The functional unit, which is the basis for comparison, is a unit volume of concrete produced in the United States from domestically produced cement, SCMs, and aggregates. For ready mixed and precast concrete, the LCI data in this report are presented on the basis of a unit volume of concrete in both International Systems of Units (one cubic meter of concrete) and U.S. Customary Units (one cubic yard of concrete). For concrete masonry, the LCI results are presented on the basis of 100 standard 8×8×16-in. concrete masonry units, which contain approximately one cubic yard of concrete.

System Boundary. The system boundary, which is shown in Figure 1, is chosen to include cement and slag cement manufacture; aggregate production; transportation of fuel, cement, SCMs, and aggregates to the concrete plant; and plant operations (including truck mixer wash-out in the case of ready mixed concrete). The upstream profiles of portland cement and slag cement are imported into the concrete system boundary. The energy used to heat, cool and light plant buildings is included in plant operations because most of the concrete plants surveyed for this update do not separate manufacturing energy from building operating energy. For example, natural gas may be used in a boiler to provide both building heat and provide hot water for concrete batch water in winter. Plant operations are described in greater detail in the respective product sections.

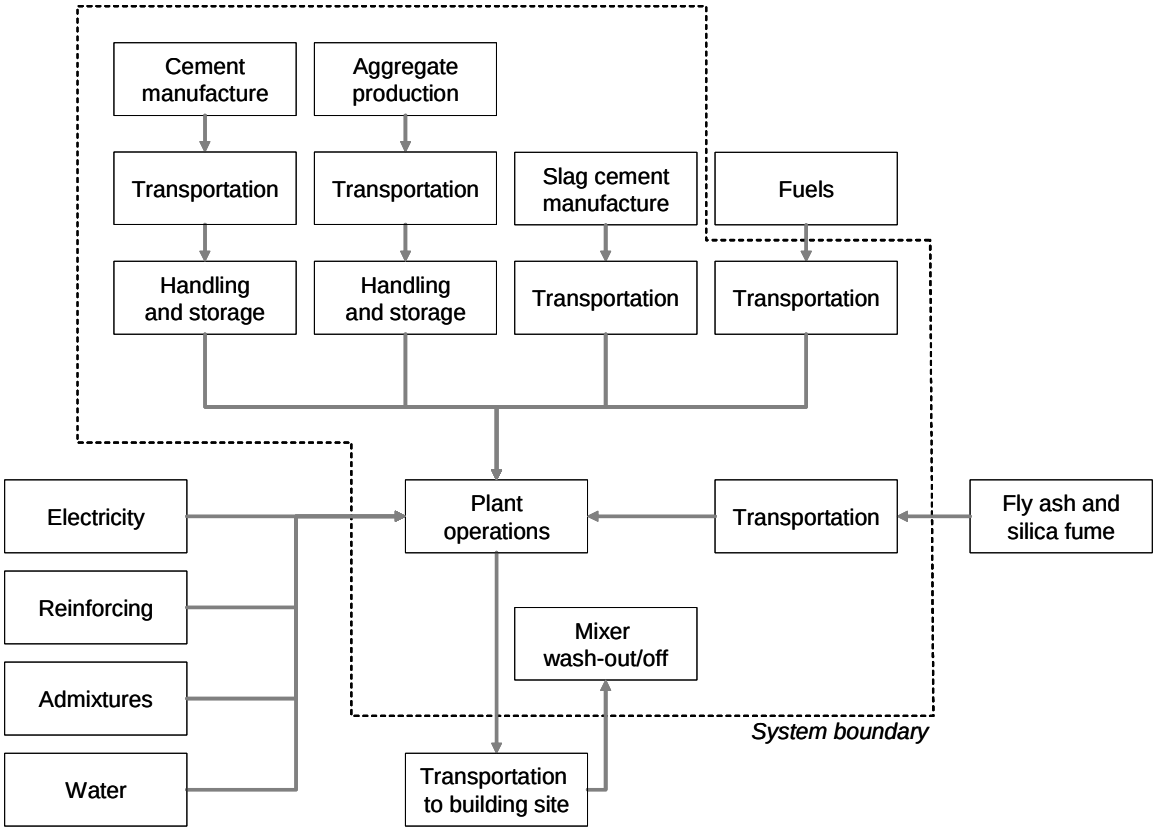

Figure 1. The system boundary of concrete production defines the limits of the life cycle inventory.

The ISO 14041 guidelines (ISO 1998) suggest that energy and material flows that do not constitute a significant portion of intermediate or final products need not be included in the LCI if they have a negligible environmental impact. Thus, the energy, materials, and emissions associated with construction of concrete plant equipment and buildings are not included in the LCI. The system boundary also excludes the creation of infrastructure, accidents, human resources, and environmental burdens caused by the work force. Further, the LCI results do not include the upstream profiles of fly ash and silica fume because these are industrial waste materials (from other product systems) that are used in concrete without transformation. The LCI results do not include the upstream profiles of fuels and electricity, for example the energy to produce natural gas and the associated emissions. The type and amount of reinforcing (steel bars, steel fibers, polymer fibers, and others) in reinforced concrete varies considerably depending on the concrete's intended use; therefore, reinforcing is not included in the system boundary.

Data Sources

Fuel and Electricity. Data on fuel and electricity use at concrete plants are from confidential life cycle inventory surveys of concrete plants (Marceau, VanGeem, and Ranchero 2006a, 2006b, 2006c). Information about the surveys is available in Appendices E, F, and G. Most of the data on fuel and electricity to produce sand and gravel is from the U.S. Census Bureau (USCB 1999a) with additional information from the U.S. Geological Survey (Bolen 2003 and 1997). Most of the data on fuel and electricity to produced coarse aggregate from crushed stone is from the U.S. Census Bureau (USCB 1999b, 1999c, and 1999d) with additional information from the U.S. Geological Survey (Tepordei 2003 and 1997). Data on heating value[†] of fuels and electricity are from the U.S. Department of Energy (Davis and Diegle 2004).

Raw Materials. Data on raw material use in concrete proportioning are based on the previous report. The validity of using this data has been confirmed by the National Ready Mix Concrete Association (Lobo 2006), the National Concrete Masonry Association (Werner 2006), the Precast Concrete Institute (Freedman 2006) and the Slag Cement Association (Prusinski 2006). Data on water use and material wasted are from confidential life cycle inventory surveys of concrete plants (Marceau, VanGeem, and Ranchero 2006a, 2006b, 2006c).

Transportation. Data on transportation modes and distances for raw materials are primarily from the U.S. Census Bureau (USCB 2004a) and the U.S. Army Corp of Engineers (USACOE 2003), with supplementary information from the U.S. Department of Energy (Stacy and Diegel 2004). Transportation energy intensities are calculated from data from the U.S. Census Bureau (USCB 2004b) and the U.S. Department of Energy (Stacy and Diegel 2004).

Emissions. The sources of data on emissions are shown in Table 1. Quarry overburden is often used in quarry reclamation, so there is essentially no generation of solid waste associated with quarries.

[†] Heating value is used to convert units of fuel and electricity—such as mass, volume, or kWh—to units of energy. Higher heating values are used throughout this report. Higher heating value includes the latent heat of vaporization and is determined when water vapor in the fuel combustion products is condensed (ASHRAE 2005).

Table 1. Sources of Information on Emissions

Source of emission	Source and reference
Transportation	U.S. Life Cycle Inventory Database (NREL on-going) and U.S. Environmental Protection Agency (EPA 2003)
Mobile equipment	
Unpaved roads	National Stone Association (Richards and Brozell 1996)
Quarry operations	U.S. Environmental Protection Agency emission factors (EPA 2004a and 2004b)
Concrete plant operations	U.S. Environmental Protection Agency emission factors (EPA 2004c)
Solid waste	Marceau, VanGeem, and Ranchero (2006)

Calculation Methodology

Wherever possible, environmental flows are presented as production-weighted averages. New cement and concrete plants usually have higher production rates, are cleaner, and are more energy efficient than older plants; therefore, the environment aspects of cement and concrete are not proportional to the number of plants, but rather to the amount of production. For this reason, the use of simple arithmetic averages for any particular environmental flow should be avoided in favor of production-weighted averages.

Although the results are presented in both International System of Units and U.S. Customary Units, most of the intermediate calculations are done using data in U.S. Customary Units; therefore, results in U.S. Customary Units should be regarded as the official results. Further, in some tables, data shown may not add to the totals shown due to independent rounding.

UPSTREAM PROFILES

Transportation

The transportation modes and distances used to get raw materials to the plant are shown below. Transportation energy within the plant—for example, front end loaders—is accounted for in plant operations. Table 2 shows the fraction of materials transported by the various modes and the associated distances. Transportation energy intensities for the various modes are summarized in Table 3. Transportation energy intensity is the amount of energy to transport material, including the energy to run the vehicle. The transportation energy intensities do not include precombustion energy for fuel acquisition.

Quarry Haul-Road Emissions. The original version the concrete LCI used the U.S. Environmental Protection Agency (EPA) Aerometric Information Retrieval System (AIRS) emission factor (EPA 1990) to estimate fugitive dust caused by truck traffic on unpaved quarry haul roads. This factor was chosen because there was not enough information to permit application of the EPA AP-42 unpaved haul-road equation (EPA 1995). The AIRS factor for uncontrolled emissions is 15 kg of total suspended particulates per vehicle km traveled (52 lb/mile). With an assumed dust control factor of 70% resulting from water sprays, these haul

Table 2. Transportation Modes and Distances[1]

Material	Truck[2]		Rail[2]		Barge[4]	
	Fraction	km (mile)	fraction	km (mile)	fraction	km (mile)
Fly ash, portland cement, silica fume, and slag cement	0.951	146 (91)[3]	0.039	146 (91)[3]	0.010	702 (436)
Lime	0.951	146 (91)[3]	0.039	146 (91)[3]	0.010	662 (411)
Limestone, ground	0.905	43 (27)	0.047	1373 (853)	0.048	562 (349)
Manufactured, natural, and recycled coarse aggregate; expanded shale, clay, slate; and manufactured fine aggregate.	0.905	43 (27)	0.047	562 (349)	0.048	222 (138)
Fine aggregate, natural	0.888	61 (38)	0.049	422 (262)	0.063	222 (138)

[1]One-way transportation.

[2]Adapted from "Table 7. Shipment Characteristics by Two-Digit Commodity and Mode of Transportation for the United States: 2002", p. 19 ff., in USCB (2004a).

[3]Adapted from "Table 6. Shipment Characteristics by Three-Digit Commodity for the United States: 2002", p. 14, in USCB (2004a).

[4]Adapted from "Table 2-2: Summary of Domestic Waterborne Commerce, Ton-Miles by Type of Traffic and Commodity (thousand short tons)" and "Table 2-3: Domestic Barge Traffic by Type of Traffic and Commodity (million short ton-miles)" in USACOR (2003).

Table 3. Transportation Energy Intensity Factors[1,2]

Mode	Vehicle, fuel (fraction of vehicles)	Energy Intensity		
		gallon/1000 ton·mile	Btu/ton·mile	kJ/metric ton·km
Road[4]	Single-unit dump truck, gasoline (0.549)	4.10	513	371
	Single-unit dump truck, diesel (0.451)	3.37	468	338
	Dry bulk tank truck-tractor, diesel	8.28	1148	830
	Van, basic enclosed, diesel[3]	5.38	746	539
Rail[3,5]	Locomotive, diesel	2.49	345	249
Waterborne[3,6]	Barge, distillate fuel oil (0.304)	1.03	143	103
	Barge, residual fuel oil (0.696)	2.19	328	237

[1]Does not include precombustion energy for fuel acquisition.

[2]Unless specified, assumes empty return.

[3]Full return.

[4]Adapted from "Table 4. Trucks by Vehicle Size: 2002", p. 38 & 40, in USCB (2004b). Additional information based on information available at http://www.komatsuamerica.com/index.cfm?resource_id=113: empty weight of dump trucks is 44% of full load, empty weight of flatbed, stake, and platform trucks is 30% of full load, empty weight of dry bulk tank trucks is 30% of full load, and empty weight of basic enclosed vans is 30% of full load.

[5]Adpted from "Table 9.9 Summary Statistics for Class I Freight Railroads" in Davis and Diegel (2004).

[6]Adapted from "Table 9.5 Summary Statistics for Domestic Waterborne Commerce" and "Table A.10 Diesel and Residual Fuel Oil for Vessel Bunkering" in Davis and Diegel (2004).

road emissions per unit mass of quarried material were considered to be too high. The National Stone Association commissioned a study (Richards and Brozell 1996) whose objective was to review and update the AP-42 unpaved haul-road equation. In this study, tests were conducted in three quarries and it was found that the AP-42 equation overestimated PM-10 (dust particles with a mass median aerodynamic diameter of less than 10 micrometers) emissions by a factor ranging from 2 to 5 times. The test conditions at the tested quarries are presented in Table 4.

Table 4. Test Conditions for Quarry Study of Particulate Emissions

Variable	Quarry No. 1	Quarry No. 2	Quarry No. 3
Average silt content, %	7.39	7.35	7.49
Average moisture content, %	6.42	4.9	5.96
Average truck speed, km/hr (mile/hr)	29.9 (18.55)	27.1 (16.87)	27.3 (16.94)
Average truck weight, metric ton (ton)	47.6 (52.5)	47.6 (52.5)	47.6 (52.5)
Average wind speed, km/hr (mile/hr)	9.2 (5.74)	8.2 (5.07)	2.6 (1.6)
Average watering interval, hour	2.97	3.98	2.29
Water application rates, L/m^2	0.846	0.846	0.846

Adapted from Richards and Brozell (1996).

The measured PM-10 emissions resulted in an average emission factor for the three quarries of 0.47 kg/vehicle-km traveled (1.04 lb/vehicle-mile) as shown in Table 5. Multiplying the amount of PM-10 (in lb/vehicle-mile traveled) by 2.1 (EPA 1995) gives an emission factor for total suspended particulates of 0.61 kg/vehicle-km traveled (2.18 lb/vehicle-mile traveled). Both these PM and PM-10 factors are used in this LCI to estimate dust emissions from unpaved haul-roads in crushed-stone operations and sand and gravel operations. However, data based on such a small sample is probably not representative of all quarry operations.

Table 5. Test Results for Quarry Study of Particulate Emissions

Test location	Emission factor			
	kg/vehicle-km traveled		lb/vehicle-mile traveled	
	PM-10	PM-total	PM-10	PM-total
Quarry no. 1	0.08	0.17	0.29	0.61
Quarry no. 2	0.49	1.03	1.74	3.65
Quarry no. 3	0.30	0.64	1.08	2.27
Average	**0.29**	**0.61**	**1.04**	**2.18**

Adapted from Richards and Brozell (1996).

Cement

The manufacture of cement has its own set of environmental flows and these are imported into the concrete LCI. For example, approximately 1.6 metric tons of raw material are needed to produce one metric ton of cement primarily because of calcination of calcium carbonate, which typically comprises 75% to 80% of the raw material. The upstream profile of cement is imported from *Life Cycle Inventory of Portland Cement Manufacture* (Marceau, Nisbet, and VanGeem, 2006). Further, this upstream profile was updated with the latest data on cement plant fuel and electricity inputs from *U.S. and Canadian Labor-Energy Input Survey 2003* (PCA 2005) and the emissions associated with fuel inputs. The system boundary of cement includes the four main steps in manufacturing portland cement: (1) quarrying and crushing, (2) raw meal preparation, (3) pyroprocessing, and (4) finish grinding. The system boundary also includes transporting all fuel and materials from their source to the cement plant. That is, it includes the emissions, such as from burning fuel in internal combustion engines, to transport materials to the cement plant. It also includes combustion of fuel in the cement kiln. It does not include upstream profiles of

producing fuel and electricity. For example, it does not include the energy and emissions associated with extracting coal or generating electricity.

Supplementary cementitious materials

Fly ash, slag cement, and silica fume are supplementary cementitious materials that can be used to replace some of the cement in concrete. In cases where they are used, they are assumed to replace cement in concrete on a one-to-one basis. The upstream profiles of fly ash and silica fume are not included in this LCI because theses are waste products from other industries requiring no additional processing to be used in concrete. The upstream profile of slag cement, however, is imported from *Life Cycle Inventory of Pavement Concrete and Mass Concrete for Transportation Structures Containing Slag Cement* (Marceau and VanGeem, 2005) because blast furnace slag must be granulated and ground before it can be used as SCM. The system boundary of slag cement includes the following processes: (1) quenching and granulation, (2) dewatering and drying, (3) crushing, (4) grinding, and (5) storage. It does not include upstream profiles of energy sources, but the quantities of all fuels are included and the emissions to air from combustion of natural gas are included.

Aggregates

Aggregates in concrete consist of fine and coarse aggregate. Fine aggregate in concrete is usually quarried natural sand while coarse aggregate can be quarried or manufactured from crushed stone. The upstream profile of aggregate production is allocated to concrete on the basis of the relative amounts of sand, gravel, and coarse aggregate from crushed stone used in concrete in the US (latest available data). As shown in Table 6, 74% of the aggregate in concrete is natural quarried sand and gravel and 26% is coarse aggregate from crushed stone (Bolen 2003 and Tepordei 2003).

Table 6. Sand, Gravel, and Crushed Stone Used in Concrete in the US in 2003

Material and use	Quantity, thousand metric ton	Relative fraction
Construction sand and gavel		
Concrete aggregate	260,000	
Plaster and gunite sands	1,240	
Concrete products	6,990	
Subtotal	**268,230**	0.74
Stone, crushed		
Coarse aggregate, graded, concrete	75,700	
Fine aggregate, concrete	16,000	
Coarse and fine aggregate terrazzo, etc.	1,270	
Subtotal	**92,970**	0.26
Total	**361,200**	**1.00**

Adapted from “Table 6. Construction Sand and Gravel Sold or Used in the United States in 2003, by Major Use” in Bolen (2003) and “Table 13. Crushed Stone Sold or Used by Producers in the United States in 2003, by Use” in Tepordei (2003).

A concrete mix specifies quantities of coarse and fine aggregates. There are no readily available data distinguishing between the energy and emissions associated with production of natural quarried fine and coarse aggregates. Therefore, the aggregates used in a particular mix are assumed to be a combination of sand, gravel, and coarse aggregate from crushed stone. For example, a mix design for 20 MPa (3,000 psi) concrete is show in Table 7.

Table 7. Relative Amounts of Sand, Gravel, and Crushed Stone in a 20-MPa (3000-psi) Example Mix Design

Raw material	Amount	
	kg/m^3	lb/yd^3
Cement	223	376
Water	141	237
Coarse aggregate, natural quarried	834	1,406
Coarse aggregate, crushed stone	293	494
Fine aggregate, natural quarried	831	1,400
Total	**2,322**	**3,913**

Data from the U.S. Census Bureau and the U.S. Geological Survey were used to calculate the energy to produce aggregate. The energy to produce sand and gravel is 23,190 kJ/metric ton (19,940 Btu/ton), and the energy to produce crushed stone is 35,440 kJ/metric ton (30,470 Btu/ton). Table 8 shows a comparison between these values and the values estimated or calculated in other published sources. Note that the value for sand and gravel used in this report is slightly greater than the other values, while the value for crushed stone is less then the other values. A more detailed breakdown of fuels and electricity to produce sand and gravel is presented in Table 9. Details for crushed stone are presented in Table 10.

Table 8. Estimates of Energy to Produce Construction Aggregates[1]

<table>
<tr><th>Aggregate</th><th colspan="2">Energy to produce aggregates, kJ/metric ton[2]</th><th>Data source</th></tr>
<tr><td rowspan="4">Sand and gravel</td><td>17,000</td><td>||||||||</td><td>Epps 1977)</td></tr>
<tr><td>17,000</td><td>||||||||</td><td>Wixson (1977)</td></tr>
<tr><td>17,000</td><td>||||||||</td><td>AI (1979)</td></tr>
<tr><td>23,190</td><td>|||||||||||</td><td>This report</td></tr>
<tr><td rowspan="9">Crushed stone or gravel</td><td>47,000</td><td>|||||||||||||||||||||||</td><td>Epps (1977)</td></tr>
<tr><td>81,000</td><td>||||||||||||||||||||||||||||||||||||||||</td><td>Epps (1977)</td></tr>
<tr><td>47,000</td><td>|||||||||||||||||||||||</td><td>AI (1979)</td></tr>
<tr><td>65,000</td><td>||||||||||||||||||||||||||||||||</td><td>AI (1979)</td></tr>
<tr><td>40,000</td><td>||||||||||||||||||||</td><td>Vickers (1997)</td></tr>
<tr><td>67,000</td><td>|||||||||||||||||||||||||||||||||</td><td>Vickers (1997)</td></tr>
<tr><td>210,000</td><td>|||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||||</td><td>Vickers (1997)</td></tr>
<tr><td>81,000</td><td>||||||||||||||||||||||||||||||||||||||||</td><td>Wixson (1977)</td></tr>
<tr><td>35,440</td><td>|||||||||||||||||</td><td>This report</td></tr>
</table>

[1]Some sources report multiple estimates or a range of estimates.
[2]One bar equals 2000 kJ.

Table 9. Energy Used to Produce Sand and Gravel

Fuel or electricity	Total energy used[1]		Energy/ton aggregate[2]		
	Amount	MBtu	Amount	Btu/ton	kJ/metric ton
Distillate (light) grade nos. 1, 2, 4, & light diesel fuel, gallon	58,959,600	8,177,697	0.0562	7,793	9,060
Residual (heavy) grade nos. 5 and 6 & heavy diesel fuel, gallon	13,234,200	1,981,160	0.0126	1,888	2,200
Gas (natural, manufactured, and mixed), 1000 cu ft	1,400,000	1,437,800	0.00133	1,370	1,590
Gasoline used as a fuel, gallon	5,700,000	712,500	0.00543	679	790
Electricity purchased, 1000 kWh	2,525,053	8,615,481	0.00241	8,210	9,550
Total	…	**20,924,637**	…	**19,940**	**23,190**

1. Adapted from USCB (1999a).

2. Since the U.S. Census Bureau data does not include the total quantity of material processed, the annual production from the U.S. Geological Survey (1,049,400,072 ton) is used from "Table 6. Construction Sand and Gravel Sold or Used in the United States in 1997" in Bolen (1997). Combining the two sources of data probably introduces some error; however, since the cost of material represented in the two sources does not differ by more than 12%, the error is not significant.

Table 10. Energy Used to Produce Coarse Aggregate form Crushed Stone

Fuel or electricity	Total energy used[1]		Energy/ton aggregate[2]		
	Amount	MBtu	Amount/ton	Btu/ton	kJ/metric ton
Coal, ton[3]	43,000	903,516	0.0000275	577	670
Distillate (light) grade nos. 1, 2, 4, & light diesel fuel, gallon	145,811,400	20,224,041	0.0932	12,920	15,030
Residual (heavy) grade nos. 5 and 6 & heavy diesel fuel, gallon	22,663,200	3,392,681	0.0145	2,167	2,520
Gas (natural, manufactured, and mixed), 1000 cu ft	5,400,000	5,545,800	0.00345	3,543	4,120
Gasoline used as a fuel, gallon	14,700,000	1,837,500	0.00939	1,174	1,370
Electricity purchased, 1000 kWh	4,627,887	15,790,350	0.00296	10,088	11,730
Total	…	**47,693,889**	...	**30,470**	**35,440**

1. Adapted from USCB (1999b, 1999c, and 1999d).

2. Since the U.S. Census Bureau data does not include the total quantity of material processed, the annual production from the U.S. Geological Survey (1,565,281,620 ton) is used from "Table 2. Crushed Stone Sold or Used in the United States in 1997" in Tepordei (1997). Combining the two sources of data probably introduces some error; however, since the cost of material represented in the two sources does not differ by more than 10%, the error is not significant.

3. Assume coal is used to generate electricity on site at 85% efficiency: 577 Btu coal/ton rock is equivalent to 0.144 kWh electricity/ton rock.

The U.S. EPA AP-42 emission factors (EPA 2004a) are used to calculate particulate matter emissions (total, PM-10, and PM-2.5) from the production of coarse aggregate from crushed stone. The activities included are blasting, wet drilling in unfragmented rock, product loading in open truck, unloading, primary crushing, secondary crushing, screening, conveyor transfer, and storage piles. Emission factors from the U.S. EPA FIRE database (EPA 2004b) are used to calculate particulate matter emissions (total, PM-10, and PM-2.5) from the production of sand and gravel. The activities included are product loading in open truck, material transfer and conveying, screening, pile forming with a stacker, storage piles, and bulk loading, Particulate matter emissions for hauling are calculated from the emission factors in Richards and Brozell

(1996) assuming the average distance between quarry face and paved road is 3 km (2 miles) giving a round trip of 6 km (4 miles) and quarry truck hauling capacity is 45 metric tons (50 tons). Emissions to air from plant operations are calculated from the fuel used at the plant assuming (1) middle distillates and gasoline are used in single-unit mobile equipment and (2) residual oil and natural gas are used in industrial boilers.

Ancillary Materials: Admixtures

The Society of Environmental Toxicology and Chemistry (SETAC) guidelines for conducting an LCA (SETAC 1993) indicate that inputs to a process do not need to be included in an LCA if (1) they are less than 1% of the total mass of the processed materials or product, (2) they do not have a significant associated energy consumption, and (3) they do not contribute significantly to a toxic emission.

Admixtures are widely used in concrete to control its properties and performance. The dosage rate of admixtures in concrete is typically well below one percent by mass, as noted in Table 11, and therefore are excluded from the concrete LCI. A personal communication from Grace Construction Products (Rear 1997) indicates that admixtures within concrete are not likely to be a source of emissions or effluent contamination because they are largely chemically bound and retained in the concrete product.

Table 11. Typical Admixture Dosage Rates in Concrete

Admixture	Dosage rate, mL/100 kg cement	Dosage rate, oz/100 lb cement	Admixture, as percent of mass of 35 MPa (5,000 psi) mix
Air entraining	30 – 520	0.5 – 8	0.004 – 0.071
Water reducers	190 – 590	3 – 9	0.026 – 0.079
Accelerators	390 - 5,200	6 – 80	0.053 – 0.705
Superplasticizers	390 – 630	6 – 25	0.053 – 0.220

Adapted from Rear (1997).

READY MIXED CONCRETE

Ready Mix Plant Operations

The concrete plant system boundary was presented in Figure 1. A description of ready mix plant operations is presented below. The description is taken from “Concrete Batching” in Chapter 11 of *Compilation of Air Pollution Emission Factors* (EPA 2004c).

> *Approximately 75 percent of the U.S. concrete manufactured is produced at plants that store, convey, measure and discharge these constituents into trucks for transport to a job site. At most of these plants, sand, aggregate, cement and water are all gravity fed from the weight hopper into the mixer trucks. The concrete is mixed on the way to the site where the concrete is to be poured. At some of these plants, the concrete may also be manufactured in a central mix drum and transferred to a transport truck. Most of the remaining concrete manufactured are products cast in a factory setting. Precast products range from concrete bricks and paving stones to bridge girders, structural components, and panels for cladding. Concrete masonry, another type of manufactured concrete, may be best known for its conventional 8 x 8 x 16-inch block. In a few cases concrete is dry batched or prepared at a building construction site.*

The raw materials can be delivered to a plant by rail, truck or barge. The cement is transferred to elevated storage silos pneumatically or by bucket elevator. The sand and coarse aggregate are transferred to elevated bins by front end loader, clam shell crane, belt conveyor, or bucket elevator. From these elevated bins, the constituents are fed by gravity or screw conveyor to weigh hoppers, which combine the proper amounts of each material.

Particulate matter, consisting primarily of cement and pozzolan dust but including some aggregate and sand dust emissions, is the primary pollutant of concern. In addition, there are emissions of metals that are associated with this particulate matter. All but one of the emission points are fugitive in nature. The only point sources are the transfer of cement and pozzolan material to silos, and these are usually vented to a fabric filter or "sock". Fugitive sources include the transfer of sand and aggregate, truck loading, mixer loading, vehicle traffic, and wind erosion from sand and aggregate storage piles. The amount of fugitive emissions generated during the transfer of sand and aggregate depends primarily on the surface moisture content of these materials. The extent of fugitive emission control varies widely from plant to plant.

Types of controls used may include water sprays, enclosures, hoods, curtains, shrouds, movable and telescoping chutes, central duct collection systems, and the like. A major source of potential emissions, the movement of heavy trucks over unpaved or dusty surfaces in and around the plant, can be controlled by good maintenance and wetting of the road surface.

Data on process inputs and water use are from *Confidential Life Cycle Inventory Survey of Ready-Mix Concrete Plant* (Marceau, VanGeem, and Ranchero 2006a). This survey was distributed to a sample of member-plants of the National Ready Mixed Concrete Association. The sample was chosen so that the plants in the sample are representative of climates of the conterminous United States and plant size in terms of production in cubic yards of ready mixed concrete. The sample consists of 47 plants, and unless stated otherwise, the entire sample was used to calculate results. The surveys were completed with the understanding that plant-specific operating data would be kept confidential. A blank questionnaire is included in Appendix B. The raw data were used to calculate inputs and emissions on a production-weighted basis per unit volume of concrete.

Energy. The types and amounts of fuel used at ready mix plants vary from plant-to-plant. Plants reported using gasoline in plant-only vehicles and power washers; middle distillates in plant-only vehicles, loaders, forklifts, boilers (for hot water and building heat), concrete production, space heaters, and generators; residual oil in boilers (for hot water); natural gas in boilers (for hot water and building heat); liquefied petroleum gas in torches, water heating, and forklifts; and propane for miscellaneous uses. However, most of the energy used was diesel oil in light trucks (15.7% of the energy used at the plant), diesel oil in industrial boilers for hot water (21.2%) and building heat (2.4%), natural gas in industrial boilers for hot water (19.6%) and building heat (6.5%), and electricity throughout the plant (34.6%). A summary of the data is presented in Table 12.

Table 12. Plant Energy Used to Produce Ready Mixed Concrete

Fuel and electricity	Where it's used	Input/unit volume concrete		
		Amount	Btu/yd^3	kJ/m^3
Nos. 1, 2*** & 4 diesel fuel, gallon	Light trucks: fork-lift, pick-up, etc.	0.0352	4,880	6,730
	Industrial boiler (hot water and building heat)	0.0879	7,310	10,090
Natural gas, cu ft	Industrial boiler (hot water and building heat)	7.91	8,120	11,210
Electricity, kWh	Throughout plant	3.15	10,730	14,810
Total	…	…	**31,040**	**42,840**

Source: Marceau, VanGeem, and Ranchero (2006a).

Water. Water consumption, other than batch water, is affected by three main factors: (1) type of plant—central mix plants load a wet product into the concrete trucks and tend to require less wash off water than transit mixer operations that load out a dry material, (2) plant location—rural plants with longer average hauls to job sites are more likely to use transit mixers than urban plants that have shorter hauls, and (3) plant size—larger plants, particularly those in urban areas, are more likely to have water-recycling systems. The average water consumption (not including batch water) is 65 L/m^3 (13 gal/yd^3) of ready mixed concrete (based on responses from 26 plants). The average amount of water disposed is 35 L/m^3 (7 gal/yd^3) (based on responses form 23 plants). Water not discarded is recycled back into the process or into other products. Some plants did not measure water use or discharge, hence the low response rate.

Solid Waste

There is very little solid waste at the ready mix plant because most returned material is recycled. The high level of recycling is due to high landfill costs, which typically range from $28 to $55 per metric ton ($25 to $50 per ton). The average amount of solid waste is 24 kg/m^3 (41 lb/yd^3) of ready-mixed concrete (based on responses from 43 plants). Solid waste consists of concrete and small amounts of paste (cement and water after aggregate has been reclaimed). Recycling consists of (1) windrowing returned material, letting it harden, then crushing it and using it as fill or aggregate, (2) using hydration control agents and re-shipping, (3) pouring returned material into forms such as blocks or other shapes, (4) using returned material to pave plant property, and (5) reclaiming and reusing the slurry. It is assumed that materials such as lubricating oil and solvents used in maintaining plant and mobile equipment are used in insignificant quantities compared to primary fuels and materials.

Representative Mixes

The compressive strength of concrete is usually specified for a particular use. Structural concrete for beams, columns, floors, slabs, and other uses often specify 25 or 35 MPa (4,000 or 5,000 psi). Residential and other general use concrete is often 20 MPa or less (3,000 psi). Seven representative concrete mixes are shown in Table 13. Ready Mixes 1 through 3 represent concrete with 28-day compressive strengths of 35, 25, and 20 MPa (5,000, 4,000, and 3,000 psi, respectively). Ready Mixes 4 and 5 represent 20-MPa concrete with 20 and 25% of the cementitious materials replaced with fly ash. Ready Mixes 6 and 7 represent 20-MPa (3,000-psi)

concrete with 35 and 50% of the cementitious materials replaced with slag cement. Mixes incorporating SCM are included to demonstrate the reductions in energy and emissions resulting from replacement of cement with SCM. Approximately 90% of the market for ready mixed concrete is in the 20-MPa range, approximately 8% is in the 25- to 30-MPa range, and only 1 to 2% is for higher strengths (Vickers 1990). The weight of materials, including cementitious materials, aggregates, and water remain relatively constant at about 2,350 kg/m^3 (4,000 lb/yd^3) of concrete regardless of the mix design. As the cementitious content increases in the higher strength mixes it is balanced by a decrease in aggregate content.

Table 13a. Concrete Mix Designs and Properties (SI Units)

Concrete mix description	**Ready Mix 1**	**Ready Mix 2**	**Ready Mix 3**	**Ready Mix 4**	**Ready Mix 5**	**Ready Mix 6**	**Ready Mix 7**
28-day compressive strength, MPa	35	25	20	20	20	20	20
Fly ash, %	0	0	0	20	25	0	0
Slag cement	0	0	0	0	0	35	50
Unit weight, kg/m^3	2,370	2,380	2,320	2,320	2,320	2,320	2,320
Raw material, kg/m^3 concrete							
Cement	335	279	223	179	167	145	112
Fly ash	0	0	0	44	56	0	0
Slag cement	0	0	0	0	0	78	112
Water	141	141	141	141	141	141	141
Coarse aggregate	1,187	1,187	1,127	1,127	1,127	1,127	1,127
Fine aggregate	712	771	831	831	831	831	831
Total*	**2,374**	**2,377**	**2,321**	**2,321**	**2,321**	**2,321**	**2,321**

*Data may not add to total shown due to conversion from U.S. Customary Units and independent rounding.

Table 13b. Concrete Mix Designs and Properties (U.S. Customary Units)

Concrete mix description	**Ready Mix 1**	**Ready Mix 2**	**Ready Mix 3**	**Ready Mix 4**	**Ready Mix 5**	**Ready Mix 6**	**Ready Mix 7**
28-day compressive strength, psi	5,000	4,000	3,000	3,000	3,000	3,000	3,000
Fly ash, %	0	0	0	20	25	0	0
Slag cement	0	0	0	0	0	35	50
Unit weight, lb/ft^3	148	148	145	145	145	145	145
Raw material, lb/yd^3 concrete							
Cement	564	470	376	301	282	244	188
Fly ash	0	0	0	75	94	0	0
Slag cement	0	0	0	0	0	132	188
Water	237	237	237	237	237	237	237
Coarse aggregate	2,000	2,000	1,900	1,900	1,900	1,900	1,900
Fine aggregate	1,200	1,300	1,400	1,400	1,400	1,400	1,400
Total	**4,001**	**4,007**	**3,913**	**3,913**	**3,913**	**3,913**	**3,913**

Ready Mixed Concrete LCI Results

The LCI results are presented individually for each mix in the Tables of Appendix E. A summary of the results is also presented in Table 15. The headings of the tables in Appendix E show (in order, from left to right) the names of the inputs and outputs and the units of measurement if different from kilograms or pounds; the upstream profiles for portland cement, slag cement, natural and manufactured aggregates; plant operations; gate-to-gate transportation; and the total.

Ready Mixed Concrete LCI Analysis

Energy. The most important determinant of energy consumption is cement content in a mix: ranging from 0.732 GJ/m^3 (0.531 MBtu/yd^3) for the 20-MPa (3,000-psi) concrete with 112 kg of cement per m^3 (188 lb/yd^3) and 112 kg of slag cement per m^3 (188 lb/yd^3) [Ready Mix 7] to 1.63 GJ/m^3 (1.18 MBtu/yd^3) for the 35-MPa (5,000-psi) concrete with 335 kg of cement per m^3 (564 lb/yd^3) [Ready Mix 1]. The energy consumed in aggregate production, concrete plant operation, and transportation is an order of magnitude smaller and relatively constant by comparison: approximately 0.05 GJ/m^3 (0.04 MBtu/yd^3) in aggregate productions, 0.04 GJ/m^3 (0.03 MBtu/yd^3) in concrete plant operations; and approximately 0.08 GJ/m^3 (0.06 MBtu/yd^3) in transportation. Energy consumption is reduced by replacing cement with SCMs, such as fly ash and slag cement, as shown in Figure 2. A 1% replacement of cement with fly ash or slag cement results in approximately 1% reduction in energy consumption per unit of concrete.

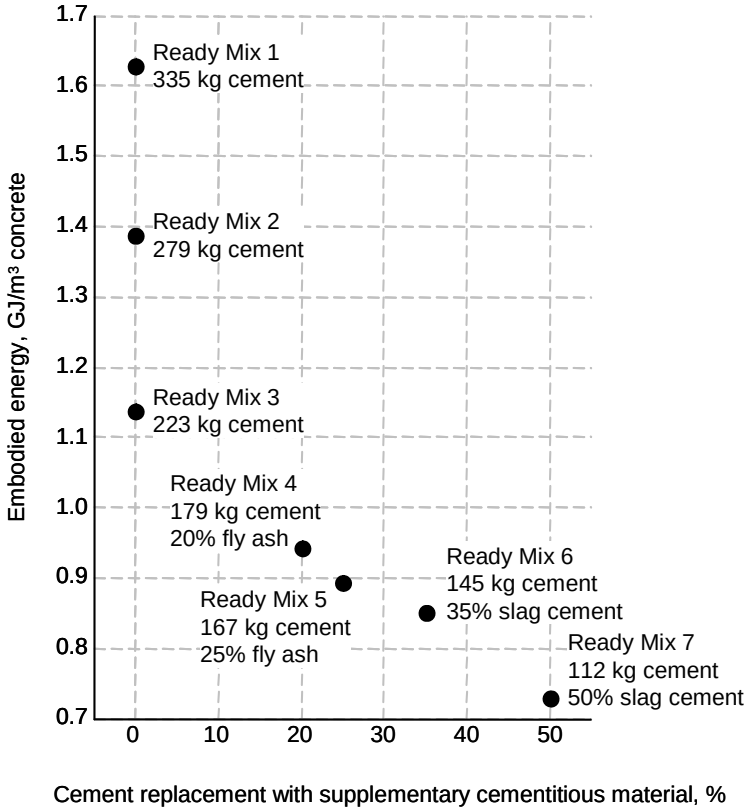

Figure 2. The embodied energy is reduced by replacing portland cement with supplementary cementitious materials like fly ash and slag cement.

Emissions. Carbon dioxide (CO_2) emissions from calcination in the cement manufacturing process, shown in Table 15 and in the tables of Appendix E, are approximately 60% of the total CO_2 emissions from cement manufacturing. Since CO_2 emissions from cement manufacturing are two orders of magnitude larger than any other stage of concrete production, approximately 60% of the CO_2 emissions embodied in concrete are from calcination.

Aggregate production and cement manufacturing produce similar amounts of particulate matter (same order of magnitude). As shown in the tables in Appendix E, total particulate matter emissions from cement manufacturing range from 0.309 to 0.926 kg/m^3 (0.520 and 1.56 lb/yd^3). Total particulate matter emissions from aggregate production are approximately 0.2 kg/m^3 (0.4 lb/yd^3). Particulate emissions in the concrete plant are approximately 0.05 kg/m^3 (0.08 lb/yd^3).

The amounts of CO_2 and other combustion gases embodied in concrete are primarily a function of the cement content in the mix designs. The CO_2 emissions range from 112 kg/m^3 (190 lb/yd^3) for the 20-MPa (3,000-psi) concrete with 50% slag cement (Ready Mix 7) to 313 kg/m^3 (527 lb/yd^3) for the 35-MPa (5,000-psi) concrete (Ready Mix 1). Emissions of SO_2 range from 0.170 to 0.432 kg/m^3 (0.287 to 0.729 lb/yd^3) for the same mixes, while emissions of NO_X range from 0.323 to 0.824 kg/m^3 (0.544 to 1.39 lb/yd^3).

Sensitivity Analyses

Energy. Embodied energy per unit of concrete is primarily a function of cement content. In the 20-MPa (3,000-psi) mix without SCMs (Ready Mix 3), cement manufacturing accounts for about 85% of total energy, concrete plant operations and aggregate processing are each responsible for about 4%, and transportation consumes the remaining 7%. The relative importance of the energy contribution from cement increases as cement content in the mix increases is shown in Figure 2. Therefore, the concrete life cycle energy use is sensitive to the cement content of a concrete mix, and the imported cement upstream profile.

Combustion gases. Fuel consumption, meaning energy sources other than electricity, in concrete production follows the same pattern as total energy embodied in concrete. The fuel consumption for the 20-MPa (3,000-psi) mix without SCM is provided in Table 14. The fact that cement manufacturing accounts for approximately 86% of fuel consumption per unit volume of concrete indicates that the LCI combustion gas results are sensitive to the cement content of a concrete mix and the data on fuel consumption in cement manufacturing. Because the relative amount of CO_2 emissions from calcination and fuel combustion in cement manufacture is so large, the cement content of the concrete mix accounts for 96% of CO_2 emissions embodied in the 20-MPa (3,000- psi) mix without SCMs (Ready Mix 3). Thus, concrete LCI results are significantly influenced by the cement content of a concrete mix and CO_2 data from the cement manufacturing process.

Table 14. Fuel Consumption by Process Step for Energy Sources Other than Electricity for 20-MPa (3,000-psi) Concrete

Process step	GJ/m^3	MBtu/yd^3	Percent of total
Cement manufacturing	0.858	0.622	86
Aggregate production	0.029	0.021	3
Transportation	0.075	0.054	8
Concrete plant operations	0.028	0.020	3
Total*	**0.990**	**0.718**	**100**

*Data may not add to totals shown due to independent rounding.

Total Particulate Matter Emissions. The single largest contributor to particulate emissions in both cement manufacturing and aggregate production is quarry operations. In cement manufacturing, quarry operations account for almost 90% of total particulate emissions. In aggregate production, quarry operations account for 100%, and most of these are from unpaved quarry haul-roads. Approximately 70% of the total particulate emissions embodied in concrete are from cement manufacturing and approximately 30% are from aggregate production.

Table 15a. Summary of Ready Mix LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Ready Mix 1	Ready Mix 2	Ready Mix 3	Ready Mix 4	Ready Mix 5	Ready Mix 6	Ready Mix 7
Raw material							
Limestone	3.89E+02	3.24E+02	2.60E+02	2.08E+02	1.95E+02	1.68E+02	1.30E+02
Cement rock, marl	6.67E+01	5.56E+01	4.45E+01	3.56E+01	3.33E+01	2.89E+01	2.22E+01
Shale	1.68E+01	1.40E+01	1.12E+01	8.98E+00	8.42E+00	7.28E+00	5.61E+00
Clay	2.05E+01	1.71E+01	1.37E+01	1.10E+01	1.03E+01	8.89E+00	6.85E+00
Bottom ash	3.32E+00	2.77E+00	2.22E+00	1.77E+00	1.66E+00	1.44E+00	1.11E+00
Fly ash	4.42E+00	3.68E+00	2.95E+00	4.69E+01	5.80E+01	1.91E+00	1.47E+00
Foundry sand	1.33E+00	1.11E+00	8.88E-01	7.11E-01	6.66E-01	5.76E-01	4.44E-01
Sand	1.34E+01	1.12E+01	8.95E+00	7.16E+00	6.71E+00	5.81E+00	4.47E+00
Iron, iron ore	4.59E+00	3.82E+00	3.06E+00	2.45E+00	2.29E+00	1.98E+00	1.53E+00
Blast furnace slag	6.90E+00	5.75E+00	4.60E+00	3.68E+00	3.45E+00	8.13E+01	1.14E+02
Slate	3.42E-01	2.85E-01	2.28E-01	1.83E-01	1.71E-01	1.48E-01	1.14E-01
Other raw material	9.44E+00	7.87E+00	6.30E+00	5.04E+00	4.72E+00	4.09E+00	3.15E+00
Gypsum, anhydrite	1.62E+01	1.35E+01	1.08E+01	8.67E+00	8.12E+00	7.03E+00	5.41E+00
Water, process (includes batch water)	1.67E+02	1.63E+02	1.59E+02	1.55E+02	1.54E+02	1.52E+02	1.50E+02
Water, non-process	2.67E+02	2.24E+02	1.81E+02	1.46E+02	1.38E+02	1.92E+02	1.97E+02
Coarse aggregate, natural	8.78E+02	8.78E+02	8.34E+02	8.34E+02	8.34E+02	8.34E+02	8.34E+02
Coarse aggregate, manufactured	3.09E+02	3.09E+02	2.93E+02	2.93E+02	2.93E+02	2.93E+02	2.93E+02
Fine aggregate, natural	7.12E+02	7.71E+02	8.31E+02	8.31E+02	8.31E+02	8.31E+02	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	7.83E+01	1.12E+02
Ancillary material							
Explosives	9.87E-02	8.23E-02	6.58E-02	5.27E-02	4.94E-02	4.27E-02	3.29E-02
Refractory	2.10E-01	1.75E-01	1.40E-01	1.12E-01	1.05E-01	9.08E-02	6.99E-02
Grinding media	4.68E-02	3.90E-02	3.12E-02	2.50E-02	2.34E-02	4.79E-02	5.50E-02
Grinding aids	1.20E-01	1.00E-01	8.03E-02	6.43E-02	6.02E-02	5.22E-02	4.03E-02
Filter bags	6.44E-03	5.37E-03	4.30E-03	3.44E-03	3.22E-03	3.12E-03	2.62E-03
Oil & grease	4.35E-02	3.62E-02	2.90E-02	2.32E-02	2.17E-02	1.88E-02	1.45E-02
Oil (L)	...	...	...	...	...	8.30E-04	1.18E-03
Grease (L)	...	...	...	...	...	1.79E-03	2.56E-03
Solvent (L)	...	...	...	...	...	7.19E-05	1.02E-04
Cement bags	2.28E-01	1.90E-01	1.52E-01	1.21E-01	1.14E-01	9.84E-02	7.58E-02
Chains	6.41E-03	5.34E-03	4.27E-03	3.42E-03	3.20E-03	2.77E-03	2.14E-03
Fuel and electricity							
Coal (metric ton)	3.37E-02	2.81E-02	2.25E-02	1.80E-02	1.69E-02	1.46E-02	1.12E-02
Gasoline (L)	5.61E-01	5.78E-01	5.81E-01	5.79E-01	5.79E-01	5.78E-01	5.76E-01
Liquefied petroleum gas (L)	9.40E-03	7.83E-03	6.27E-03	5.02E-03	4.70E-03	4.07E-03	3.13E-03
Middle distillates (L)	2.91E+00	2.72E+00	2.50E+00	2.46E+00	2.45E+00	2.52E+00	2.53E+00
Natural gas (thousand m^3)	1.70E-03	1.48E-03	1.27E-03	1.09E-03	1.05E-03	1.66E-03	1.83E-03
Petroleum coke (metric ton)	7.52E-03	6.27E-03	5.01E-03	4.01E-03	3.76E-03	3.25E-03	2.51E-03
Residual oil (L)	2.33E-01	2.33E-01	2.27E-01	2.22E-01	2.21E-01	2.19E-01	2.16E-01
Wastes (GJ)	1.35E-01	1.13E-01	9.02E-02	7.22E-02	6.76E-02	5.85E-02	4.51E-02
Electricity (kWh)	5.64E+01	4.87E+01	4.09E+01	3.46E+01	3.31E+01	3.70E+01	3.54E+01
Energy equivalent, GJ							
Coal	8.25E-01	6.87E-01	5.50E-01	4.40E-01	4.12E-01	3.57E-01	2.75E-01
Gasoline	1.95E-02	2.02E-02	2.02E-02	2.02E-02	2.02E-02	2.01E-02	2.01E-02
Liquefied petroleum gas	2.38E-04	1.98E-04	1.59E-04	1.27E-04	1.19E-04	1.03E-04	7.93E-05
Middle distillates	1.12E-01	1.05E-01	9.66E-02	9.50E-02	9.46E-02	9.76E-02	9.80E-02
Natural gas	6.51E-02	5.68E-02	4.84E-02	4.18E-02	4.01E-02	6.36E-02	7.00E-02
Petroleum coke	2.64E-01	2.20E-01	1.76E-01	1.41E-01	1.32E-01	1.14E-01	8.78E-02
Residual oil	9.74E-03	9.71E-03	9.45E-03	9.27E-03	9.23E-03	9.14E-03	9.00E-03
Wastes	1.35E-01	1.13E-01	9.02E-02	7.22E-02	6.76E-02	5.85E-02	4.51E-02
Electricity	2.03E-01	1.75E-01	1.47E-01	1.25E-01	1.19E-01	1.33E-01	1.27E-01
Subtotal	1.63E+00	1.39E+00	1.14E+00	9.44E-01	8.95E-01	8.53E-01	7.32E-01
Emission to water							
Aluminum	2.88E-04	2.40E-04	1.92E-04	1.54E-04	1.44E-04	1.24E-04	9.59E-05
Ammonia, ammonium	3.17E-04	2.64E-04	2.11E-04	1.69E-04	1.59E-04	1.37E-04	1.06E-04
Chemical oxygen demand, COD	...	...	...	...	...	2.27E-06	3.24E-06
Chlorides	2.43E-01	2.03E-01	1.62E-01	1.30E-01	1.22E-01	1.05E-01	8.11E-02
Copper	1.99E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08
Dissolved organic compounds	4.61E-03	3.84E-03	3.07E-03	2.46E-03	2.31E-03	1.99E-03	1.54E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table 15a. Summary of Ready Mix LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Ready Mix 1	Ready Mix 2	Ready Mix 3	Ready Mix 4	Ready Mix 5	Ready Mix 6	Ready Mix 7
Iron	1.99E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08	2.00E-08
Nitric, nitrites	1.97E-03	1.64E-03	1.32E-03	1.05E-03	9.87E-04	8.54E-04	6.58E-04
Oil and grease	2.52E-03	2.10E-03	1.68E-03	1.34E-03	1.26E-03	1.09E-03	8.39E-04
pH	8.45	8.45	8.45	8.45	8.45	8.45	8.45
Phenolics	7.38E-06	6.15E-06	4.92E-06	3.94E-06	3.69E-06	3.19E-06	2.46E-06
Phosphorus	1.84E-06	1.54E-06	1.23E-06	9.84E-07	9.22E-07	7.98E-07	6.15E-07
Sulfates	2.06E-01	1.72E-01	1.37E-01	1.10E-01	1.03E-01	8.91E-02	6.87E-02
Sulfides	2.21E-05	1.84E-05	1.48E-05	1.18E-05	1.11E-05	9.57E-06	7.38E-06
Suspended solids	7.84E-02	6.54E-02	5.23E-02	4.19E-02	3.92E-02	3.44E-02	2.68E-02
Water (that leaves site) (L)	1.26E+03	1.06E+03	8.53E+02	6.90E+02	6.48E+02	5.93E+02	4.83E+02
Zinc	1.11E-05	9.22E-06	7.38E-06	5.91E-06	5.53E-06	4.79E-06	3.69E-06
Emission to air							
1,3 Butadiene	6.99E-13	7.16E-13	7.09E-13	7.09E-13	7.09E-13	7.09E-13	7.09E-13
Acetaldehyde	6.50E-11	6.66E-11	6.59E-11	6.59E-11	6.59E-11	6.59E-11	6.59E-11
Acrolein	1.04E-11	1.07E-11	1.05E-11	1.05E-11	1.05E-11	1.05E-11	1.05E-11
Ammonia, NH_3	1.59E-03	1.33E-03	1.06E-03	8.50E-04	7.96E-04	6.89E-04	5.31E-04
Arsenic	3.86E-07	3.87E-07	3.79E-07	4.01E-07	4.06E-07	4.18E-07	4.34E-07
Benzene	1.25E-08	1.26E-08	1.26E-08	1.26E-08	1.26E-08	1.26E-08	1.26E-08
Beryllium	5.12E-08	5.12E-08	5.05E-08	5.25E-08	5.30E-08	5.40E-08	5.55E-08
Cadmium	3.49E-08	3.51E-08	3.50E-08	7.90E-08	9.02E-08	1.12E-07	1.45E-07
Carbon dioxide, CO_2	3.13E+02	2.62E+02	2.11E+02	1.71E+02	1.61E+02	1.42E+02	1.12E+02
Carbon dioxide, CO_2, calcination	1.84E+02	1.54E+02	1.23E+02	9.84E+01	9.22E+01	7.98E+01	6.15E+01
Carbon dioxide, CO_2, combustion	1.29E+02	1.08E+02	8.82E+01	7.29E+01	6.85E+01	6.21E+01	5.10E+01
Carbon monoxide, CO	3.91E-01	3.32E-01	2.72E-01	2.24E-01	2.12E-01	1.94E-01	1.60E-01
Chromium	1.29E-06	1.30E-06	1.26E-06	1.29E-06	1.30E-06	1.31E-06	1.33E-06
Cobalt	7.42E-08	7.64E-08	7.64E-08	7.64E-08	7.64E-08	7.64E-08	7.64E-08
Copper	4.34E-08	4.34E-08	4.34E-08	4.34E-08	4.34E-08	4.34E-08	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	3.36E-11	2.82E-11	2.27E-11	1.84E-11	1.73E-11	1.51E-11	1.18E-11
Ethylbenzene	5.20E-11	5.33E-11	5.27E-11	5.27E-11	5.27E-11	5.27E-11	5.27E-11
Formaldehyde	7.58E-07	7.70E-07	7.69E-07	7.69E-07	7.69E-07	7.69E-07	7.69E-07
Hydrogen chlorine, HCl	2.45E-02	2.05E-02	1.64E-02	1.31E-02	1.23E-02	1.06E-02	8.21E-03
Hydrogen sulfide, H_2S	...	...	...	...	...	2.11E-02	3.01E-02
Lead	5.45E-07	5.46E-07	5.35E-07	5.46E-07	5.49E-07	5.55E-07	5.63E-07
Manganese	9.07E-06	9.09E-06	8.86E-06	8.86E-06	8.86E-06	8.86E-06	8.87E-06
Mercury, Hg	2.04E-05	1.70E-05	1.36E-05	1.09E-05	1.02E-05	8.84E-06	6.81E-06
Metals, not specified	...	...	...	...	...	5.13E-06	7.31E-06
Methane, CH_4	1.29E-02	1.08E-02	8.76E-03	7.11E-03	6.69E-03	5.96E-03	4.77E-03
Methylene chloride	2.92E-07	2.94E-07	2.94E-07	2.94E-07	2.94E-07	2.94E-07	2.94E-07
Naphthalene	1.67E-08	1.71E-08	1.71E-08	1.71E-08	1.71E-08	1.71E-08	1.71E-08
Nickel	2.62E-06	2.65E-06	2.61E-06	2.66E-06	2.67E-06	2.70E-06	2.73E-06
Nitric oxide, NO (unspecified)	2.62E-04	2.55E-04	2.43E-04	2.43E-04	2.43E-04	2.43E-04	2.43E-04
Nitrogen oxides, NO_X	8.24E-01	6.97E-01	5.69E-01	4.69E-01	4.44E-01	3.96E-01	3.23E-01
Non-methane organic gases, NMOG	2.10E-06	2.10E-06	2.10E-06	2.10E-06	2.10E-06	2.10E-06	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	3.57E-12	3.66E-12	3.63E-12	3.63E-12	3.63E-12	3.63E-12	3.63E-12
Particulates, PM-2.5	4.78E-05	4.27E-05	3.68E-05	3.28E-05	3.17E-05	2.97E-05	2.67E-05
Particulates, PM-10	5.75E-01	5.51E-01	5.17E-01	4.88E-01	4.81E-01	4.67E-01	4.46E-01
Particulates, total	1.18E+00	1.03E+00	8.77E-01	7.54E-01	7.23E-01	6.72E-01	5.85E-01
Perchloroethylene	4.84E-09	4.86E-09	4.86E-09	4.86E-09	4.86E-09	4.86E-09	4.86E-09
Phenolic compounds	2.20E-07	2.22E-07	2.22E-07	2.22E-07	2.22E-07	2.22E-07	2.22E-07
Phosphorus	4.44E-06	4.45E-06	4.33E-06	4.41E-06	4.43E-06	4.47E-06	4.53E-06
Propylene oxide	4.71E-11	4.83E-11	4.78E-11	4.78E-11	4.78E-11	4.78E-11	4.78E-11
Radionuclides (kBq)	2.64E-02	2.66E-02	2.66E-02	2.66E-02	2.66E-02	2.66E-02	2.66E-02
Selenium	1.48E-07	1.49E-07	1.48E-07	1.50E-07	1.50E-07	1.51E-07	1.52E-07
Sulfur dioxide, SO_2	4.32E-01	3.60E-01	2.88E-01	2.31E-01	2.16E-01	2.05E-01	1.70E-01
Sulfur oxides, SO_X	3.49E-03	3.45E-03	3.33E-03	3.33E-03	3.33E-03	3.33E-03	3.33E-03
Toluene	2.11E-10	2.16E-10	2.14E-10	2.14E-10	2.14E-10	2.14E-10	2.14E-10
Total hydrocarbon, THC	2.04E-06	2.04E-06	2.04E-06	2.04E-06	2.04E-06	2.04E-06	2.04E-06
Volatile organic compounds, VOC	2.07E-02	1.80E-02	1.52E-02	1.31E-02	1.26E-02	1.17E-02	1.02E-02
Xylenes	1.04E-10	1.07E-10	1.05E-10	1.05E-10	1.05E-10	1.05E-10	1.05E-10
Zinc	2.89E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08
Emission to land							
Cement kiln dust, CKD	1.30E+01	1.08E+01	8.64E+00	6.92E+00	6.48E+00	5.61E+00	4.32E+00
Slag reject	...	...	...	...	...	7.20E-02	1.03E-01
Other solid waste	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table 15b. Summary of Ready Mix LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Ready Mix 1	Ready Mix 2	Ready Mix 3	Ready Mix 4	Ready Mix 5	Ready Mix 6	Ready Mix 7
Raw material							
Limestone	6.56E+02	5.47E+02	4.38E+02	3.50E+02	3.28E+02	2.84E+02	2.19E+02
Cement rock, marl	1.12E+02	9.37E+01	7.49E+01	6.00E+01	5.62E+01	4.86E+01	3.75E+01
Shale	2.84E+01	2.36E+01	1.89E+01	1.51E+01	1.42E+01	1.23E+01	9.46E+00
Clay	3.46E+01	2.89E+01	2.31E+01	1.85E+01	1.73E+01	1.50E+01	1.15E+01
Bottom ash	5.60E+00	4.67E+00	3.74E+00	2.99E+00	2.80E+00	2.42E+00	1.87E+00
Fly ash	7.45E+00	6.21E+00	4.97E+00	7.90E+01	9.77E+01	3.22E+00	2.48E+00
Foundry sand	2.25E+00	1.87E+00	1.50E+00	1.20E+00	1.12E+00	9.72E-01	7.49E-01
Sand	2.26E+01	1.89E+01	1.51E+01	1.21E+01	1.13E+01	9.79E+00	7.54E+00
Iron, iron ore	7.73E+00	6.44E+00	5.15E+00	4.13E+00	3.87E+00	3.34E+00	2.58E+00
Blast furnace slag	1.16E+01	9.69E+00	7.75E+00	6.21E+00	5.81E+00	1.37E+02	1.92E+02
Slate	5.77E-01	4.81E-01	3.85E-01	3.08E-01	2.88E-01	2.50E-01	1.92E-01
Other raw material	1.59E+01	1.33E+01	1.06E+01	8.50E+00	7.96E+00	6.89E+00	5.31E+00
Gypsum, anhydrite	2.74E+01	2.28E+01	1.82E+01	1.46E+01	1.37E+01	1.18E+01	9.12E+00
Water, process (includes batch water)	2.82E+02	2.75E+02	2.67E+02	2.61E+02	2.60E+02	2.57E+02	2.52E+02
Water, non-process	4.51E+02	3.78E+02	3.05E+02	2.47E+02	2.32E+02	3.24E+02	3.32E+02
Coarse aggregate, natural	1.48E+03	1.48E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03	1.41E+03
Coarse aggregate, manufactured	5.20E+03	5.20E+03	4.94E+02	4.94E+02	4.94E+02	4.94E+02	4.94E+02
Fine aggregate, natural	1.20E+03	1.30E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	1.32E+02	1.88E+02
Ancillary material							
Explosives	1.66E-01	1.39E-01	1.11E-01	8.88E-02	8.32E-02	7.20E-02	5.55E-02
Refractory	3.54E-01	2.95E-01	2.36E-01	1.89E-01	1.77E-01	1.53E-01	1.18E-01
Grinding media	7.90E-02	6.58E-02	5.26E-02	4.21E-02	3.95E-02	8.08E-02	9.27E-02
Grinding aids	2.03E-01	1.69E-01	1.35E-01	1.08E-01	1.02E-01	8.80E-02	6.79E-02
Filter bags	1.09E-02	9.05E-03	7.24E-03	5.80E-03	5.43E-03	5.26E-03	4.41E-03
Oil & grease	7.33E-02	6.11E-02	4.89E-02	3.91E-02	3.67E-02	3.17E-02	2.44E-02
Oil (gallon)	...	...	...	...	...	1.68E-04	2.39E-04
Grease (gallon)	...	...	...	...	...	3.62E-04	5.16E-04
Solvent (gallon)	...	...	...	...	...	1.45E-05	2.07E-05
Cement bags	3.84E-01	3.20E-01	2.56E-01	2.05E-01	1.92E-01	1.66E-01	1.28E-01
Chains	1.08E-02	9.00E-03	7.20E-03	5.77E-03	5.40E-03	4.67E-03	3.60E-03
Fuel and electricity							
Coal (ton)	2.84E-02	2.37E-02	1.90E-02	1.52E-02	1.42E-02	1.23E-02	9.48E-03
Gasoline (gallon)	1.13E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.17E-01	1.16E-01
Liquefied petroleum gas (gallon)	1.90E-03	1.58E-03	1.27E-03	1.01E-03	9.49E-04	8.21E-04	6.33E-04
Middle distillates (gallon)	5.87E-01	5.49E-01	5.04E-01	4.96E-01	4.94E-01	5.10E-01	5.12E-01
Natural gas (thousand cu ft)	4.59E-02	4.01E-02	3.42E-02	2.95E-02	2.83E-02	4.49E-02	4.94E-02
Petroleum coke (ton)	6.34E-03	5.28E-03	4.23E-03	3.38E-03	3.17E-03	2.74E-03	2.11E-03
Residual oil (gallon)	4.71E-02	4.70E-02	4.58E-02	4.49E-02	4.47E-02	4.42E-02	4.36E-02
Wastes (MBtu)	9.80E-02	8.17E-02	6.54E-02	5.23E-02	4.90E-02	4.24E-02	3.27E-02
Electricity (kWh)	4.31E+01	3.73E+01	3.13E+01	2.65E+01	2.53E+01	2.83E+01	2.70E+01
Energy equivalent, MBtu							
Coal	5.98E-01	4.98E-01	3.98E-01	3.19E-01	2.99E-01	2.59E-01	1.99E-01
Gasoline	1.42E-02	1.46E-02	1.47E-02	1.46E-02	1.46E-02	1.46E-02	1.46E-02
Liquefied petroleum gas	1.72E-04	1.44E-04	1.15E-04	9.20E-05	8.62E-05	7.46E-05	5.75E-05
Middle distillates	8.14E-02	7.62E-02	7.00E-02	6.88E-02	6.85E-02	7.07E-02	7.10E-02
Natural gas	4.71E-02	4.12E-02	3.51E-02	3.03E-02	2.91E-02	4.61E-02	5.07E-02
Petroleum coke	1.91E-01	1.59E-01	1.27E-01	1.02E-01	9.55E-02	8.26E-02	6.37E-02
Residual oil	7.06E-03	7.04E-03	6.85E-03	6.72E-03	6.69E-03	6.62E-03	6.53E-03
Wastes	9.80E-02	8.17E-02	6.54E-02	5.23E-02	4.90E-02	4.24E-02	3.27E-02
Electricity	1.47E-01	1.27E-01	1.07E-01	9.04E-02	8.62E-02	9.66E-02	9.23E-02
Subtotal	1.18E+00	1.01E+00	8.24E-01	6.84E-01	6.48E-01	6.18E-01	5.31E-01
Emission to water							
Aluminum	4.85E-04	4.04E-04	3.23E-04	2.59E-04	2.42E-04	2.10E-04	1.62E-04
Ammonia, ammonium	5.35E-04	4.46E-04	3.56E-04	2.85E-04	2.67E-04	2.31E-04	1.78E-04
Chemical oxygen demand, COD	...	...	...	...	...	3.83E-06	5.46E-06
Chlorides	4.10E-01	3.42E-01	2.74E-01	2.19E-01	2.05E-01	1.78E-01	1.37E-01
Copper	3.35E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08
Dissolved organic compounds	7.77E-03	6.48E-03	5.18E-03	4.15E-03	3.89E-03	3.36E-03	2.59E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234 × 10-2 which is equal to 0.01234. Three dots "…" mean zero.

Table 15b. Summary of Ready Mix LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Ready Mix 1	Ready Mix 2	Ready Mix 3	Ready Mix 4	Ready Mix 5	Ready Mix 6	Ready Mix 7
Iron	3.35E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08	3.37E-08
Nitric, nitrites	3.33E-03	2.77E-03	2.22E-03	1.78E-03	1.66E-03	1.44E-03	1.11E-03
Oil and grease	4.24E-03	3.53E-03	2.83E-03	2.26E-03	2.12E-03	1.83E-03	1.41E-03
pH	8.45	8.45	8.45	8.45	8.45	8.45	8.45
Phenolics	1.24E-05	1.04E-05	8.29E-06	6.64E-06	6.22E-06	5.38E-06	4.14E-06
Phosphorus	3.11E-06	2.59E-06	2.07E-06	1.66E-06	1.55E-06	1.34E-06	1.04E-06
Sulfates	3.47E-01	2.89E-01	2.31E-01	1.85E-01	1.74E-01	1.50E-01	1.16E-01
Sulfides	3.73E-05	3.11E-05	2.49E-05	1.99E-05	1.87E-05	1.61E-05	1.24E-05
Suspended solids	1.32E-01	1.10E-01	8.81E-02	7.05E-02	6.61E-02	5.80E-02	4.52E-02
Water (that leaves site) (gallon)	2.55E+02	2.14E+02	1.72E+02	1.39E+02	1.31E+02	1.20E+02	9.76E+01
Zinc	1.87E-05	1.55E-05	1.24E-05	9.95E-06	9.33E-06	8.07E-06	6.22E-06
Emission to air							
1,3 Butadiene	1.18E-12	1.21E-12	1.19E-12	1.19E-12	1.19E-12	1.19E-12	1.19E-12
Acetaldehyde	1.10E-10	1.12E-10	1.11E-10	1.11E-10	1.11E-10	1.11E-10	1.11E-10
Acrolein	1.75E-11	1.80E-11	1.78E-11	1.78E-11	1.78E-11	1.78E-11	1.78E-11
Ammonia, NH_3	2.68E-03	2.24E-03	1.79E-03	1.43E-03	1.34E-03	1.16E-03	8.94E-04
Arsenic	6.51E-07	6.53E-07	6.38E-07	6.75E-07	6.85E-07	7.04E-07	7.32E-07
Benzene	2.11E-08	2.12E-08	2.12E-08	2.12E-08	2.12E-08	2.12E-08	2.12E-08
Beryllium	8.63E-08	8.64E-08	8.51E-08	8.85E-08	8.94E-08	9.11E-08	9.36E-08
Cadmium	5.89E-08	5.91E-08	5.90E-08	1.33E-07	1.52E-07	1.90E-07	2.45E-07
Carbon dioxide, CO_2	5.27E+02	4.42E+02	3.56E+02	2.88E+02	2.71E+02	2.39E+02	1.90E+02
Carbon dioxide, CO_2, calcination	3.11E+02	2.59E+02	2.07E+02	1.66E+02	1.52E+02	1.34E+02	1.04E+02
Carbon dioxide, CO_2, combustion	2.17E+02	1.83E+02	1.49E+02	1.22E+02	1.16E+02	1.05E+02	8.60E+01
Carbon monoxide, CO	6.59E-01	5.59E-01	4.58E-01	3.78E-01	3.58E-01	3.26E-01	2.70E-01
Chromium	2.18E-06	2.18E-06	2.13E-06	2.17E-06	2.19E-06	2.21E-06	2.24E-06
Cobalt	1.25E-07	1.29E-07	1.29E-07	1.29E-07	1.29E-07	1.29E-07	1.29E-07
Copper	7.31E-08	7.31E-08	7.31E-08	7.31E-08	7.31E-08	7.31E-08	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	5.76E-11	4.75E-11	3.83E-11	3.10E-11	2.91E-11	2.54E-11	1.99E-11
Ethylbenzene	8.76E-11	8.98E-11	8.89E-11	8.89E-11	8.89E-11	8.89E-11	8.89E-11
Formaldehyde	1.28E-06	1.30E-06	1.30E-06	1.30E-06	1.30E-06	1.30E-06	1.30E-06
Hydrogen chlorine, HCl	4.14E-02	3.45E-02	2.76E-02	2.21E-02	2.07E-02	1.79E-02	1.38E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	3.56E-02	5.07E-02
Lead	9.19E-07	9.21E-07	9.01E-07	9.20E-07	9.25E-07	9.35E-07	9.49E-07
Manganese	1.53E-05	1.53E-05	1.49E-05	1.49E-05	1.49E-05	1.49E-05	1.49E-05
Mercury, Hg	3.44E-05	2.87E-05	2.29E-05	1.84E-05	1.72E-05	1.49E-05	1.15E-05
Metals, not specified	...	...	...	...	...	8.65E-06	1.23E-05
Methane, CH_4	2.18E-02	1.83E-02	1.48E-02	1.20E-02	1.13E-02	1.00E-02	8.04E-03
Methylene chloride	4.93E-07	4.96E-07	4.96E-07	4.96E-07	4.96E-07	4.96E-07	4.96E-07
Naphthalene	2.82E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08	2.89E-08
Nickel	4.41E-06	4.47E-06	4.40E-06	4.48E-06	4.50E-06	4.54E-06	4.61E-06
Nitric oxide, NO (unspecified)	4.41E-04	4.29E-04	4.09E-04	4.09E-04	4.09E-04	4.09E-04	4.09E-04
Nitrogen oxides, NO_X	1.39E+00	1.18E+00	9.59E-01	7.91E-01	7.48E-01	6.68E-01	5.44E-01
Non-methane organic gases, NMOG	3.53E-06	3.53E-06	3.53E-06	3.53E-06	3.53E-06	3.53E-06	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	6.02E-12	6.17E-12	6.11E-12	6.11E-12	6.11E-12	6.11E-12	6.11E-12
Particulates, PM-2.5	8.05E-05	7.20E-05	6.20E-05	5.52E-05	5.35E-05	5.00E-05	4.50E-05
Particulates, PM-10	9.69E-01	9.29E-01	8.71E-01	8.23E-01	8.11E-01	7.87E-01	7.51E-01
Particulates, total	1.99E+00	1.74E+00	1.48E+00	1.27E+00	1.22E+00	1.13E+00	9.87E-01
Perchloroethylene	8.15E-09	8.20E-09	8.19E-09	8.19E-09	8.19E-09	8.19E-09	8.19E-09
Phenolic compounds	3.71E-07	3.74E-07	3.73E-07	3.73E-07	3.73E-07	3.73E-07	3.73E-07
Phosphorus	7.48E-06	7.49E-06	7.31E-06	7.44E-06	7.47E-06	7.54E-06	7.64E-06
Propylene oxide	7.94E-11	8.14E-11	8.06E-11	8.06E-11	8.06E-11	8.06E-11	8.06E-11
Radionuclides (kBq)	4.46E-02	4.48E-02	4.48E-02	4.48E-02	4.48E-02	4.48E-02	4.48E-02
Selenium	2.50E-07	2.51E-07	2.49E-07	2.52E-07	2.53E-07	2.54E-07	2.56E-07
Sulfur dioxide, SO_2	7.29E-01	6.07E-01	4.86E-01	3.89E-01	3.64E-01	3.46E-01	2.87E-01
Sulfur oxides, SO_X	5.88E-03	5.81E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03	5.62E-03
Toluene	3.56E-10	3.65E-10	3.61E-10	3.61E-10	3.61E-10	3.61E-10	3.61E-10
Total hydrocarbon, THC	3.43E-06	3.43E-06	3.43E-06	3.43E-06	3.43E-06	3.43E-06	3.43E-06
Volatile organic compounds, VOC	3.49E-02	3.04E-02	2.57E-02	2.21E-02	2.13E-02	1.98E-02	1.72E-02
Xylenes	1.75E-10	1.80E-10	1.78E-10	1.78E-10	1.78E-10	1.78E-10	1.78E-10
Zinc	4.88E-08	4.88E-08	4.88E-08	4.88E-08	4.88E-08	4.88E-08	4.88E-08
Emission to land							
Cement kiln dust, CKD	2.18E+01	1.82E+01	1.46E+01	1.17E+01	1.09E+01	9.45E+00	7.28E+00
Slag reject	...	...	...	...	...	1.21E-01	1.73E-01
Other solid waste	4.13E+01	4.13E+01	4.13E+01	4.13E+01	4.13E+01	4.13E+01	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

CONCRETE MASONRY UNITS

Concrete Masonry Plant Operations

The concrete plant system boundary was presented in Figure 1. Concrete masonry plant operations are similar to those of a ready mix plant with the addition of molding and curing stages prior to shipment of the product. Concrete masonry plants (commonly called concrete block plants) usually produce a variety of units for different applications; however, the standard 200×200×400-mm (8×8×16-in.) concrete masonry unit (CMU) is the dominant product. CMUs are produced by placing no-slump concrete in molds. After removal from the molds, the blocks are subjected to accelerated curing. The curing temperatures from plant to plant vary from ambient to about 90°C (190°F). Curing energy depends on (1) kiln design and insulation, (2) curing process, whether continuous or batch; (3) climate; (4) season, whether summer or winter; and (5) curing temperature. As a general practice, concrete masonry is molded and cured in a twenty-four-hour cycle at a temperature and humidity that results in one-day compressive strength that allows the blocks to be stacked and transported to the storage yard. Strength gain at ambient temperature is relatively slow and generally the block must be yard stored for about seven days before shipping. The volume of the cores in a CMU and the volume of air voids in the concrete matrix vary, but on average one cubic yard of concrete will yield approximately 100 CMUs.

Data on process inputs and water use are from *Confidential Life Cycle Inventory Survey of Concrete Masonry Plant* (Marceau, VanGeem, and Ranchero 2006b). This survey was distributed to a sample of member-plants of the National Concrete Masonry Association. The sample was chosen so that the plants in the sample are representative of climates of the conterminous United States and plant size in terms of production of CMUs. The sample consists of 13 plants, and unless stated otherwise, the entire sample was used to calculate results. The surveys were completed with the understanding that plant-specific operating data would be kept confidential. A blank questionnaire is included in Appendix C. The raw data were used to calculate inputs and emissions on a production-weighted basis per 100 CMUs.

Energy. The types and amounts of fuel used at concrete masonry plants vary from plant-to-plant. Plants reported using gasoline in mowers and sweepers; middle distillates in plant-only vehicles, loaders, forklifts; and natural gas in kilns and boilers (for steam and vapor curing) and in boilers for building heat. However, most of the fuel used was diesel oil in light trucks (24.4% of the energy used at the plant), natural gas in industrial boilers for steam and vapor curing (62.2%), and electricity throughout the plant (13.3%). A summary of the data is presented in Table 16.

Table 16. Plant Energy Used to Produce Concrete Masonry

Fuel and electricity	Where it's used	Input/100 CMU		
		Amount	Btu	kJ
Nos. 1, 2*** & 4 diesel fuel, gallon	Light trucks: fork-lift, loaders, etc.	0.414	57,470	79,310
Natural gas, cu ft	Kiln and industrial boiler (for steam and vapor)	142	146,300	201,890
Electricity, kWh	Throughout plant	3.15	31,360	43,270
Total	…	…	**235,130**	**324,470**

Source: Marceau, VanGeem, and Ranchero (2006b).

Water. Concrete masonry plants do not have the truck wash-off and wash-out requirements that ready mix plants have. However, water (as steam or vapor) is used to cure the product. The average water consumption (not including batch water) is 89.7 L (23.7 gal) per 100 CMU (based on responses from 8 plants). The average amount of water disposed is 4.5 L (1.2 gal) per 100 CMU (based on responses form 8 plants). Water not discarded is lost as steam. Some plants did not measure water use or discharge, hence the low response rate.

Solid Waste. The average amount of solid waste is 51 kg (113 lb) of concrete per 100 CMU (based on responses from 8 plants). It is assumed that materials such as lubricating oil and solvents used in maintaining plant and mobile equipment are used in insignificant quantities compared to primary fuels and materials.

Representative Mixes

Table 17 presents two mix designs. The first is the CMU mix (shown on a basis of 131 and 100 CMUs in the SI table). The second is Ready Mix 3, the 20-MPa (3,000-psi) mix presented earlier in Table 13 and presented again here for comparison purposes. As noted earlier, one cubic yard of concrete will yield approximately 100 CMUs; thus one cubic meter will yield approximately 131 CMUs. However, in this LCI the functional unit is 100 CMUs, and all concrete masonry LCI results are presented on a basis of 100 CMUs. The yield per cubic meter is only shown to allow the reader to compare Ready Mix 3 and the CMU mix on an equal basis.

Table 17a. Concrete Mix Designs and Properties (SI Units)

Concrete mix description	CMU Mix 131 CMUs	CMU Mix 100 CMUs*	Ready Mix 3
28-day compressive strength, MPa	Unspecified	Unspecified	20
Unit weight, kg/m^3	2,380	2,380	2,320
Raw material, kg/m^3 concrete			
Cement	208	159	223
Water	142	109	141
Coarse aggregate	619	473	1,127
Fine aggregate	1,414	1,081	831
Total*	**2,383**	**1,822**	**2,321**

* The functional unit is 100 CMUs.

** Data may not add to total shown due to conversion from U.S. Customary Units and independent rounding.

Table 17b. Concrete Mix Designs and Properties (U.S. Customary Units)

Concrete mix description	CMU Mix*	Ready Mix 3
28-day compressive strength, psi	Unspecified	3,000
Unit weight, lb/ft^3	149	145
Raw material, lb/yd^3 concrete		
Cement	350	376
Water	240	237
Coarse aggregate	1,043	1,900
Fine aggregate	2,384	1,400
Total	**4,017**	**3,913**

*Yield is approximately 100 CMUs.

Concrete Masonry LCI Results

The LCI results are presented in the tables of Appendix F. A summary of the results is also presented in Table 18. The LCI results are presented as inputs and emissions per 100 CMU. The headings in Appendix F show (in order, from left to right) the names of the inputs and outputs and the units of measurement if different from kilograms or pounds; the upstream profiles for portland cement, slag cement, natural and manufactured aggregates; plant operations; gate-to-gate transportation; and the total.

Concrete Masonry LCI Analysis

Energy. The embodied energy in 100 CMUs, including curing energy, is 1.01 GJ (0.962 MBtu) compared to 0.87 GJ (0.824 MBtu) for an equivalent amount of material from the 20-MPa (3,000-psi) mix without SCMs (Ready Mix 3). The additional energy per 100 CMUs is due to curing. Energy consumption of the CMUs varies primarily with cement content. Energy to produce cement in 100 CMUs, 0.691 GJ (0.655 MBtu/yd^3), dominates energy from other steps of the block production process. Energy required to produce aggregate is relatively small: 0.038 GJ (0.036 MBtu/yd^3). Transportation energy is 0.059 GJ (0.056 MBtu) and energy used in the masonry plant is 0.227 GJ (0.215 MBtu).

Emissions to air. Similar to ready mixed concrete, the amounts of CO_2 and other combustion gases associated with concrete masonry are primarily a function of the cement content in the mix design. Aggregate production and cement manufacture are similar in their contributions to particulate emissions associated with concrete block production. Total particulate matter emissions are 0.171 kg (0.377 lb) from aggregate production and 0.44 kg (0.969 lb) from cement manufacturing.

Sensitivity Analysis

The system boundary for concrete masonry is essentially the same as the boundary for ready mixed concrete but with the addition of a curing stage. The CMU LCI results have similar sensitivities as ready mixed concrete plus sensitivity to data relevant to the curing step. The cement content of the CMU accounts for 91% of the CO_2 content embodied in the CMU.

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Table 18a. Summary of Concrete Masonry LCI Results (SI Units)*

Inputs and outputs per 100 CMU (kg unless otherwise specified)	100 CMUs	Ready Mix 3**
Raw material		
Limestone	1.85E+02	2.60E+02
Cement rock, marl	3.16E+01	4.45E+01
Shale	7.99E+00	1.12E+01
Clay	9.75E+00	1.37E+01
Bottom ash	1.58E+00	2.22E+00
Fly ash	2.10E+00	2.95E+00
Foundry sand	6.32E-01	8.88E-01
Sand	6.37E+00	8.95E+00
Iron, iron ore	2.18E+00	3.06E+00
Blast furnace slag	3.27E+00	4.60E+00
Slate	1.62E-01	2.28E-01
Other raw material	4.48E+00	6.30E+00
Gypsum, anhydrite	7.70E+00	1.08E+01
Water, process (includes batch water)	1.22E+02	1.59E+02
Water, non-process	1.34E+02	1.81E+02
Coarse aggregate, natural	3.50E+02	8.34E+02
Coarse aggregate, manufactured	1.23E+02	2.93E+02
Fine aggregate, natural	1.08E+03	8.31E+02
Fine aggregate, manufactured	...	...
Silica fume	...	...
Slag cement, i.e., GGBFS	...	...
Ancillary material		
Explosives	4.68E-02	6.58E-02
Refractory	9.96E-02	1.40E-01
Grinding media	2.22E-02	3.12E-02
Grinding aids	5.72E-02	8.03E-02
Filter bags	3.06E-03	4.30E-03
Oil & grease	2.06E-02	2.90E-02
Oil (L)	...	...
Grease (L)	...	...
Solvent (L)	...	...
Cement bags	1.08E-01	1.52E-01
Chains	3.04E-03	4.27E-03
Fuel and electricity		
Coal (metric ton)	1.60E-02	2.25E-02
Gasoline (L)	4.96E-01	5.81E-01
Liquefied petroleum gas (L)	1.57E+00	6.27E-03
Middle distillates (L)	1.56E+00	2.50E+00
Natural gas (thousand m^3)	4.73E-03	1.27E-03
Petroleum coke (metric ton)	3.57E-03	5.01E-03
Residual oil (L)	1.82E-01	2.27E-01
Wastes (GJ)	6.42E-02	9.02E-02
Electricity (kWh)	3.57E+01	4.09E+01
Energy equivalent, GJ		
Coal	3.91E-01	5.50E-01
Gasoline	1.73E-02	2.02E-02
Liquefied petroleum gas	3.98E-02	1.59E-04
Middle distillates	6.02E-02	9.66E-02
Natural gas	1.81E-01	4.84E-02
Petroleum coke	1.25E-01	1.76E-01
Residual oil	7.61E-03	9.45E-03
Wastes	6.42E-02	9.02E-02
Electricity	1.29E-01	1.47E-01
Subtotal	1.01E+00	1.14E+00
Emission to water		
Aluminum	1.37E-04	1.92E-04
Ammonia, ammonium	1.51E-04	2.11E-04
Chemical oxygen demand, COD	...	...
Chlorides	1.15E-01	1.62E-01
Copper	3.55E-09	2.00E-08
Dissolved organic compounds	2.19E-03	3.07E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

**The basis of this mix is m^3, which yields approximately 131 CMUs.

Table 18a. Summary of Concrete Masonry LCI Results (SI Units) (Continued)*

Inputs and outputs per 100 CMU (kg unless otherwise specified)	100 CMUs	Ready Mix 3**
Iron	3.55E-09	2.00E-08
Nitric, nitrites	9.36E-04	1.32E-03
Oil and grease	1.19E-03	1.68E-03
pH	8.45	8.45
Phenolics	3.50E-06	4.92E-06
Phosphorus	8.75E-07	1.23E-06
Sulfates	9.77E-02	1.37E-01
Sulfides	1.05E-05	1.48E-05
Suspended solids	3.72E-02	5.23E-02
Water (that leaves site) (L)	5.87E+02	8.53E+02
Zinc	5.25E-06	7.38E-06
Emission to air		
1,3 Butadiene	5.12E-13	7.09E-13
Acetaldehyde	4.76E-11	6.59E-11
Acrolein	7.62E-12	1.05E-11
Ammonia, NH_3	7.55E-04	1.06E-03
Arsenic	2.87E-07	3.79E-07
Benzene	1.38E-07	1.26E-08
Beryllium	2.34E-08	5.05E-08
Cadmium	7.75E-08	3.50E-08
Carbon dioxide, CO_2	1.57E+02	2.11E+02
Carbon dioxide, CO_2, calcination	8.75E+01	1.23E+01
Carbon dioxide, CO_2, combustion	7.00E+01	8.82E+01
Carbon monoxide, CO	2.02E-01	2.72E-01
Chromium	1.06E-06	1.26E-06
Cobalt	6.51E-08	7.64E-08
Copper	...	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.57E-11	2.27E-11
Ethylbenzene	3.81E-11	5.27E-11
Formaldehyde	5.17E-06	7.69E-07
Hydrogen chlorine, HCl	1.16E-02	1.64E-02
Hydrogen sulfide, H_2S	...	...
Lead	3.99E-07	5.35E-07
Manganese	6.95E-06	8.86E-06
Mercury, Hg	9.68E-06	1.36E-05
Metals, not specified	...	...
Methane, CH_4	6.42E-03	8.76E-03
Methylene chloride	4.78E-08	2.94E-07
Naphthalene	5.06E-08	1.71E-08
Nickel	2.16E-06	2.61E-06
Nitric oxide, NO (unspecified)	3.24E-04	2.43E-04
Nitrogen oxides, NO_X	4.14E-01	5.69E-01
Non-methane organic gases, NMOG	1.89E-05	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	2.62E-12	3.63E-12
Particulates, PM-2.5	2.14E-05	3.68E-05
Particulates, PM-10	4.09E-01	5.17E-01
Particulates, total	6.47E-01	8.77E-01
Perchloroethylene	6.94E-10	4.86E-09
Phenolic compounds	3.60E-08	2.22E-07
Phosphorus	3.41E-06	4.33E-06
Propylene oxide	3.45E-11	4.78E-11
Radionuclides (kBq)	1.00E-02	2.66E-02
Selenium	3.25E-08	1.48E-07
Sulfur dioxide, SO_2	2.05E-01	2.88E-01
Sulfur oxides, SO_X	2.50E-03	3.33E-03
Toluene	1.55E-10	2.14E-10
Total hydrocarbon, THC	1.84E-05	2.04E-06
Volatile organic compounds, VOC	1.16E-02	1.52E-02
Xylenes	7.62E-11	1.05E-10
Zinc	...	2.89E-08
Emission to land		
Cement kiln dust, CKD	6.15E+00	8.64E+00
Slag reject	...	...
Other solid waste	5.11E+01	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

**The basis of this mix is m^3, which yields approximately 131 CMUs.

Table 18b. Summary of Concrete Masonry LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	100 CMUs	Ready Mix 3
Raw material		
Limestone	4.07E+02	4.38E+02
Cement rock, marl	6.98E+01	7.49E+01
Shale	1.76E+01	1.89E+01
Clay	2.15E+01	2.31E+01
Bottom ash	3.48E+00	3.74E+00
Fly ash	4.62E+00	4.97E+00
Foundry sand	1.39E+00	1.50E+00
Sand	1.40E+01	1.51E+01
Iron, iron ore	4.80E+00	5.15E+00
Blast furnace slag	7.22E+00	7.75E+00
Slate	3.58E-01	3.85E-01
Other raw material	9.88E+00	1.06E+01
Gypsum, anhydrite	1.70E+01	1.82E+01
Water, process (includes batch water)	2.68E+02	2.67E+02
Water, non-process	2.95E+02	3.05E+02
Coarse aggregate, natural	7.72E+02	1.41E+03
Coarse aggregate, manufactured	2.71E+02	4.94E+02
Fine aggregate, natural	2.38E+03	1.40E+03
Fine aggregate, manufactured	...	...
Silica fume	...	...
Slag cement, i.e., GGBFS	...	...
Ancillary material		
Explosives	1.03E-01	1.11E-01
Refractory	2.19E-01	2.36E-01
Grinding media	4.90E-02	5.26E-02
Grinding aids	1.26E-01	1.35E-01
Filter bags	6.74E-03	7.24E-03
Oil & grease	4.55E-02	4.89E-02
Oil (gallon)	...	...
Grease (gallon)	...	...
Solvent (gallon)	...	...
Cement bags	2.38E-01	2.56E-01
Chains	6.70E-03	7.20E-03
Fuel and electricity		
Coal (ton)	1.76E-02	1.90E-02
Gasoline (gallon)	1.31E-01	1.17E-01
Liquefied petroleum gas (gallon)	4.16E-01	1.27E-03
Middle distillates (gallon)	4.12E-01	5.04E-01
Natural gas (thousand cu ft)	1.67E-01	3.42E-02
Petroleum coke (ton)	3.93E-03	4.23E-03
Residual oil (gallon)	4.82E-02	4.58E-02
Wastes (MBtu)	6.08E-02	6.54E-02
Electricity (kWh)	3.57E+01	3.13E+01
Energy equivalent, MBtu		
Coal	3.71E-01	3.98E-01
Gasoline	1.64E-02	1.47E-02
Liquefied petroleum gas	3.77E-02	1.15E-04
Middle distillates	5.71E-02	7.00E-02
Natural gas	1.71E-01	3.51E-02
Petroleum coke	1.18E-01	1.27E-01
Residual oil	7.21E-03	6.85E-03
Wastes	6.08E-02	6.54E-02
Electricity	1.22E-01	1.07E-01
Subtotal	9.62E-01	8.24E-01
Emission to water		
Aluminum	3.01E-04	3.23E-04
Ammonia, ammonium	3.32E-04	3.56E-04
Chemical oxygen demand, COD	...	...
Chlorides	2.55E-01	2.74E-01
Copper	7.83E-09	3.37E-08
Dissolved organic compounds	4.82E-03	5.18E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234 × 10-2 which is equal to 0.01234. Three dots "…" mean zero.

Table 18b. Summary of Concrete Masonry LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	100 CMs	Ready Mix 3
Iron	7.83E-09	3.37E-08
Nitric, nitrites	2.06E-03	2.22E-03
Oil and grease	2.63E-03	2.83E-03
pH	8.45	8.45
Phenolics	7.72E-06	8.29E-06
Phosphorus	1.93E-06	2.07E-06
Sulfates	2.15E-01	2.31E-01
Sulfides	2.31E-05	2.49E-05
Suspended solids	8.20E-02	8.81E-02
Water (that leaves site) (gallon)	1.55E+02	1.72E+02
Zinc	1.16E-05	1.24E-05
Emission to air		
1,3 Butadiene	1.13E-12	1.19E-12
Acetaldehyde	1.05E-10	1.11E-10
Acrolein	1.68E-11	1.78E-11
Ammonia, NH_3	1.67E-03	1.79E-03
Arsenic	6.32E-07	6.38E-07
Benzene	3.04E-07	2.12E-08
Beryllium	5.15E-08	8.51E-08
Cadmium	1.71E-07	5.90E-08
Carbon dioxide, CO_2	3.47E+02	3.56E+02
Carbon dioxide, CO_2, calcination	1.93E+02	2.07E+02
Carbon dioxide, CO_2, combustion	1.54E+02	1.49E+02
Carbon monoxide, CO	4.46E-01	4.58E-01
Chromium	2.34E-06	2.13E-06
Cobalt	1.44E-07	1.29E-07
Copper	...	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	3.45E-11	3.83E-11
Ethylbenzene	8.40E-11	8.89E-11
Formaldehyde	1.14E-05	1.30E-06
Hydrogen chlorine, HCl	2.56E-02	2.76E-02
Hydrogen sulfide, H_2S	...	...
Lead	8.80E-07	9.01E-07
Manganese	1.53E-05	1.49E-05
Mercury, Hg	2.13E-05	2.29E-05
Metals, not specified	...	...
Methane, CH_4	1.42E-02	1.48E-02
Methylene chloride	1.05E-07	4.96E-07
Naphthalene	1.12E-07	2.89E-08
Nickel	4.76E-06	4.40E-06
Nitric oxide, NO (unspecified)	7.15E-04	4.09E-04
Nitrogen oxides, NO_X	9.13E-01	9.59E-01
Non-methane organic gases, NMOG	4.16E-05	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	5.77E-12	6.11E-12
Particulates, PM-2.5	4.71E-05	6.20E-05
Particulates, PM-10	9.01E-01	8.71E-01
Particulates, total	1.43E+00	1.48E+00
Perchloroethylene	1.53E-09	8.19E-09
Phenolic compounds	7.94E-08	3.73E-07
Phosphorus	7.51E-06	7.31E-06
Propylene oxide	7.61E-11	8.06E-11
Radionuclides (kBq)	2.20E-02	4.48E-02
Selenium	7.17E-08	2.49E-07
Sulfur dioxide, SO_2	4.52E-01	4.86E-01
Sulfur oxides, SO_X	5.52E-03	5.62E-03
Toluene	3.41E-10	3.61E-10
Total hydrocarbon, THC	4.05E-05	3.43E-06
Volatile organic compounds, VOC	2.56E-02	2.57E-02
Xylenes	1.68E-10	1.78E-10
Zinc	...	4.88E-08
Emission to land		
Cement kiln dust, CKD	1.36E+01	1.46E+01
Slag reject	...	...
Other solid waste	1.13E+02	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

PRECAST CONCRETE

Precast Concrete Plant Operations

The concrete plant system boundary was presented in Figure 1. Precast concrete plant operations are similar to those of a ready mix plant with the addition of forming and curing stages prior to shipment of the product. Precast operations generally offer economies of scale and a high level of quality control. Precast concrete components for walls, columns, floors, roofs, facades, and other applications are made by placing concrete into forms at the plant and curing. Production procedures vary between the different categories of precast concrete products. Architectural precast concrete is usually made with conventional reinforcement in custom-made individual forms. These forms can be made of wood, fiberglass, concrete, or steel. Wood or fiberglass forms can generally be used 40 to 50 times without major maintenance while concrete and steel forms have practically unlimited service lives. Form-release agents are applied to forms prior to placing the concrete to prevent the concrete from sticking to the forms when they are removed. The steps in the precast production process include: (1) concrete mixing; (2) conveying to the form in ready mix trucks, specially designed transporters with a dumping mechanism that places the concrete in the form, or concrete buckets carried by overhead cranes; (3) placing the concrete in the form; (4) consolidation by vibration, leveling, and surface finishing; (5) curing; and (6) form stripping.

Data on process inputs and water use are from *Confidential Life Cycle Inventory Survey of Precast Concrete Plant* (Marceau, VanGeem, and Ranchero 2006c). This survey was distributed to a sample of member-plants of the Precast/Prestressed Concrete Institute. The sample was chosen so that the plants in the sample are representative of climates of the conterminous United States and plant size in terms of production in cubic yards of precast concrete. The sample consists of 15 plants, and unless stated otherwise, the entire sample was used to calculate results. The surveys were completed with the understanding that plant-specific operating data would be kept confidential. A blank questionnaire is included in Appendix D. The raw data were used to calculate inputs and emissions on a production-weighted basis per unit volume of concrete.

Energy. The types and amounts of fuel used at precast concrete plants vary from plant-to-plant. Plants reported using gasoline in plant-only vehicles, forklifts welding machines, and saws; middle distillates in plant-only vehicles, forklifts, welding machines, saws, boilers (for steam curing), and portable heaters; natural gas in kilns and boilers (for steam curing and building heat); and liquefied petroleum gas in boilers (for steam curing and building heat), and various manufacturing equipment (like welding machines and forklifts). However, most of the energy used was gasoline in light trucks (4.0% of the energy used at the plant); middle distillates in light trucks (28.4%), and industrial boilers (1.1%); natural gas in industrial boilers for steam curing (36.3%) and building heat (6.4%); liquefied petroleum in industrial boilers for steam curing (6.4%) and light trucks (0.7%); and electricity throughout the plant (16.7%). A summary of the data is presented in Table 19.

Table 19. Plant Energy Used to Produce Precast Concrete

		Input/unit volume concrete		
Fuel and electricity	**Where it's used**	**Amount**	**Btu/yd^3**	**kJ/m^3**
Gasoline, gallon	Light trucks: fork-lift, pick-up, etc.	0.188	23,530	32,470
Nos. 1, 2*** & 4 diesel fuel, gallon	Light trucks: fork-lift, pick-up, etc.	0.484	67,070	92,550
Nos. 1, 2 & 4 fuel oil, gallon	Light trucks: fork-lift, pick-up, etc.	0.730	101,300	139,790
	Industrial boiler for steam curing	0.0466	6,470	8,920
Kerosene, gallon	Portable building heater	0.00391	540	750
Natural gas, cu ft	Industrial boiler for steam curing	210	215,470	297,340
	Building heat	37	38,020	52,470
Liquefied petroleum gas, gallon	Industrial boiler for steam curing	0.416	37,760	52,100
	Various manufacturing equipment: welders, fork-lift, etc.	0.0462	4,200	5,790
Electricity, kWh	Throughout plant	29.1	99,360	137,110
Total	…	…	**593,720**	**819,290**

Source: Marceau, VanGeem, and Ranchero (2006c).

Water. The average water consumption (not including batch water) is 844 L/m^3 (170.5 gallon/yd^3) of precast concrete (based on responses from 14 plants). The average amount of water recycled back into the process or into other products is 24 L/m^3 (4.8 gallon/yd^3) (based on responses from 14 plants). The average amount of water disposed of is 499 L/m^3 (100.8 gallon/yd^3) (based on responses from 11 plants). The difference between the amount of water consumed and discarded not accounted for in recycling is due to water (as steam or vapor) used for moist curing and vapor lost through evaporation.

Solid Waste. The average amount of solid waste is 76 kg/m^3 (128 lb/yd^3) of concrete (based on responses from 14 plants).

Representative Mixes

Table 20 presents three typical precast concrete mix designs. They are Precast Mix 1, which is 50 MPa (7,500 psi); Precast Mix 2, which is 70 MPa (10,000 psi), and Precast Mix 3, which is typical of architectural precast concrete. The table also shows Ready Mix 3 for comparison purposes. Note that silica fume is used in the higher strength precast mix.

Table 20a. Precast Concrete Mix Designs and Properties (SI Units)

Concrete mix description	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
28-day compressive strength, MPa	50	70	Unspecified	20
Silica fume	0	0	0	0
Unit weight, kg/m^3	2,290	2,380	2,320	2,320
Raw material, kg/m^3 concrete				
Cement	504	445	386	223
Silica fume	0	56	0	0
Water	178	136	154	141
Coarse aggregate	1,050	1,112	1,068	1,127
Fine aggregate	555	611	742	831
Total*	**2,287**	**2,361**	**2,349**	**2,321**

*Data may not add to total shown due to conversion from U.S. Customary Units and independent rounding.

Table 20b. Precast Concrete Mix Designs and Properties (U.S. Customary Units)

Concrete mix description	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
28-day compressive strength, psi	7,500	10,000	Unspecified	3,000
Silica fume	0	0	0	0
Unit weight, lb/ft^3	143	147	147	145
Raw material, lb/ft^3 concrete				
Cement	850	750	650	376
Silica fume	0	95	0	0
Water	300	230	260	237
Coarse aggregate	1,770	1,875	1,800	1,900
Fine aggregate	935	1,030	1,250	1,400
Total	**3,855**	**3,980**	**3,960**	**3,913**

Precast Concrete LCI Results

The LCI results are presented individually for each mix in the tables of Appendix G. The results are summarized in Table 20. The headings of Appendix G show (in order, from left to right) the names of the inputs and outputs and the units of measurement if different from kilograms or pounds; the upstream profiles for portland cement, slag cement, natural and manufactured aggregates; plant operations; gate-to-gate transportation; and the total.

Precast Concrete LCI Analysis

Energy. Energy consumption varies primarily with cement content of the mix ranging from 2.63 GJ/m^3 (1.91 MBtu/yd^3) for the architectural precast mix (Precast Mix 3), which contains 386 kg (850 lb) of cement, to 3.15 GJ/m^3 (2.29 MBtu/yd^3) for the 50-MPa (7,500-psi) mix (Precast Mix 1), which contains 504 kg (850 lb) of cement. Energy required to produce aggregate is approximately 0.04 GJ/m^3 (0.03 MBtu/yd^3). Transportation energy is approximately

0.10 GJ/m^3 (0.07 MBtu/yd^3), and energy used in the precast plant is approximately 0.82 GJ/m^3 (0.59 MBtu/yd^3).

Emissions to air. The amounts of CO_2 and other emissions of combustion gases associated with precast concrete production are primarily a function of the cement content in the mix designs. Total CO_2 emissions range from 382 kg/m^3 (645 lb/yd^3) for the architectural precast mix (Precast Mix 3) to 490 kg/m^3 (826 lb/yd^3) for 50-MPa (7,500-psi) mix (Precast Mix 1). SO_2 ranges from 0.50 to 0.65 kg/m^3 (0.84 to 1.10 lb/yd^3) for the same mixes, while NO_x ranges from 0.96 to 1.23 kg/m^3 (1.62 to 2.08 lb/yd^3). Total particulate matter emissions range from 1.31 to 1.62 kg/m^3 (2.21 to 2.72 lb/yd^3).

Sensitivity

The system boundary for precast concrete is essentially the same as the boundary for ready mixed concrete with the addition of a curing stage. The precast concrete LCI results have similar sensitivities as ready mixed concrete plus sensitivity to data relevant to the curing step. The cement content of the precast concrete accounts for 92% of the CO_2 embodied in the precast concrete.

Table 21a. Summary of Precast Concrete LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
Raw material				
Limestone	5.87E+02	5.18E+02	4.49E+02	2.60E+02
Cement rock, marl	1.01E+02	8.87E+01	7.69E+01	4.45E+01
Shale	2.54E+01	2.24E+01	1.94E+01	1.12E+01
Clay	3.10E+01	2.73E+01	2.37E+01	1.37E+01
Bottom ash	5.01E+00	4.42E+00	3.83E+00	2.22E+00
Fly ash	6.66E+00	5.88E+00	5.10E+00	2.95E+00
Foundry sand	2.01E+00	1.77E+00	1.54E+00	8.88E-01
Sand	2.02E+01	1.79E+01	1.55E+01	8.95E+00
Iron, iron ore	6.91E+00	6.10E+00	5.29E+00	3.06E+00
Blast furnace slag	1.04E+01	9.17E+00	7.95E+00	4.60E+00
Slate	5.16E-01	4.55E-01	3.94E-01	2.28E-01
Other raw material	1.42E+01	1.26E+01	1.09E+01	6.30E+00
Gypsum, anhydrite	2.45E+01	2.16E+01	1.87E+01	1.08E+01
Water, process (includes batch water)	2.19E+02	1.72E+02	1.85E+02	1.59E+02
Water, non-process	4.92E+02	4.46E+02	4.00E+02	1.81E+02
Coarse aggregate, natural	7.77E+02	8.23E+02	7.90E+02	8.34E+02
Coarse aggregate, manufactured	2.73E+02	2.89E+02	2.78E+02	2.93E+02
Fine aggregate, natural	5.55E+02	6.11E+02	7.42E+02	8.31E+02
Fine aggregate, manufactured	...	...	...	...
Silica fume	...	5.64E+01	...	...
Slag cement, i.e., GGBFS	...	...	...	...
Ancillary material				
Explosives	1.49E-01	1.31E-01	1.14E-01	6.58E-02
Refractory	3.16E-01	2.79E-01	2.42E-01	1.40E-01
Grinding media	7.06E-02	6.23E-02	5.40E-02	3.12E-02
Grinding aids	1.82E-01	1.60E-01	1.39E-01	8.03E-02
Filter bags	9.71E-03	8.57E-03	7.43E-03	4.30E-03
Oil & grease	6.56E-02	5.78E-02	5.01E-02	2.90E-02
Oil (L)	...	...	...	...
Grease (L)	...	...	...	...
Solvent (L)	...	...	...	...
Cement bags	3.43E-01	3.03E-01	2.62E-01	1.52E-01
Chains	9.66E-03	8.52E-03	7.39E-03	4.27E-03
Fuel and electricity				
Coal (metric ton)	5.09E-02	4.49E-02	3.89E-02	2.25E-02
Gasoline (L)	1.41E+00	1.44E+00	1.47E+00	5.81E-01
Liquefied petroleum gas (L)	2.30E+00	2.30E+00	2.30E+00	6.27E-03
Middle distillates (L)	9.23E+00	9.23E+00	8.88E+00	2.50E+00
Natural gas (thousand m^3)	1.12E-02	1.10E-02	1.07E-02	1.27E-03
Petroleum coke (metric ton)	1.13E-02	1.00E-02	8.67E-03	5.01E-03
Residual oil (L)	2.24E-01	2.31E-01	2.31E-01	2.27E-01
Wastes (GJ)	2.04E-01	1.80E-01	1.56E-01	9.02E-02
Electricity (kWh)	1.13E+02	1.05E+02	9.73E+01	4.09E+01
Energy equivalent, GJ				
Coal	1.24E+00	1.10E+00	9.50E-01	5.50E-01
Gasoline	4.92E-02	5.03E-02	5.14E-02	2.02E-02
Liquefied petroleum gas	5.82E-02	5.82E-02	5.82E-02	1.59E-04
Middle distillates	3.57E-01	3.57E-01	3.43E-01	9.66E-02
Natural gas	4.28E-01	4.20E-01	4.11E-01	4.84E-02
Petroleum coke	3.97E-01	3.50E-01	3.04E-01	1.76E-01
Residual oil	9.36E-03	9.62E-03	9.66E-03	9.45E-03
Wastes	2.04E-01	1.80E-01	1.56E-01	9.02E-02
Electricity	4.08E-01	3.80E-01	3.50E-01	1.47E-01
Subtotal	3.15E+00	2.90E+00	2.63E+00	1.14E+00
Emission to water				
Aluminum	4.34E-04	3.83E-04	3.32E-04	1.92E-04
Ammonia, ammonium	4.78E-04	4.22E-04	3.66E-04	2.11E-04
Chemical oxygen demand, COD	...	...	...	...
Chlorides	3.67E-01	3.24E-01	2.81E-01	1.62E-01
Copper	1.19E-08	1.22E-08	1.24E-08	2.00E-08
Dissolved organic compounds	6.95E-03	6.13E-03	5.31E-03	3.07E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table 21a. Summary of Precast Concrete LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
Iron	1.19E-08	1.22E-08	1.24E-08	2.00E-08
Nitric, nitrites	2.97E-03	2.62E-03	2.27E-03	1.32E-03
Oil and grease	3.79E-03	3.35E-03	2.90E-03	1.68E-03
pH	8.45	8.45	8.45	8.45
Phenolics	1.11E-05	9.81E-06	8.50E-06	4.92E-06
Phosphorus	2.78E-06	2.45E-06	2.13E-06	1.23E-06
Sulfates	3.10E-01	2.74E-01	2.37E-01	1.37E-01
Sulfides	3.34E-05	2.94E-05	2.55E-05	1.48E-05
Suspended solids	1.18E-01	1.04E-01	9.04E-02	5.23E-02
Water (that leaves site) (L)	2.35E+03	2.13E+03	1.91E+03	8.53E+02
Zinc	1.67E-05	1.47E-05	1.28E-05	7.38E-06
Emission to air				
1,3 Butadiene	5.96E-13	6.38E-13	6.58E-13	7.09E-13
Acetaldehyde	5.55E-11	5.94E-11	6.12E-11	6.59E-11
Acrolein	8.87E-12	9.50E-12	9.80E-12	1.05E-11
Ammonia, NH_3	2.75E-03	2.46E-03	2.18E-03	1.06E-03
Arsenic	3.81E-07	4.28E-07	3.96E-07	3.79E-07
Benzene	3.10E-07	3.10E-07	3.10E-07	1.26E-08
Beryllium	4.21E-08	4.61E-08	4.32E-08	5.05E-08
Cadmium	1.81E-07	2.37E-07	1.81E-07	3.50E-08
Carbon dioxide, CO_2	4.90E+02	4.37E+02	3.82E+02	2.11E+02
Carbon dioxide, CO_2, calcination	2.78E+02	2.45E+02	2.12E+02	1.23E+01
Carbon dioxide, CO_2, combustion	2.12E+02	1.92E+02	1.70E+02	8.82E+01
Carbon monoxide, CO	6.61E-01	5.99E-01	5.36E-01	2.72E-01
Chromium	1.41E-06	1.51E-06	1.46E-06	1.26E-06
Cobalt	7.48E-08	7.93E-08	8.25E-08	7.64E-08
Copper	2.49E-08	2.49E-08	2.49E-08	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	4.99E-11	4.41E-11	3.83E-11	2.27E-11
Ethylbenzene	4.44E-11	4.75E-11	4.90E-11	5.27E-11
Formaldehyde	1.13E-05	1.14E-05	1.14E-05	7.69E-07
Hydrogen chlorine, HCl	3.69E-02	3.26E-02	2.83E-02	1.64E-02
Hydrogen sulfide, H_2S	...	...	...	...
Lead	5.61E-07	6.01E-07	5.80E-07	5.35E-07
Manganese	8.61E-06	9.09E-06	8.96E-06	8.86E-06
Mercury, Hg	3.08E-05	2.71E-05	2.35E-05	1.36E-05
Metals, not specified	...	...	...	...
Methane, CH_4	1.97E-02	1.75E-02	1.53E-02	8.76E-03
Methylene chloride	1.84E-07	1.88E-07	1.90E-07	2.94E-07
Naphthalene	1.01E-07	1.02E-07	1.03E-07	1.71E-08
Nickel	2.66E-06	2.87E-06	2.83E-06	2.61E-06
Nitric oxide, NO (unspecified)	8.57E-04	8.67E-04	8.50E-04	2.43E-04
Nitrogen oxides, NO_X	1.23E+00	1.10E+00	9.64E-01	5.69E-01
Non-methane organic gases, NMOG	6.51E-03	6.51E-03	6.51E-03	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	3.05E-12	3.27E-12	3.37E-12	3.63E-12
Particulates, PM-2.5	6.12E-05	5.67E-05	5.07E-05	3.68E-05
Particulates, PM-10	6.30E-01	6.14E-01	5.94E-01	5.17E-01
Particulates, total	1.62E+00	1.47E+00	1.31E+00	8.77E-01
Perchloroethylene	3.01E-09	3.07E-09	3.10E-09	4.86E-09
Phenolic compounds	1.39E-07	1.41E-07	1.43E-07	2.22E-07
Phosphorus	4.19E-06	4.52E-06	4.36E-06	4.33E-06
Propylene oxide	4.02E-11	4.31E-11	4.44E-11	4.78E-11
Radionuclides (kBq)	3.04E-02	3.07E-02	3.09E-02	2.66E-02
Selenium	1.03E-07	1.07E-07	1.05E-07	1.48E-07
Sulfur dioxide, SO_2	6.52E-01	5.75E-01	4.98E-01	2.88E-01
Sulfur oxides, SO_X	3.46E-03	3.61E-03	3.48E-03	3.33E-03
Toluene	1.80E-10	1.93E-10	1.99E-10	2.14E-10
Total hydrocarbon, THC	6.65E-03	6.65E-03	6.65E-03	2.04E-06
Volatile organic compounds, VOC	3.59E-02	3.34E-02	3.04E-02	1.52E-02
Xylenes	8.87E-11	9.50E-11	9.80E-11	1.05E-10
Zinc	1.66E-08	1.66E-08	1.66E-08	2.89E-08
Emission to land				
Cement kiln dust, CKD	1.95E+01	1.72E+01	1.49E+01	8.64E+00
Slag reject	...	...	...	...
Other solid waste	7.60E+01	7.60E+01	7.60E+01	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table 21b. Summary of Precast Concrete LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
Raw material				
Limestone	9.89E+02	8.73E+02	7.56E+02	4.38E+02
Cement rock, marl	1.69E+02	1.49E+02	1.30E+02	7.49E+01
Shale	4.28E+01	3.77E+01	3.27E+01	1.89E+01
Clay	5.22E+01	4.60E+01	3.99E+01	2.31E+01
Bottom ash	8.45E+00	7.45E+00	6.46E+00	3.74E+00
Fly ash	1.12E+01	9.91E+00	8.59E+00	4.97E+00
Foundry sand	3.38E+00	2.99E+00	2.59E+00	1.50E+00
Sand	3.41E+01	3.01E+01	2.61E+01	1.51E+01
Iron, iron ore	1.17E+01	1.03E+01	8.91E+00	5.15E+00
Blast furnace slag	1.75E+01	1.55E+01	1.34E+01	7.75E+00
Slate	8.69E-01	7.67E-01	6.65E-01	3.85E-01
Other raw material	2.40E+01	2.12E+01	1.83E+01	1.06E+01
Gypsum, anhydrite	4.13E+01	3.64E+01	3.15E+01	1.82E+01
Water, process (includes batch water)	3.68E+02	2.90E+02	3.12E+02	2.67E+02
Water, non-process	8.30E+02	7.52E+02	6.75E+02	3.05E+02
Coarse aggregate, natural	1.31E+03	1.39E+03	1.33E+03	1.41E+03
Coarse aggregate, manufactured	4.60E+02	4.88E+02	4.68E+02	4.94E+02
Fine aggregate, natural	9.35E+02	1.03E+03	1.25E+03	1.40E+03
Fine aggregate, manufactured	...	...	...	...
Silica fume	...	9.50E+01	...	...
Slag cement, i.e., GGBFS	...	...	...	...
Ancillary material				
Explosives	2.51E-01	2.21E-01	1.92E-01	1.11E-01
Refractory	5.33E-01	4.70E-01	4.08E-01	2.36E-01
Grinding media	1.19E-01	1.05E-01	9.10E-02	5.26E-02
Grinding aids	3.06E-01	2.70E-01	2.34E-01	1.35E-01
Filter bags	1.64E-02	1.44E-02	1.25E-02	7.24E-03
Oil & grease	1.11E-01	9.75E-02	8.45E-02	4.89E-02
Oil (gallon)	...	...	...	...
Grease (gallon)	...	...	...	...
Solvent (gallon)	...	...	...	...
Cement bags	5.78E-01	5.10E-01	4.42E-01	2.56E-01
Chains	1.63E-02	1.44E-02	1.25E-02	7.20E-03
Fuel and electricity				
Coal (ton)	4.29E-02	3.78E-02	3.28E-02	1.90E-02
Gasoline (gallon)	2.85E-01	2.92E-01	2.98E-01	1.17E-01
Liquefied petroleum gas (gallon)	4.65E-01	4.65E-01	4.64E-01	1.27E-03
Middle distillates (gallon)	1.86E+00	1.87E+00	1.79E+00	5.04E-01
Natural gas (thousand cu ft)	3.02E-01	2.96E-01	2.90E-01	3.42E-02
Petroleum coke (ton)	9.55E-03	8.43E-03	7.31E-03	4.23E-03
Residual oil (gallon)	4.53E-02	4.66E-02	4.67E-02	4.58E-02
Wastes (MBtu)	1.48E-01	1.30E-01	1.13E-01	6.54E-02
Electricity (kWh)	8.67E+01	8.06E+01	7.44E+01	3.13E+01
Energy equivalent, MBtu				
Coal	9.01E-01	7.95E-01	6.89E-01	3.98E-01
Gasoline	3.56E-02	3.65E-02	3.72E-02	1.47E-02
Liquefied petroleum gas	4.22E-02	4.22E-02	4.21E-02	1.15E-04
Middle distillates	2.58E-01	2.59E-01	2.49E-01	7.00E-02
Natural gas	3.11E-01	3.04E-01	2.98E-01	3.51E-02
Petroleum coke	2.88E-01	2.54E-01	2.20E-01	1.27E-01
Residual oil	6.78E-03	6.97E-03	7.00E-03	6.85E-03
Wastes	1.48E-01	1.30E-01	1.13E-01	6.54E-02
Electricity	2.96E-01	2.75E-01	2.54E-01	1.07E-01
Subtotal	2.29E+00	2.10E+00	1.91E+00	8.24E-01
Emission to water				
Aluminum	7.31E-04	6.45E-04	5.59E-04	3.23E-04
Ammonia, ammonium	8.06E-04	7.11E-04	6.16E-04	3.56E-04
Chemical oxygen demand, COD	...	...	...	...
Chlorides	6.18E-01	5.46E-01	4.73E-01	2.74E-01
Copper	2.01E-08	2.06E-08	2.09E-08	3.37E-08
Dissolved organic compounds	1.17E-02	1.03E-02	8.96E-03	5.18E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234 × 10-2 which is equal to 0.01234. Three dots "…" mean zero.

Table 21b. Summary of Precast Concrete LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Precast Mix 1	Precast Mix 2	Precast Mix 3	Ready Mix 3
Iron	2.01E-08	2.06E-08	2.09E-08	3.37E-08
Nitric, nitrites	5.01E-03	4.42E-03	3.83E-03	2.22E-03
Oil and grease	6.39E-03	5.64E-03	4.89E-03	2.83E-03
pH	8.45	8.45	8.45	8.45
Phenolics	1.87E-05	1.65E-05	1.43E-05	8.29E-06
Phosphorus	4.68E-06	4.13E-06	3.58E-06	2.07E-06
Sulfates	5.23E-01	4.62E-01	4.00E-01	2.31E-01
Sulfides	5.62E-05	4.96E-05	4.30E-05	2.49E-05
Suspended solids	1.99E-01	1.76E-01	1.52E-01	8.81E-02
Water (that leaves site) (gallon)	4.74E+02	4.30E+02	3.86E+02	1.72E+02
Zinc	2.81E-05	2.48E-05	2.15E-05	1.24E-05
Emission to air				
1,3 Butadiene	1.00E-12	1.08E-12	1.11E-12	1.19E-12
Acetaldehyde	9.35E-11	1.00E-10	1.03E-10	1.11E-10
Acrolein	1.50E-11	1.60E-11	1.65E-11	1.78E-11
Ammonia, NH_3	4.63E-03	4.15E-03	3.68E-03	1.79E-03
Arsenic	6.43E-07	7.21E-07	6.67E-07	6.38E-07
Benzene	5.22E-07	5.22E-07	5.23E-07	2.12E-08
Beryllium	7.09E-08	7.77E-08	7.28E-08	8.51E-08
Cadmium	3.05E-07	3.99E-07	3.06E-07	5.90E-08
Carbon dioxide, CO_2	8.26E+02	7.36E+02	6.45E+02	3.56E+02
Carbon dioxide, CO_2, calcination	4.68E+02	4.13E+02	3.58E+02	2.07E+02
Carbon dioxide, CO_2, combustion	3.58E+02	3.23E+02	2.86E+02	1.49E+02
Carbon monoxide, CO	1.11E+00	1.01E+00	9.03E-01	4.58E-01
Chromium	2.38E-06	2.55E-06	2.47E-06	2.13E-06
Cobalt	1.26E-07	1.34E-07	1.39E-07	1.29E-07
Copper	4.20E-08	4.20E-08	4.20E-08	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	8.41E-11	7.43E-11	6.45E-11	3.83E-11
Ethylbenzene	7.48E-11	8.01E-11	8.26E-11	8.89E-11
Formaldehyde	1.91E-05	1.91E-05	1.92E-05	1.30E-06
Hydrogen chlorine, HCl	6.23E-02	5.49E-02	4.76E-02	2.76E-02
Hydrogen sulfide, H_2S	...	...	...	...
Lead	9.46E-07	1.01E-06	9.78E-07	9.01E-07
Manganese	1.45E-05	1.53E-05	1.51E-05	1.49E-05
Mercury, Hg	5.18E-05	4.57E-05	3.97E-05	2.29E-05
Metals, not specified	...	...	...	...
Methane, CH_4	3.33E-02	2.96E-02	2.59E-02	1.48E-02
Methylene chloride	3.10E-07	3.17E-07	3.21E-07	4.96E-07
Naphthalene	1.70E-07	1.72E-07	1.73E-07	2.89E-08
Nickel	4.49E-06	4.84E-06	4.77E-06	4.40E-06
Nitric oxide, NO (unspecified)	1.44E-03	1.46E-03	1.43E-03	4.09E-04
Nitrogen oxides, NO_X	2.08E+00	1.86E+00	1.62E+00	9.59E-01
Non-methane organic gases, NMOG	1.10E-02	1.10E-02	1.10E-02	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	5.14E-12	5.51E-12	5.68E-12	6.11E-12
Particulates, PM-2.5	1.03E-04	9.56E-05	8.54E-05	6.20E-05
Particulates, PM-10	1.06E+00	1.03E+00	1.00E+00	8.71E-01
Particulates, total	2.72E+00	2.47E+00	2.21E+00	1.48E+00
Perchloroethylene	5.08E-09	5.17E-09	5.23E-09	8.19E-09
Phenolic compounds	2.34E-07	2.39E-07	2.42E-07	3.73E-07
Phosphorus	7.07E-06	7.62E-06	7.35E-06	7.31E-06
Propylene oxide	6.78E-11	7.26E-11	7.48E-11	8.06E-11
Radionuclides (kBq)	5.12E-02	5.17E-02	5.20E-02	4.48E-02
Selenium	1.73E-07	1.80E-07	1.77E-07	2.49E-07
Sulfur dioxide, SO_2	1.10E+00	9.69E-01	8.40E-01	4.86E-01
Sulfur oxides, SO_X	5.83E-03	6.09E-03	5.86E-03	5.62E-03
Toluene	3.04E-10	3.25E-10	3.35E-10	3.61E-10
Total hydrocarbon, THC	1.12E-02	1.12E-02	1.12E-02	3.43E-06
Volatile organic compounds, VOC	6.06E-02	5.63E-02	5.13E-02	2.57E-02
Xylenes	1.50E-10	1.60E-10	1.65E-10	1.78E-10
Zinc	2.80E-08	2.80E-08	2.80E-08	4.88E-08
Emission to land				
Cement kiln dust, CKD	3.29E+01	2.90E+01	2.52E+01	1.46E+01
Slag reject	...	...	...	...
Other solid waste	1.28E+02	1.28E+02	1.28E+02	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Data Quality

The energy data used for cement refer to 2003 and are national in scope. They include the four main cement manufacturing technologies: wet, long dry, dry with preheater, and dry with preheater and precalciner. The data are reported from plants representing approximately 80% of the total U.S. cement consumption (Marceau, Nisbet, and VanGeem 2006). We believe the data that have a significant impact on results have a good level of accuracy. A set of industry-standard data-quality indicators complying with ISO 14401 has not yet been developed. Emissions to air, with the exception of CO_2 from cement manufacturing, are based largely on EPA emission factors for which qualitative quality indicators are available.

The data on aggregate production and concrete plant operations come from published reports and other sources provided by concrete industry associations as well as industry-wide surveys in 2005 and 2006. The data on which the LCI is based and the LCI results have been peer reviewed by the PCA membership and its relevant allied groups.

SUMMARY

This report presents the results of the life cycle inventory analysis (LCI) of three concrete products: ready mixed concrete, concrete masonry, and precast concrete. The results are the average of inputs and emissions associated with one unit volume of concrete produced in the United States and, in the case of concrete masonry, 100 CMUs. The system boundary, which defines the scope of the LCI, includes cement and slag cement manufacture; aggregate production; transportation of fuel, cement, supplementary cementitious materials, and aggregates to the concrete plant; and concrete plant operations (including truck mixer wash-out in the case of ready mixed concrete).

The LCI has been carried out according to ISO standards 14040, 14041 and 14044. Cement data are taken from the cement manufacturing LCI originally carried out by the Portland Cement Association in 1996 and updated in 2006 with the most recent (2003) energy data. It includes the four main technologies: wet, long dry, dry with preheater, and dry with preheater and precalciner. The data are reported from plants representing approximately 80% of the U.S. cement consumption. We believe these data have a good level of accuracy. A set of industry standard data quality indicators complying with ISO 14041 has not yet been developed. Emissions to air are based largely on EPA emission factors for which qualitative quality indicators are available.

Due to increases in energy efficiency, newer plants replacing older ones, and more accurate data (particularly for concrete plants and aggregate production), the present LCI results are lower for most of the flows reported in the previous edition. For example, for a typical 20-MPa (3,000-psi) concrete mix, embodied energy is 30% lower and CO_2 emissions are about 7% lower. For concrete masonry, embodied energy is about 20% lower and CO_2 emissions are about the same. For 50-MPa (7,500-psi) precast concrete, embodied energy and CO_2 are unchanged because the LCI now includes energy and emissions at the precast concrete plant.

Data on inputs and emissions from concrete production are from recent (2006) industry surveys, emission factors, and information provided by relevant industry associations. The data referring to aggregate production and the operations of concrete plants come from published reports and other sources provided by concrete industry associations. We believe the data are reasonably representative of current technology.

The LCI data and results have been peer reviewed by the PCA membership and its relevant allied groups.

RECOMMENDATIONS

In order to ensure that life cycle inventory of concrete products is representative, it is recommended that the concrete LCI be update approximately every five years with the following information:

- Water consumption and recycling at concrete plants.
- Concrete plant solid waste generation and recycling.
- Transportation distances for cement, aggregates, fly ash, and silica fume.
- Fuel and energy consumption in concrete plants.
- Quarry haul-road distances and unpaved road emissions.

Representatives of the cement and concrete industries have reviewed the data used in the report. However, the LCI report does not contain indicators of data quality. It is recommended that suitable indicators be developed in compliance with the requirements of ISO 14041; however, a set of industry standard data quality indicators complying with ISO 14041 has not yet been developed.

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APPENDIX A – TARGET AUDIENCES AND INFORMATION TO BE COMMUNICATED

This report is one of many for the Environmental Life Cycle Assessment (LCA) of Portland Cement Concrete project sponsored by the Portland Cement Association. The objectives of publishing reports and disseminating information are to:

- Determine the environmental life cycle benefits associated with the use of these products.
- Produce comparisons of concrete and other building materials.
- Provide information about these benefits to manufacturers and users of these products.
- Provide life cycle inventory (LCI) and LCA information to practitioners and others, such as database providers in need of accurate data on cement and concrete.

The contents of the reports will provide information for the following audiences:

- Members of the Portland Cement Association (PCA) and other organizations that promote the use of cement and concrete, generally called "allied industries."
- Members of the Environmental Council of Concrete Organizations (ECCO).
- LCA practitioners and database developers.
- Engineers, architects, and designers.
- Public agencies and programs (for example, Departments of Transportation, Energy Star, Environmentally Preferable Purchasing Program).
- The public.

The report *formats* are not particularly suited for all audiences. The reports are intended to document the particular LCI or LCA. They provide data in a transparent, traceable format for documentation purposes. The intent is that abbreviated papers, brochures, data packages, presentations, or press releases can be developed from the project reports. The materials presenting the results of this project will be matched, in form and format, to the needs of the target audience. The materials have been categorized as follows:

- General Information:
    - Purpose of life cycle assessments (LCAs) and how they are done.
    - Limited life cycle results of portland cement concrete products from production through use to demolition and recycling.
- Summary Results:
    - Presentation of selected life cycle inventory (LCI) data in the form of summary information, bar charts or other diagrams; for example PowerPoint™ presentations.
    - Published papers or articles.
- Detailed Results:
    - LCI results for databases or LCA models, such as BEES or Athena.
    - Description of the LCI methodology used in the project and specific assumptions, information sources/references, and detailed results.

APPENDIX B – CONFIDENTIAL LIFE CYCLE INVENTORY SURVEY OF READY-MIX CONCRETE PLANT – BLANK QUESTIONNAIRE

PCA LCI Update (06-10)
CTLGroup Project No. 312081

CTLGROUP
Building Knowledge. Delivering Results.
CONSTRUCTION TECHNOLOGY LABORATORIES
ENGINEERS & CONSTRUCTION TECHNOLOGY CONSULTANTS
www.CTLGroup.com

Thank you for your assistance in updating the environmental life cycle inventory (LCI) of ready-mix concrete. This document provides background information on the LCI project and contains the questionnaire on fuel and electricity use at ready-mix concrete plants.

QUESTIONNAIRE

The questionnaire is included at the end of this letter. **Please return the completed questionnaire by August 18, 2006 to:**

Medgar Marceau, PE (Illinois), LEED-AP
Building Science Engineer

Phone: 847-972-3154
Fax: 847-965-5416
MMarceau@CTLGroup.com

The completed questionnaire will be kept confidential. To ensure that specific operating data cannot be traced to a particular plant, only the summarized results (average, standard deviation, etc.) will be published. This is the same process used by the Portland Cement Association (PCA) and other industries to collect and report data. If you need help completing the questionnaire, please do not hesitate to contact Medgar Marceau.

BACKGROUND

In 2000, the PCA published the LCI of ready-mixed concrete and concrete products[1]. An LCI lists quantities of all fuel, materials, and emissions associated with a product or process throughout its life cycle: from the extraction of raw material through manufacture, use, and disposal.

PCA has contracted with CTLGroup to update the LCI. Some of the data on ready-mix concrete in the 2000 LCI report were based on much older data and broad assumptions. Further, new technologies and improvements in manufacturing mean that these data may no longer be representative of today's industry.

An LCI is the first step in conducting a life cycle *assessment* (LCA). An LCA is a systematic approach to comparing the environmental impact of products and processes. It can be used to determine whether products are "environmentally friendly" or "green".

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[1]Nisbet, M.A., VanGeem, M.G., Gajda, J., and Marceau, M.L., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D Serial No. 2137, Portland Cement Association, Skokie, Illinois, 2000.

Main Office 5400 Old Orchard Road Skokie, Illinois 60077-1030 Phone 847-965-7500 Fax 847-965-5416
Northeast Office 5565 Sterrett Place, Suite 312 Columbia, Maryland 21044-2685 Phone 410-997-0400 Fax 410-997-8480

Many LCA software tools are being developed by life cycle practitioners outside the cement and concrete industry. For example, LCA data will be used to develop the next version of LEED[2]. LCA data are used in models such as ATHENA[3] and BEES[4]. LCA data will also be used to develop the next version of GreenGlobes[5]. However, if the ready-mix industry does not provide data, practitioners tend to make erroneous assumptions that often result in worse impacts than actually exist. Providing accurate data ensures that the ready-mix industry is fairly represented and adds credibility to the industry.

Your input will help all of us promote quality ready-mix concrete as the "green" material of choice.

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[2]For information on the LCA into LEED project, please contact, leedinfo@usgbc.org.
[3]www.athenasmi.ca.
[4]www.bfrl.nist.gov/oae/software/bees/please/bees_please.html.
[5]www.TheGBI.org.

Confidential Life Cycle Inventory Survey of Ready-Mix Concrete Plant – Part 1, General Plant Information

Plant location (city, state):_____
(Plant location will be kept confidential)

Questionnaire completed by (name, telephone number):_____

Reporting period (preferably 12 consecutive months):_____

Plant production based on reporting period (cubic yard of concrete):_____

How much material is recycled back into the process or into other products (please specify)?_____

_____

Which of the following recycled secondary cementitious materials or aggregates are used in your products?

1. fly ash _____, 2. slag _____, 3. glass _____, 4. other _____.

How much material is wasted (for example, land filled or otherwise dumped)?_____

_____

How much water is used (do not include batch water)?_____

_____

How much water is recycled back into the process or into other products (please specify)?_____

_____

How much water is disposed of (for example, down drains)?_____

Confidential Life Cycle Inventory Survey of Ready-Mix Concrete Plant – Part 2, Fuel and Electricity Use

Fuel and electricity (used on-site)	Units		Quantity	Specify for what purpose and relative percent	Data quality		
	Assumed	Specify if other			Source*	Type**	Year
Gasoline (for example in fork-lifts)	gallons						
Middle distillates (for example in front-end loaders)							
Nos. 1, 2*** & 4 diesel fuel	gallons						
Nos. 1, 2 & 4 fuel oil	gallons						
Kerosene	gallons						
Residual oils							
Nos. 5 & 6 fuel oils	gallons						
Natural gas (for example, in electricity generators)	cubic feet						
Liquefied petroleum gas	cubic feet						
Electricity (all purchased electricity used at the plant)	kWh						
Other?							
Other?							
Other?							

*Specify source: F = site specific, L = from literature, or O = other source.

**Specify type: M = measured, C = calculated, A = average value, E = estimated, or U = unknown.

***If diesel fuel No. 2 is used, is it low sulfur (sulfur level below 0.05% by weight)?_____

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APPENDIX C – CONFIDENTIAL LIFE CYCLE INVENTORY SURVEY OF CONCRETE MASONRY PLANT – BLANK QUESTIONNAIRE

PCA LCI Update (06-10)
CTLGroup Project No. 312081

Thank you for your assistance in updating the environmental life cycle inventory (LCI) of concrete masonry. This document provides background information on the LCI project and contains the questionnaire on fuel and electricity use at concrete masonry plants.

QUESTIONNAIRE

The questionnaire is included at the end of this letter. **Please return the completed questionnaire by June 23, 2006 to:**

Medgar Marceau, PE (Illinois), LEED-AP
Building Science Engineer

Phone: 847-972-3154
Fax: 847-965-5416
MMarceau@CTLGroup.com

The completed questionnaire will be kept confidential. To ensure that specific operating data cannot be traced to a particular plant, only the summarized results (average, standard deviation, etc.) will be published. This is the same process used by the Portland Cement Association (PCA) and other industries to collect and report data. If you need help completing the questionnaire, please do not hesitate to contact Medgar Marceau.

BACKGROUND

In 2000, the PCA published the LCI of ready-mixed concrete and concrete products including concrete masonry[1]. An LCI lists quantities of all energy, materials, and emissions associated with a product or process throughout its life cycle: from the extraction of raw material, through manufacture, use, and disposal.

PCA has contracted with CTLGroup to update the LCI. Some of the data on concrete masonry in the 2000 LCI report were based on much older data and broad assumptions. Further, new technologies and improvements in manufacturing mean that these data may no longer be representative of today's industry.

An LCI is the first step in conducting a life cycle *assessment* (LCA). An LCA is a systematic approach to comparing the environmental impact of products and processes. It can be used to determine whether products are "environmentally friendly" or "green".

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[1]Nisbet, M.A., VanGeem, M.G., Gajda, J., and Marceau, M.L., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D Serial No. 2137, Portland Cement Association, Skokie, Illinois, 2000.

Many LCA software tools are being developed by life cycle practitioners outside the cement and concrete industry. For example, LCA data will be used to develop the next version of LEED[2]. LCA data are used in models such as ATHENA[3] and BEES[4]. It will also be used to develop the next version of GreenGlobes[5]. However, if the masonry industry does not provide data, practitioners tend to make erroneous assumptions that often result in worse impacts than actually exist. Providing accurate data ensures that the masonry industry is fairly represented and adds credibility to the industry.

Your input will help all of us promote quality masonry and masonry products as "green" materials of choice.

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[2]For information on the LCA into LEED project, please contact, leedinfo@usgbc.org.
[3]www.athenasmi.ca
[4]www.bfrl.nist.gov/oae/software/bees/please/bees_please.html
[5]www.TheGBI.org .

Confidential Life Cycle Inventory Survey of Concrete Masonry Plant – Part 1, General Plant Information

Plant location (city, state):_____
(Plant location will be kept confidential)

Questionnaire completed by (name, telephone number):_____

Reporting period (preferably 12 consecutive months):_____

Plant production based on reporting period (equivalent 8-in. CMU):_____

Types of product manufactured:_____

_____

Is fuel or electricity used in product curing?_____

How much material is recycled back into the process or into other products (please specify)?_____

_____

Which of the following recycled secondary cementitious materials or aggregates are used in your products?

1. fly ash _____, 2. slag _____, 3. glass _____, 4. other _____.

How much material is wasted (for example, land filled)?_____

_____

How much water is used (do not include batch water)?_____

_____

How much water is recycled back into the process or into other products (please specify)?_____

_____

How much water is disposed of (for example, down drains)?_____

Confidential Life Cycle Inventory Survey of Concrete Masonry Plant – Part 2, Fuel and Electricity Use

Fuel and electricity (used on-site)	Units		Quantity	Specify for what purpose and relative percent	Data quality		
	Assumed	Specify if other			Source*	Type**	Year
Gasoline (for example in fork-lifts)	gallons						
Middle distillates (for example in front-end loaders)							
Nos. 1, 2*** & 4 diesel fuel	gallons						
Nos. 1, 2 & 4 fuel oil	gallons						
Kerosene	gallons						
Residual oils							
Nos. 5 & 6 fuel oils	gallons						
Natural gas (for example, in steam curing, in electricity generators)	cubic feet						
Liquefied petroleum gas	cubic feet						
Electricity (all purchased electricity used at the plant)	kWh						
Other?							
Other?							
Other?							

*Specify source: F = site specific, L = from literature, or O = other source.

**Specify type: M = measured, C = calculated, A = average value, E = estimated, or U = unknown.

***If diesel fuel No. 2 is used, is it low sulfur (sulfur level below 0.05% by weight)?_____

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APPENDIX D – CONFIDENTIAL LIFE CYCLE INVENTORY SURVEY OF PRECAST CONCRETE PLANT – BLANK QUESTIONNAIRE

PCA LCI Update (06-10)
CTLGroup Project No. 312081

Thank you for your assistance in updating the environmental life cycle inventory (LCI) of precast concrete products. This document provides background information on the LCI project and contains the questionnaire on fuel and electricity use at precast concrete plants.

QUESTIONNAIRE

The questionnaire is included at the end of this letter. **Please return the completed questionnaire by June 23, 2006 to:**

Medgar Marceau, PE (Illinois), LEED-AP
Building Science Engineer

Phone: 847-972-3154
Fax: 847-965-5416
MMarceau@CTLGroup.com

The completed questionnaire will be kept confidential. To ensure that specific operating data cannot be traced to a particular plant, only the summarized results (average, standard deviation, etc.) will be published. This is the same process used by PCA and other industries to collect and report data. If you need help completing the questionnaire, please do not hesitate to contact Medgar Marceau.

BACKGROUND

In 2000, the Portland Cement Association (PCA) published the LCI of ready-mixed concrete and concrete products including precast concrete[1]. An LCI lists quantities of all energy, materials, and emissions associated with a product or process throughout its life cycle: from the extraction of raw material, through manufacture, use, and disposal.

PCA has contracted with CTLGroup to update the LCI. Some of the data on precast concrete in the 2000 LCI report were based on much older data and broad assumptions. Further, new technologies and improvements in manufacturing mean that these data may no longer be representative of today's industry.

An LCI is the first step in conducting a life cycle *assessment* (LCA). An LCA is a systematic approach to comparing the environmental impact of products and processes. It can be used to determine whether products are "environmentally friendly" or "green".

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[1]Nisbet, M.A., VanGeem, M.G., Gajda, J., and Marceau, M.L., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D Serial No. 2137, Portland Cement Association, Skokie, Illinois, 2000.

Many LCA software tools are being developed by life cycle practitioners outside the cement and concrete industry. For example, LCA data will be used to develop the next version of LEED[2]. LCA data are used in models such as ATHENA[3] and BEES[4]. It will also be used to develop the next version of GreenGlobes[5]. If the concrete industry does not provide accurate and defensible data, practitioners tend to make erroneous assumptions that often result in worse impacts than actually exist. Providing accurate data ensures that the concrete industry is fairly represented and adds credibility to the industry.

Your input will help all of us promote quality concrete and concrete products as the "green" materials of choice.

---

[2] For information on the LCA into LEED project, please contact, leedinfo@usgbc.org.

[3] www.athenasmi.ca

[4] www.bfrl.nist.gov/oae/software/bees/please/bees_please.html

[5] www.TheGBI.org .

Confidential Life Cycle Inventory Survey of Precast Concrete Plant – Part 1, General Plant Information

Plant location (city, state):_____
(Plant location will be kept confidential)

Questionnaire completed by (name, telephone number):_____

Reporting period (preferably 12 consecutive months):_____

Plant production based on reporting period (cubic yards of concrete):_____

Types of product manufactured:_____

_____

Is fuel or electricity used in product curing?_____

How much material is recycled back into the process or into other products (please specify)?_____

_____

How much material is wasted (for example, land filled)?_____

_____

How much water is used (do not include batch water)?_____

_____

How much water is recycled back into the process or into other products (please specify)?_____

_____

How much water is disposed of (for example, down drains)?_____

_____

Confidential Life Cycle Inventory Survey of Precast Concrete Plant – Part 2, Fuel and Electricity Use

Fuel and electricity (used on-site)	Units		Quantity	Specify for what purpose and relative percent	Data quality		
	Assumed	Specify if other			Source*	Type**	Year
Gasoline (for example in fork-lifts)	gallons						
Middle distillates (for example in front-end loaders)							
Nos. 1, 2*** & 4 diesel fuel	gallons						
Nos. 1, 2 & 4 fuel oil	gallons						
Kerosene	gallons						
Residual oils							
Nos. 5 & 6 fuel oils	gallons						
Natural gas (for example, in steam curing, in electricity generators)	cubic feet						
Liquefied petroleum gas	cubic feet						
Electricity (all purchased electricity used at the plant)	kWh						
Other?							
Other?							
Other?							

*Specify source: F = site specific, L = from literature, or O = other source.

**Specify type: M = measured, C = calculated, A = average value, E = estimated, or U = unknown.

***If diesel fuel No. 2 is used, is it low sulfur (sulfur level below 0.05% by weight)?_____

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APPENDIX E – READY MIXED CONCRETE LCI RESULTS

Table E1a. Ready Mix 1 (35-MPa) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	3.89E+02	...	...	...	...	...	3.89E+02
Cement rock, marl	6.67E+01	...	...	...	...	...	6.67E+01
Shale	1.68E+01	...	...	...	...	...	1.68E+01
Clay	2.05E+01	...	...	...	...	...	2.05E+01
Bottom ash	3.32E+00	...	...	...	...	...	3.32E+00
Fly ash	4.42E+00	...	...	...	...	...	4.42E+00
Foundry sand	1.33E+00	...	...	...	...	...	1.33E+00
Sand	1.34E+01	...	...	...	...	...	1.34E+01
Iron, iron ore	4.59E+00	...	...	...	...	...	4.59E+00
Blast furnace slag	6.90E+00	...	...	...	...	...	6.90E+00
Slate	3.42E-01	...	...	...	...	...	3.42E-01
Other raw material	9.44E+00	...	...	...	...	...	9.44E+00
Gypsum, anhydrite	1.62E+01	...	...	...	...	...	1.62E+01
Water, process	2.69E+01	...	...	...	...	...	1.67E+02
Water, non-process	2.60E+02	...	no data	no data	7.74E+00	...	2.67E+02
Coarse aggregate, natural	...	...	8.78E+02	...	...	...	8.78E+02
Coarse aggregate, manufactured	...	...	...	3.09E+02	...	...	3.09E+02
Fine aggregate, natural	...	...	7.12E+02	...	...	...	7.12E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	9.87E-02	...	no data	no data	...	...	9.87E-02
Refractory	2.10E-01	...	...	...	...	...	2.10E-01
Grinding media	4.68E-02	...	...	...	...	...	4.68E-02
Grinding aids	1.20E-01	...	...	...	...	...	1.20E-01
Filter bags	6.44E-03	...	...	...	...	...	6.44E-03
Oil & grease	4.35E-02	...	...	...	no data	...	4.35E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	2.28E-01	...	...	...	...	...	2.28E-01
Chains	6.41E-03	...	...	...	...	...	6.41E-03
Fuel and electricity							
Coal (metric ton)	3.37E-02	...	...	...	...	…	3.37E-02
Gasoline (L)	1.40E-02	...	3.60E-02	1.21E-02	...	4.98E-01	5.61E-01
Liquefied petroleum gas (L)	9.40E-03	...	...	...	...	…	9.40E-03
Middle distillates (L)	3.12E-01	...	3.73E-01	1.20E-01	4.35E-01	1.67E+00	2.91E+00
Natural gas (thousand m^3)	1.31E-03	...	6.62E-05	3.32E-05	2.93E-04	…	1.70E-03
Petroleum coke (metric ton)	7.52E-03	...	...	...	...	…	7.52E-03
Residual oil (L)	3.22E-02	...	8.37E-02	1.86E-02	...	9.89E-02	2.33E-01
Wastes (GJ)	1.35E-01	...	...	...	...	…	1.35E-01
Electricity (kWh)	4.70E+01	...	4.22E+00	1.05E+00	4.11E+00	…	5.64E+01
Energy equivalent, GJ							
Coal	8.25E-01	...	...	...	...	…	8.25E-01
Gasoline	4.89E-04	...	1.26E-03	4.21E-04	...	1.74E-02	1.95E-02
Liquefied petroleum gas	2.38E-04	...	...	...	...	…	2.38E-04
Middle distillates	1.20E-02	...	1.44E-02	4.64E-03	1.68E-02	6.44E-02	1.12E-01
Natural gas	5.00E-02	...	2.53E-03	1.27E-03	1.12E-02	…	6.51E-02
Petroleum coke	2.64E-01	...	...	...	...	…	2.64E-01
Residual oil	1.34E-03	...	3.49E-03	7.78E-04	...	4.13E-03	9.74E-03
Wastes	1.35E-01	...	...	...	...	…	1.35E-01
Electricity	1.69E-01	...	1.52E-02	3.80E-03	1.48E-02	…	2.03E-01
Subtotal	1.46E+00	...	3.69E-02	1.09E-02	4.28E-02	8.59E-02	1.63E+00
Emission to water							
Aluminum	2.88E-04	...	...	...	...	…	2.88E-04
Ammonia, ammonium	3.17E-04	...	...	...	...	…	3.17E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.43E-01	...	7.18E-10	1.60E-10	3.09E-09	…	2.43E-01
Copper	...	...	3.59E-09	8.00E-10	1.55E-08	…	1.99E-08
Dissolved organic compounds	4.61E-03	...	...	...	...	…	4.61E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E1a. Ready Mix 1 (35-MPa) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.59E-09	8.00E-10	1.55E-08	…	1.99E-08
Nitric, nitrites	1.97E-03	...	...	...	...	…	1.97E-03
Oil and grease	2.52E-03	...	5.38E-08	1.20E-08	2.32E-07	…	2.52E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	7.38E-06	...	...	...	...	…	7.38E-06
Phosphorus	1.84E-06	...	...	...	...	…	1.84E-06
Sulfates	2.06E-01	...	...	...	...	…	2.06E-01
Sulfides	2.21E-05	...	...	...	...	…	2.21E-05
Suspended solids	7.84E-02	...	1.08E-07	2.40E-08	4.64E-07	…	7.84E-02
Water (that leaves site) (L)	1.23E+03	...	...	...	3.48E+01	…	1.26E+03
Zinc	1.11E-05	...	...	...	...	…	1.11E-05
Emission to air							
1,3 Butadiene	...	...	4.65E-13	2.33E-13	...	…	6.99E-13
Acetaldehyde	...	...	4.33E-11	2.17E-11	...	…	6.50E-11
Acrolein	...	...	6.92E-12	3.47E-12	...	…	1.04E-11
Ammonia, NH_3	1.59E-03	...	...	...	1.78E-08	…	1.59E-03
Arsenic	...	...	1.32E-08	2.95E-09	3.70E-07	…	3.86E-07
Benzene	...	...	2.16E-09	4.84E-10	9.85E-09	…	1.25E-08
Beryllium	...	...	2.79E-10	6.21E-11	5.09E-08	…	5.12E-08
Cadmium	...	...	3.99E-09	8.89E-10	3.01E-08	…	3.49E-08
Carbon dioxide, CO_2	3.03E+02	...	1.45E+00	4.40E-01	1.76E+00	6.34E+00	3.13E+02
Carbon dioxide, CO_2, calcination	1.84E+02	...	...	...	...	…	1.84E+02
Carbon dioxide, CO_2, combustion	1.19E+02	...	1.45E+00	4.40E-01	1.76E+00	6.34E+00	1.29E+02
Carbon monoxide, CO	3.57E-01	...	3.09E-03	1.01E-03	6.59E-04	2.92E-02	3.91E-01
Chromium	...	...	8.47E-09	1.89E-09	1.28E-06	…	1.29E-06
Cobalt	...	...	6.04E-08	1.34E-08	3.94E-10	…	7.42E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
s and furans, TEQ 2,3,7,8-TCDD	3.27E-11	...	1.50E-13	3.34E-14	7.23E-13	…	3.36E-11
Ethylbenzene	...	...	3.46E-11	1.74E-11	...	…	5.20E-11
Formaldehyde	...	...	3.32E-07	7.41E-08	3.52E-07	…	7.58E-07
Hydrogen chlorine, HCl	2.45E-02	...	7.01E-06	1.56E-06	3.65E-05	…	2.45E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.51E-08	3.37E-09	5.27E-07	…	5.45E-07
Manganese	...	...	3.01E-08	6.70E-09	9.04E-06	…	9.07E-06
Mercury, Hg	2.04E-05	...	1.13E-09	2.52E-10	2.29E-08	…	2.04E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.25E-02	...	5.47E-05	1.68E-05	1.32E-05	3.66E-04	1.29E-02
Methylene chloride	...	...	4.83E-08	1.08E-08	2.33E-07	…	2.92E-07
Naphthalene	...	...	1.13E-08	2.52E-09	2.86E-09	…	1.67E-08
Nickel	...	...	8.47E-07	1.89E-07	1.58E-06	…	2.62E-06
Nitric oxide, NO (unspecified)	...	...	4.42E-05	1.41E-05	1.63E-05	1.87E-04	2.62E-04
Nitrogen oxides, NO_X	7.49E-01	...	8.85E-03	2.80E-03	1.72E-03	6.17E-02	8.24E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.38E-12	1.19E-12	...	…	3.57E-12
Particulates, PM-2.5	3.04E-05	...	...	1.74E-05	...	…	4.78E-05
Particulates, PM-10	2.13E-01	...	3.12E-01	3.16E-02	1.71E-02	1.21E-03	5.75E-01
Particulates, total	9.26E-01	...	1.78E-01	2.77E-02	4.69E-02	…	1.18E+00
Perchloroethylene	...	...	7.02E-10	1.56E-10	3.98E-09	…	4.84E-09
Phenolic compounds	...	...	3.64E-08	8.11E-09	1.76E-07	…	2.20E-07
Phosphorus	...	...	...	...	4.44E-06	…	4.44E-06
Propylene oxide	...	...	3.14E-11	1.57E-11	...	…	4.71E-11
Radionuclides (kBq)	...	...	3.77E-03	8.40E-04	2.18E-02	…	2.64E-02
Selenium	...	...	6.85E-09	1.53E-09	1.40E-07	…	1.48E-07
Sulfur dioxide, SO_2	4.32E-01	...	...	...	1.04E-08	…	4.32E-01
Sulfur oxides, SO_X	...	...	6.88E-04	1.79E-04	2.63E-04	2.36E-03	3.49E-03
Toluene	...	...	1.41E-10	7.06E-11	...	…	2.11E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	1.58E-02	...	6.50E-04	2.10E-04	3.85E-05	4.02E-03	2.07E-02
Xylenes	...	...	6.92E-11	3.47E-11	...	…	1.04E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	1.30E+01	...	...	...	...	…	1.30E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.06E-04	2.37E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E1b. Ready Mix 1 (5,000-psi) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	6.56E+02	...	...	...	...	...	6.56E+02
Cement rock, marl	1.12E+02	...	...	...	...	...	1.12E+02
Shale	2.84E+01	...	...	...	...	...	2.84E+01
Clay	3.46E+01	...	...	...	...	...	3.46E+01
Bottom ash	5.60E+00	...	...	...	...	...	5.60E+00
Fly ash	7.45E+00	...	...	...	...	...	7.45E+00
Foundry sand	2.25E+00	...	...	...	...	...	2.25E+00
Sand	2.26E+01	...	...	...	...	...	2.26E+01
Iron, iron ore	7.73E+00	...	...	...	...	...	7.73E+00
Blast furnace slag	1.16E+01	...	...	...	...	...	1.16E+01
Slate	5.77E-01	...	...	...	...	...	5.77E-01
Other raw material	1.59E+01	...	...	...	...	...	1.59E+01
Gypsum, anhydrite	2.74E+01	...	...	...	...	...	2.74E+01
Water, process	4.53E+01	...	...	...	...	...	2.82E+02
Water, non-process	4.38E+02	...	no data	no data	1.30E+01	...	4.51E+02
Coarse aggregate, natural	...	...	1.48E+03	...	...	...	1.48E+03
Coarse aggregate, manufactured	...	...	...	5.20E+02	...	...	5.20E+02
Fine aggregate, natural	...	...	1.20E+03	...	...	...	1.20E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.66E-01	...	no data	no data	...	...	1.66E-01
Refractory	3.54E-01	...	...	...	...	...	3.54E-01
Grinding media	7.90E-02	...	...	...	...	...	7.90E-02
Grinding aids	2.03E-01	...	...	...	...	...	2.03E-01
Filter bags	1.09E-02	...	...	...	...	...	1.09E-02
Oil & grease	7.33E-02	...	...	...	no data	...	7.33E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	3.84E-01	...	...	...	...	...	3.84E-01
Chains	1.08E-02	...	...	...	...	...	1.08E-02
Fuel and electricity							
Coal (ton)	2.84E-02	...	...	...	...	…	2.84E-02
Gasoline (gallon)	2.84E-03	...	7.28E-03	2.44E-03	...	1.01E-01	1.13E-01
Liquefied petroleum gas (gallon)	1.90E-03	...	...	...	...	…	1.90E-03
Middle distillates (gallon)	6.29E-02	...	7.53E-02	2.42E-02	8.79E-02	3.37E-01	5.87E-01
Natural gas (thousand cu ft)	3.53E-02	...	1.79E-03	8.97E-04	7.91E-03	…	4.59E-02
Petroleum coke (ton)	6.34E-03	...	...	...	...	…	6.34E-03
Residual oil (gallon)	6.50E-03	...	1.69E-02	3.76E-03	...	2.00E-02	4.71E-02
Wastes (MBtu)	9.80E-02	...	...	...	...	…	9.80E-02
Electricity (kWh)	3.60E+01	...	3.22E+00	8.06E-01	3.15E+00	…	4.31E+01
Energy equivalent, MBtu							
Coal	5.98E-01	...	...	...	...	…	5.98E-01
Gasoline	3.55E-04	...	9.10E-04	3.05E-04	...	1.26E-02	1.42E-02
Liquefied petroleum gas	1.72E-04	...	...	...	...	…	1.72E-04
Middle distillates	8.73E-03	...	1.04E-02	3.36E-03	1.22E-02	4.67E-02	8.14E-02
Natural gas	3.63E-02	...	1.84E-03	9.21E-04	8.12E-03	…	4.71E-02
Petroleum coke	1.91E-01	...	...	...	...	…	1.91E-01
Residual oil	9.73E-04	...	2.53E-03	5.64E-04	...	2.99E-03	7.06E-03
Wastes	9.80E-02	...	...	...	...	…	9.80E-02
Electricity	1.23E-01	...	1.10E-02	2.75E-03	1.07E-02	…	1.47E-01
Subtotal	1.06E+00	...	2.67E-02	7.90E-03	3.10E-02	6.23E-02	1.18E+00
Emission to water							
Aluminum	4.85E-04	...	...	...	...	…	4.85E-04
Ammonia, ammonium	5.35E-04	...	...	...	...	…	5.35E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	4.10E-01	...	1.21E-09	2.70E-10	5.22E-09	…	4.10E-01
Copper	...	...	6.05E-09	1.35E-09	2.61E-08	…	3.35E-08
Dissolved organic compounds	7.77E-03	...	...	...	...	…	7.77E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234 × 10-2 which is equal to 0.01234. Three dots "…" mean zero.

Table E1b. Ready Mix 1 (5,000-psi) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.05E-09	1.35E-09	2.61E-08	…	3.35E-08
Nitric, nitrites	3.33E-03	...	...	...	...	…	3.33E-03
Oil and grease	4.24E-03	...	9.08E-08	2.02E-08	3.91E-07	…	4.24E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	1.24E-05	...	...	...	...	…	1.24E-05
Phosphorus	3.11E-06	...	...	...	...	…	3.11E-06
Sulfates	3.47E-01	...	...	...	...	…	3.47E-01
Sulfides	3.73E-05	...	...	...	...	…	3.73E-05
Suspended solids	1.32E-01	...	1.82E-07	4.04E-08	7.82E-07	…	1.32E-01
Water (that leaves site) (gallon)	2.48E+02	...	...	...	7.04E+00	…	2.55E+02
Zinc	1.87E-05	...	...	...	...	…	1.87E-05
Emission to air							
1,3 Butadiene	...	...	7.84E-13	3.93E-13	...	…	1.18E-12
Acetaldehyde	...	...	7.29E-11	3.66E-11	...	…	1.10E-10
Acrolein	...	...	1.17E-11	5.86E-12	...	…	1.75E-11
Ammonia, NH_3	2.68E-03	...	...	...	2.99E-08	…	2.68E-03
Arsenic	...	...	2.23E-08	4.97E-09	6.24E-07	…	6.51E-07
Benzene	...	...	3.64E-09	8.17E-10	1.66E-08	…	2.11E-08
Beryllium	...	...	4.70E-10	1.05E-10	8.57E-08	…	8.63E-08
Cadmium	...	...	6.73E-09	1.50E-09	5.07E-08	…	5.89E-08
Carbon dioxide, CO_2	5.11E+02	...	2.44E+00	7.42E-01	2.97E+00	1.07E+01	5.27E+02
Carbon dioxide, CO_2, calcination	3.11E+02	...	...	...	...	…	3.11E+02
Carbon dioxide, CO_2, combustion	2.00E+02	...	2.44E+00	7.42E-01	2.97E+00	1.07E+01	2.17E+02
Carbon monoxide, CO	6.02E-01	...	5.21E-03	1.70E-03	1.11E-03	4.92E-02	6.59E-01
Chromium	...	...	1.43E-08	3.18E-09	2.16E-06	…	2.18E-06
Cobalt	...	...	1.02E-07	2.27E-08	6.64E-10	…	1.25E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	5.51E-11	...	2.53E-13	5.63E-14	1.22E-12	…	5.67E-11
Ethylbenzene	...	...	5.84E-11	2.93E-11	...	…	8.76E-11
Formaldehyde	...	...	5.59E-07	1.25E-07	5.93E-07	…	1.28E-06
Hydrogen chlorine, HCl	4.13E-02	...	1.18E-05	2.63E-06	6.15E-05	…	4.14E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.55E-08	5.68E-09	8.88E-07	…	9.19E-07
Manganese	...	...	5.07E-08	1.13E-08	1.52E-05	…	1.53E-05
Mercury, Hg	3.43E-05	...	1.91E-09	4.25E-10	3.86E-08	…	3.44E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	2.10E-02	...	9.22E-05	2.83E-05	2.23E-05	6.18E-04	2.18E-02
Methylene chloride	...	...	8.15E-08	1.81E-08	3.93E-07	…	4.93E-07
Naphthalene	...	...	1.91E-08	4.26E-09	4.82E-09	…	2.82E-08
Nickel	...	...	1.43E-06	3.18E-07	2.66E-06	…	4.41E-06
Nitric oxide, NO (unspecified)	...	...	7.45E-05	2.38E-05	2.75E-05	3.15E-04	4.41E-04
Nitrogen oxides, NO_X	1.26E+00	...	1.49E-02	4.71E-03	2.90E-03	1.04E-01	1.39E+00
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.01E-12	2.01E-12	...	…	6.02E-12
Particulates, PM-2.5	5.12E-05	...	...	2.94E-05	...	…	8.05E-05
Particulates, PM-10	3.59E-01	...	5.26E-01	5.33E-02	2.88E-02	2.04E-03	9.69E-01
Particulates, total	1.56E+00	...	3.00E-01	4.66E-02	7.90E-02	…	1.99E+00
Perchloroethylene	...	...	1.18E-09	2.64E-10	6.70E-09	…	8.15E-09
Phenolic compounds	...	...	6.14E-08	1.37E-08	2.96E-07	…	3.71E-07
Phosphorus	...	...	...	...	7.48E-06	…	7.48E-06
Propylene oxide	...	...	5.29E-11	2.65E-11	...	…	7.94E-11
Radionuclides (kBq)	...	...	6.36E-03	1.42E-03	3.68E-02	…	4.46E-02
Selenium	...	...	1.15E-08	2.57E-09	2.36E-07	…	2.50E-07
Sulfur dioxide, SO_2	7.29E-01	...	...	...	1.76E-08	…	7.29E-01
Sulfur oxides, SO_X	...	...	1.16E-03	3.02E-04	4.44E-04	3.98E-03	5.88E-03
Toluene	...	...	2.37E-10	1.19E-10	...	…	3.56E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	2.66E-02	...	1.10E-03	3.55E-04	6.48E-05	6.78E-03	3.49E-02
Xylenes	...	...	1.17E-10	5.86E-11	...	…	1.75E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	2.18E+01	...	...	...	...	…	2.18E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.79E-04	3.99E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E2a. Ready Mix 2 (25-MPa) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	3.24E+02	...	...	...	...	...	3.24E+02
Cement rock, marl	5.56E+01	...	...	...	...	...	5.56E+01
Shale	1.40E+01	...	...	...	...	...	1.40E+01
Clay	1.71E+01	...	...	...	...	...	1.71E+01
Bottom ash	2.77E+00	...	...	...	...	...	2.77E+00
Fly ash	3.68E+00	...	...	...	...	...	3.68E+00
Foundry sand	1.11E+00	...	...	...	...	...	1.11E+00
Sand	1.12E+01	...	...	...	...	...	1.12E+01
Iron, iron ore	3.82E+00	...	...	...	...	...	3.82E+00
Blast furnace slag	5.75E+00	...	...	...	...	...	5.75E+00
Slate	2.85E-01	...	...	...	...	...	2.85E-01
Other raw material	7.87E+00	...	...	...	...	...	7.87E+00
Gypsum, anhydrite	1.35E+01	...	...	...	...	...	1.35E+01
Water, process	2.24E+01	...	...	...	...	...	1.63E+02
Water, non-process	2.16E+02	...	no data	no data	7.74E+00	...	2.24E+02
Coarse aggregate, natural	...	...	8.78E+02	...	...	...	8.78E+02
Coarse aggregate, manufactured	...	...	...	3.09E+02	...	...	3.09E+02
Fine aggregate, natural	...	...	7.71E+02	...	...	...	7.71E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	8.23E-02	...	no data	no data	...	...	8.23E-02
Refractory	1.75E-01	...	...	...	...	...	1.75E-01
Grinding media	3.90E-02	...	...	...	...	...	3.90E-02
Grinding aids	1.00E-01	...	...	...	...	...	1.00E-01
Filter bags	5.37E-03	...	...	...	...	...	5.37E-03
Oil & grease	3.62E-02	...	...	...	no data	...	3.62E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	1.90E-01	...	...	...	...	...	1.90E-01
Chains	5.34E-03	...	...	...	...	...	5.34E-03
Fuel and electricity							
Coal (metric ton)	2.81E-02	...	...	...	...	…	2.81E-02
Gasoline (L)	1.17E-02	...	3.74E-02	1.21E-02	...	5.17E-01	5.78E-01
Liquefied petroleum gas (L)	7.83E-03	...	...	...	...	…	7.83E-03
Middle distillates (L)	2.60E-01	...	3.87E-01	1.20E-01	4.35E-01	1.52E+00	2.72E+00
Natural gas (thousand m^3)	1.09E-03	...	6.87E-05	3.32E-05	2.93E-04	…	1.48E-03
Petroleum coke (metric ton)	6.27E-03	...	...	...	...	…	6.27E-03
Residual oil (L)	2.68E-02	...	8.68E-02	1.86E-02	...	1.01E-01	2.33E-01
Wastes (GJ)	1.13E-01	...	...	...	...	…	1.13E-01
Electricity (kWh)	3.92E+01	...	4.37E+00	1.05E+00	4.11E+00	…	4.87E+01
Energy equivalent, GJ							
Coal	6.87E-01	...	...	...	...	…	6.87E-01
Gasoline	4.08E-04	...	1.30E-03	4.21E-04	...	1.80E-02	2.02E-02
Liquefied petroleum gas	1.98E-04	...	...	...	...	…	1.98E-04
Middle distillates	1.00E-02	...	1.49E-02	4.64E-03	1.68E-02	5.87E-02	1.05E-01
Natural gas	4.17E-02	...	2.63E-03	1.27E-03	1.12E-02	…	5.68E-02
Petroleum coke	2.20E-01	...	...	...	...	…	2.20E-01
Residual oil	1.12E-03	...	3.62E-03	7.78E-04	...	4.20E-03	9.71E-03
Wastes	1.13E-01	...	...	...	...	…	1.13E-01
Electricity	1.41E-01	...	1.57E-02	3.80E-03	1.48E-02	…	1.75E-01
Subtotal	1.21E+00	...	3.82E-02	1.09E-02	4.28E-02	8.09E-02	1.39E+00
Emission to water							
Aluminum	2.40E-04	...	...	...	...	…	2.40E-04
Ammonia, ammonium	2.64E-04	...	...	...	...	…	2.64E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.03E-01	...	7.45E-10	1.60E-10	3.09E-09	…	2.03E-01
Copper	...	...	3.72E-09	8.00E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	3.84E-03	...	...	...	...	…	3.84E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E2a. Ready Mix 2 (25-MPa) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.72E-09	8.00E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	1.64E-03	...	...	...	...	…	1.64E-03
Oil and grease	2.10E-03	...	5.59E-08	1.20E-08	2.32E-07	…	2.10E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	6.15E-06	...	...	...	...	…	6.15E-06
Phosphorus	1.54E-06	...	...	...	...	…	1.54E-06
Sulfates	1.72E-01	...	...	...	...	…	1.72E-01
Sulfides	1.84E-05	...	...	...	...	…	1.84E-05
Suspended solids	6.53E-02	...	1.12E-07	2.40E-08	4.64E-07	…	6.54E-02
Water (that leaves site) (L)	1.02E+03	...	...	...	3.48E+01	…	1.06E+03
Zinc	9.22E-06	...	...	...	...	…	9.22E-06
Emission to air							
1,3 Butadiene	...	...	4.83E-13	2.33E-13	...	…	7.16E-13
Acetaldehyde	...	...	4.49E-11	2.17E-11	...	…	6.66E-11
Acrolein	...	...	7.18E-12	3.47E-12	...	…	1.07E-11
Ammonia, NH_3	1.33E-03	...	...	...	1.78E-08	…	1.33E-03
Arsenic	...	...	1.37E-08	2.95E-09	3.70E-07	…	3.87E-07
Benzene	...	...	2.24E-09	4.84E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.89E-10	6.21E-11	5.09E-08	…	5.12E-08
Cadmium	...	...	4.14E-09	8.89E-10	3.01E-08	…	3.51E-08
Carbon dioxide, CO_2	2.52E+02	...	1.50E+00	4.40E-01	1.76E+00	5.95E+00	2.62E+02
Carbon dioxide, CO_2, calcination	1.54E+02	...	...	...	...	…	1.54E+02
Carbon dioxide, CO_2, combustion	9.88E+01	...	1.50E+00	4.40E-01	1.76E+00	5.95E+00	1.08E+02
Carbon monoxide, CO	2.98E-01	...	3.21E-03	1.01E-03	6.59E-04	2.93E-02	3.32E-01
Chromium	...	...	8.79E-09	1.89E-09	1.29E-06	…	1.30E-06
Cobalt	...	...	6.26E-08	1.34E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	2.73E-11	...	1.55E-13	3.34E-14	7.23E-13	…	2.82E-11
Ethylbenzene	...	...	3.59E-11	1.74E-11	...	…	5.33E-11
Formaldehyde	...	...	3.44E-07	7.41E-08	3.52E-07	…	7.70E-07
Hydrogen chlorine, HCl	2.04E-02	...	7.27E-06	1.56E-06	3.65E-05	…	2.05E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.57E-08	3.37E-09	5.27E-07	…	5.46E-07
Manganese	...	...	3.12E-08	6.70E-09	9.05E-06	…	9.09E-06
Mercury, Hg	1.70E-05	...	1.18E-09	2.52E-10	2.29E-08	…	1.70E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.04E-02	...	5.67E-05	1.68E-05	1.32E-05	3.70E-04	1.08E-02
Methylene chloride	...	...	5.01E-08	1.08E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.18E-08	2.52E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.79E-07	1.89E-07	1.58E-06	…	2.65E-06
Nitric oxide, NO (unspecified)	...	...	4.58E-05	1.41E-05	1.63E-05	1.79E-04	2.55E-04
Nitrogen oxides, NO_X	6.24E-01	...	9.18E-03	2.80E-03	1.72E-03	5.95E-02	6.97E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.47E-12	1.19E-12	...	…	3.66E-12
Particulates, PM-2.5	2.53E-05	...	...	1.74E-05	...	…	4.27E-05
Particulates, PM-10	1.78E-01	...	3.23E-01	3.16E-02	1.71E-02	1.18E-03	5.51E-01
Particulates, total	7.72E-01	...	1.84E-01	2.77E-02	4.69E-02	…	1.03E+00
Perchloroethylene	...	...	7.28E-10	1.56E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.78E-08	8.11E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.45E-06	…	4.45E-06
Propylene oxide	...	...	3.25E-11	1.57E-11	...	…	4.83E-11
Radionuclides (kBq)	...	...	3.91E-03	8.40E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.10E-09	1.53E-09	1.40E-07	…	1.49E-07
Sulfur dioxide, SO_2	3.60E-01	...	...	...	1.04E-08	…	3.60E-01
Sulfur oxides, SO_X	...	...	7.14E-04	1.79E-04	2.63E-04	2.29E-03	3.45E-03
Toluene	...	...	1.46E-10	7.06E-11	...	…	2.16E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	1.31E-02	...	6.75E-04	2.10E-04	3.85E-05	3.95E-03	1.80E-02
Xylenes	...	...	7.18E-11	3.47E-11	...	…	1.07E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	1.08E+01	...	...	...	...	…	1.08E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.10E-04	2.37E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E2b. Ready Mix 2 (4,000 psi) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	5.47E+02	...	...	...	...	...	5.47E+02
Cement rock, marl	9.37E+01	...	...	...	...	...	9.37E+01
Shale	2.36E+01	...	...	...	...	...	2.36E+01
Clay	2.89E+01	...	...	...	...	...	2.89E+01
Bottom ash	4.67E+00	...	...	...	...	...	4.67E+00
Fly ash	6.21E+00	...	...	...	...	...	6.21E+00
Foundry sand	1.87E+00	...	...	...	...	...	1.87E+00
Sand	1.89E+01	...	...	...	...	...	1.89E+01
Iron, iron ore	6.44E+00	...	...	...	...	...	6.44E+00
Blast furnace slag	9.69E+00	...	...	...	...	...	9.69E+00
Slate	4.81E-01	...	...	...	...	...	4.81E-01
Other raw material	1.33E+01	...	...	...	...	...	1.33E+01
Gypsum, anhydrite	2.28E+01	...	...	...	...	...	2.28E+01
Water, process	3.78E+01	...	...	...	...	...	2.75E+02
Water, non-process	3.65E+02	...	no data	no data	1.30E+01	...	3.78E+02
Coarse aggregate, natural	...	...	1.48E+03	...	...	...	1.48E+03
Coarse aggregate, manufactured	...	...	...	5.20E+02	...	...	5.20E+02
Fine aggregate, natural	...	...	1.30E+03	...	...	...	1.30E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.39E-01	...	no data	no data	...	...	1.39E-01
Refractory	2.95E-01	...	...	...	...	...	2.95E-01
Grinding media	6.58E-02	...	...	...	...	...	6.58E-02
Grinding aids	1.69E-01	...	...	...	...	...	1.69E-01
Filter bags	9.05E-03	...	...	...	...	...	9.05E-03
Oil & grease	6.11E-02	...	...	...	no data	...	6.11E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	3.20E-01	...	...	...	...	...	3.20E-01
Chains	9.00E-03	...	...	...	...	...	9.00E-03
Fuel and electricity							
Coal (ton)	2.37E-02	...	...	...	...	…	2.37E-02
Gasoline (gallon)	2.36E-03	...	7.55E-03	2.44E-03	...	1.04E-01	1.17E-01
Liquefied petroleum gas (gallon)	1.58E-03	...	...	...	...	…	1.58E-03
Middle distillates (gallon)	5.25E-02	...	7.81E-02	2.42E-02	8.79E-02	3.07E-01	5.49E-01
Natural gas (thousand cu ft)	2.94E-02	...	1.85E-03	8.97E-04	7.91E-03	…	4.01E-02
Petroleum coke (ton)	5.28E-03	...	...	...	...	…	5.28E-03
Residual oil (gallon)	5.41E-03	...	1.75E-02	3.76E-03	...	2.03E-02	4.70E-02
Wastes (MBtu)	8.17E-02	...	...	...	...	…	8.17E-02
Electricity (kWh)	3.00E+01	...	3.34E+00	8.06E-01	3.15E+00	…	3.73E+01
Energy equivalent, MBtu							
Coal	4.98E-01	...	...	...	...	…	4.98E-01
Gasoline	2.96E-04	...	9.44E-04	3.05E-04	...	1.31E-02	1.46E-02
Liquefied petroleum gas	1.44E-04	...	...	...	...	…	1.44E-04
Middle distillates	7.28E-03	...	1.08E-02	3.36E-03	1.22E-02	4.25E-02	7.62E-02
Natural gas	3.02E-02	...	1.90E-03	9.21E-04	8.12E-03	…	4.12E-02
Petroleum coke	1.59E-01	...	...	...	...	…	1.59E-01
Residual oil	8.11E-04	...	2.62E-03	5.64E-04	...	3.04E-03	7.04E-03
Wastes	8.17E-02	...	...	...	...	…	8.17E-02
Electricity	1.02E-01	...	1.14E-02	2.75E-03	1.07E-02	…	1.27E-01
Subtotal	8.80E-01	...	2.77E-02	7.90E-03	3.10E-02	5.86E-02	1.01E+00
Emission to water							
Aluminum	4.04E-04	...	...	...	...	…	4.04E-04
Ammonia, ammonium	4.46E-04	...	...	...	...	…	4.46E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	3.42E-01	...	1.26E-09	2.70E-10	5.22E-09	…	3.42E-01
Copper	...	...	6.28E-09	1.35E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	6.48E-03	...	...	...	...	…	6.48E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E2b. Ready Mix 2 (4,000 psi) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.28E-09	1.35E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	2.77E-03	...	...	...	...	…	2.77E-03
Oil and grease	3.53E-03	...	9.42E-08	2.02E-08	3.91E-07	…	3.53E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	1.04E-05	...	...	...	...	…	1.04E-05
Phosphorus	2.59E-06	...	...	...	...	…	2.59E-06
Sulfates	2.89E-01	...	...	...	...	…	2.89E-01
Sulfides	3.11E-05	...	...	...	...	…	3.11E-05
Suspended solids	1.10E-01	...	1.88E-07	4.04E-08	7.82E-07	…	1.10E-01
Water (that leaves site) (gallon)	2.07E+02	...	...	...	7.04E+00	…	2.14E+02
Zinc	1.55E-05	...	...	...	...	…	1.55E-05
Emission to air							
1,3 Butadiene	...	...	8.13E-13	3.93E-13	...	…	1.21E-12
Acetaldehyde	...	...	7.57E-11	3.66E-11	...	…	1.12E-10
Acrolein	...	...	1.21E-11	5.86E-12	...	…	1.80E-11
Ammonia, NH_3	2.24E-03	...	...	...	2.99E-08	…	2.24E-03
Arsenic	...	...	2.31E-08	4.97E-09	6.24E-07	…	6.53E-07
Benzene	...	...	3.77E-09	8.17E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.87E-10	1.05E-10	8.58E-08	…	8.64E-08
Cadmium	...	...	6.98E-09	1.50E-09	5.07E-08	…	5.91E-08
Carbon dioxide, CO_2	4.26E+02	...	2.53E+00	7.42E-01	2.97E+00	1.00E+01	4.42E+02
Carbon dioxide, CO_2, calcination	2.59E+02	...	...	...	...	…	2.59E+02
Carbon dioxide, CO_2, combustion	1.67E+02	...	2.53E+00	7.42E-01	2.97E+00	1.00E+01	1.83E+02
Carbon monoxide, CO	5.02E-01	...	5.41E-03	1.70E-03	1.11E-03	4.94E-02	5.59E-01
Chromium	...	...	1.48E-08	3.18E-09	2.17E-06	…	2.18E-06
Cobalt	...	...	1.06E-07	2.27E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	4.59E-11	...	2.62E-13	5.63E-14	1.22E-12	…	4.75E-11
Ethylbenzene	...	...	6.05E-11	2.93E-11	...	…	8.98E-11
Formaldehyde	...	...	5.80E-07	1.25E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	3.44E-02	...	1.23E-05	2.63E-06	6.15E-05	…	3.45E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.65E-08	5.68E-09	8.89E-07	…	9.21E-07
Manganese	...	...	5.26E-08	1.13E-08	1.52E-05	…	1.53E-05
Mercury, Hg	2.86E-05	...	1.98E-09	4.25E-10	3.86E-08	…	2.87E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.75E-02	...	9.56E-05	2.83E-05	2.23E-05	6.23E-04	1.83E-02
Methylene chloride	...	...	8.45E-08	1.81E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	1.98E-08	4.26E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.48E-06	3.18E-07	2.67E-06	…	4.47E-06
Nitric oxide, NO (unspecified)	...	...	7.72E-05	2.38E-05	2.75E-05	3.01E-04	4.29E-04
Nitrogen oxides, NO_X	1.05E+00	...	1.55E-02	4.71E-03	2.90E-03	1.00E-01	1.18E+00
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.16E-12	2.01E-12	...	…	6.17E-12
Particulates, PM-2.5	4.26E-05	...	...	2.94E-05	...	…	7.20E-05
Particulates, PM-10	2.99E-01	...	5.45E-01	5.33E-02	2.88E-02	1.98E-03	9.29E-01
Particulates, total	1.30E+00	...	3.11E-01	4.66E-02	7.90E-02	…	1.74E+00
Perchloroethylene	...	...	1.23E-09	2.64E-10	6.70E-09	…	8.20E-09
Phenolic compounds	...	...	6.37E-08	1.37E-08	2.96E-07	…	3.74E-07
Phosphorus	...	...	...	...	7.49E-06	…	7.49E-06
Propylene oxide	...	...	5.49E-11	2.65E-11	...	…	8.14E-11
Radionuclides (kBq)	...	...	6.60E-03	1.42E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.20E-08	2.57E-09	2.36E-07	…	2.51E-07
Sulfur dioxide, SO_2	6.07E-01	...	...	...	1.76E-08	…	6.07E-01
Sulfur oxides, SO_X	...	...	1.20E-03	3.02E-04	4.44E-04	3.86E-03	5.81E-03
Toluene	...	...	2.46E-10	1.19E-10	...	…	3.65E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	2.22E-02	...	1.14E-03	3.55E-04	6.48E-05	6.67E-03	3.04E-02
Xylenes	...	...	1.21E-10	5.86E-11	...	…	1.80E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	1.82E+01	...	...	...	...	…	1.82E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.86E-04	3.99E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E3a. Ready Mix 3 (20-MPa) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	2.60E+02	...	...	...	...	...	2.60E+02
Cement rock, marl	4.45E+01	...	...	...	...	...	4.45E+01
Shale	1.12E+01	...	...	...	...	...	1.12E+01
Clay	1.37E+01	...	...	...	...	...	1.37E+01
Bottom ash	2.22E+00	...	...	...	...	...	2.22E+00
Fly ash	2.95E+00	...	...	...	...	...	2.95E+00
Foundry sand	8.88E-01	...	...	...	...	...	8.88E-01
Sand	8.95E+00	...	...	...	...	...	8.95E+00
Iron, iron ore	3.06E+00	...	...	...	...	...	3.06E+00
Blast furnace slag	4.60E+00	...	...	...	...	...	4.60E+00
Slate	2.28E-01	...	...	...	...	...	2.28E-01
Other raw material	6.30E+00	...	...	...	...	...	6.30E+00
Gypsum, anhydrite	1.08E+01	...	...	...	...	...	1.08E+01
Water, process	1.79E+01	...	...	...	...	...	1.59E+02
Water, non-process	1.73E+02	...	no data	no data	7.74E+00	...	1.81E+02
Coarse aggregate, natural	...	...	8.34E+02	...	...	...	8.34E+02
Coarse aggregate, manufactured	...	...	...	2.93E+02	...	...	2.93E+02
Fine aggregate, natural	...	...	8.31E+02	...	...	...	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	6.58E-02	...	no data	no data	...	...	6.58E-02
Refractory	1.40E-01	...	...	...	...	...	1.40E-01
Grinding media	3.12E-02	...	...	...	...	...	3.12E-02
Grinding aids	8.03E-02	...	...	...	...	...	8.03E-02
Filter bags	4.30E-03	...	...	...	...	...	4.30E-03
Oil & grease	2.90E-02	...	...	...	no data	...	2.90E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	1.52E-01	...	...	...	...	...	1.52E-01
Chains	4.27E-03	...	...	...	...	...	4.27E-03
Fuel and electricity							
Coal (metric ton)	2.25E-02	...	...	...	...	…	2.25E-02
Gasoline (L)	9.36E-03	...	3.77E-02	1.15E-02	...	5.22E-01	5.81E-01
Liquefied petroleum gas (L)	6.27E-03	...	...	...	...	…	6.27E-03
Middle distillates (L)	2.08E-01	...	3.90E-01	1.14E-01	4.35E-01	1.35E+00	2.50E+00
Natural gas (thousand m^3)	8.72E-04	...	6.93E-05	3.16E-05	2.93E-04	…	1.27E-03
Petroleum coke (metric ton)	5.01E-03	...	...	...	...	…	5.01E-03
Residual oil (L)	2.14E-02	...	8.76E-02	1.77E-02	...	9.98E-02	2.27E-01
Wastes (GJ)	9.02E-02	...	...	...	...	…	9.02E-02
Electricity (kWh)	3.14E+01	...	4.42E+00	1.00E+00	4.11E+00	…	4.09E+01
Energy equivalent, GJ							
Coal	5.50E-01	...	...	...	...	…	5.50E-01
Gasoline	3.26E-04	...	1.31E-03	4.00E-04	...	1.82E-02	2.02E-02
Liquefied petroleum gas	1.59E-04	...	...	...	...	…	1.59E-04
Middle distillates	8.03E-03	...	1.51E-02	4.40E-03	1.68E-02	5.22E-02	9.66E-02
Natural gas	3.34E-02	...	2.65E-03	1.21E-03	1.12E-02	…	4.84E-02
Petroleum coke	1.76E-01	...	...	...	...	…	1.76E-01
Residual oil	8.95E-04	...	3.65E-03	7.39E-04	...	4.16E-03	9.45E-03
Wastes	9.02E-02	...	...	...	...	…	9.02E-02
Electricity	1.13E-01	...	1.59E-02	3.61E-03	1.48E-02	…	1.47E-01
Subtotal	9.71E-01	...	3.86E-02	1.04E-02	4.28E-02	7.46E-02	1.14E+00
Emission to water							
Aluminum	1.92E-04	...	...	...	...	…	1.92E-04
Ammonia, ammonium	2.11E-04	...	...	...	...	…	2.11E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	1.62E-01	...	7.52E-10	1.52E-10	3.09E-09	…	1.62E-01
Copper	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	3.07E-03	...	...	...	...	…	3.07E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E3a. Ready Mix 3 (20-MPa) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	1.32E-03	...	...	...	...	…	1.32E-03
Oil and grease	1.68E-03	...	5.64E-08	1.14E-08	2.32E-07	…	1.68E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	4.92E-06	...	...	...	...	…	4.92E-06
Phosphorus	1.23E-06	...	...	...	...	…	1.23E-06
Sulfates	1.37E-01	...	...	...	...	…	1.37E-01
Sulfides	1.48E-05	...	...	...	...	…	1.48E-05
Suspended solids	5.23E-02	...	1.13E-07	2.28E-08	4.64E-07	…	5.23E-02
Water (that leaves site) (L)	8.18E+02	...	...	...	3.48E+01	…	8.53E+02
Zinc	7.38E-06	...	...	...	...	…	7.38E-06
Emission to air							
1,3 Butadiene	...	...	4.87E-13	2.22E-13	...	…	7.09E-13
Acetaldehyde	...	...	4.53E-11	2.06E-11	...	…	6.59E-11
Acrolein	...	...	7.25E-12	3.30E-12	...	…	1.05E-11
Ammonia, NH_3	1.06E-03	...	...	...	1.78E-08	…	1.06E-03
Arsenic	...	...	1.39E-08	2.80E-09	3.62E-07	…	3.79E-07
Benzene	...	...	2.26E-09	4.60E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.92E-10	5.90E-11	5.02E-08	…	5.05E-08
Cadmium	...	...	4.18E-09	8.44E-10	3.00E-08	…	3.50E-08
Carbon dioxide, CO_2	2.02E+02	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	2.11E+02
Carbon dioxide, CO_2, calcination	1.23E+02	...	...	...	...	…	1.23E+02
Carbon dioxide, CO_2, combustion	7.91E+01	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	8.82E+01
Carbon monoxide, CO	2.38E-01	...	3.24E-03	9.59E-04	6.59E-04	2.87E-02	2.72E-01
Chromium	...	...	8.87E-09	1.79E-09	1.25E-06	…	1.26E-06
Cobalt	...	...	6.32E-08	1.28E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	2.18E-11	...	1.57E-13	3.15E-14	7.23E-13	…	2.27E-11
Ethylbenzene	...	...	3.62E-11	1.65E-11	...	…	5.27E-11
Formaldehyde	...	...	3.47E-07	7.04E-08	3.52E-07	…	7.69E-07
Hydrogen chlorine, HCl	1.63E-02	...	7.34E-06	1.48E-06	3.65E-05	…	1.64E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.59E-08	3.20E-09	5.16E-07	…	5.35E-07
Manganese	...	...	3.15E-08	6.37E-09	8.82E-06	…	8.86E-06
Mercury, Hg	1.36E-05	...	1.19E-09	2.40E-10	2.29E-08	…	1.36E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	8.31E-03	...	5.72E-05	1.59E-05	1.32E-05	3.64E-04	8.76E-03
Methylene chloride	...	...	5.06E-08	1.02E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.19E-08	2.40E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.87E-07	1.79E-07	1.54E-06	…	2.61E-06
Nitric oxide, NO (unspecified)	...	...	4.62E-05	1.34E-05	1.63E-05	1.67E-04	2.43E-04
Nitrogen oxides, NO_X	4.99E-01	...	9.27E-03	2.66E-03	1.72E-03	5.60E-02	5.69E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.49E-12	1.13E-12	...	…	3.63E-12
Particulates, PM-2.5	2.02E-05	...	...	1.66E-05	...	…	3.68E-05
Particulates, PM-10	1.42E-01	...	3.26E-01	3.01E-02	1.71E-02	1.11E-03	5.17E-01
Particulates, total	6.18E-01	...	1.86E-01	2.63E-02	4.69E-02	…	8.77E-01
Perchloroethylene	...	...	7.35E-10	1.49E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.81E-08	7.71E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.33E-06	…	4.33E-06
Propylene oxide	...	...	3.28E-11	1.50E-11	...	…	4.78E-11
Radionuclides (kBq)	...	...	3.95E-03	7.98E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.17E-09	1.45E-09	1.39E-07	…	1.48E-07
Sulfur dioxide, SO_2	2.88E-01	...	...	...	1.04E-08	…	2.88E-01
Sulfur oxides, SO_X	...	...	7.21E-04	1.70E-04	2.63E-04	2.18E-03	3.33E-03
Toluene	...	...	1.47E-10	6.70E-11	...	…	2.14E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	1.05E-02	...	6.81E-04	2.00E-04	3.85E-05	3.80E-03	1.52E-02
Xylenes	...	...	7.25E-11	3.30E-11	...	…	1.05E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	8.64E+00	...	...	...	...	…	8.64E+00
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.11E-04	2.25E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E3b. Ready Mix 3 (3,000-psi) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	4.38E+02	...	...	...	...	...	4.38E+02
Cement rock, marl	7.49E+01	...	...	...	...	...	7.49E+01
Shale	1.89E+01	...	...	...	...	...	1.89E+01
Clay	2.31E+01	...	...	...	...	...	2.31E+01
Bottom ash	3.74E+00	...	...	...	...	...	3.74E+00
Fly ash	4.97E+00	...	...	...	...	...	4.97E+00
Foundry sand	1.50E+00	...	...	...	...	...	1.50E+00
Sand	1.51E+01	...	...	...	...	...	1.51E+01
Iron, iron ore	5.15E+00	...	...	...	...	...	5.15E+00
Blast furnace slag	7.75E+00	...	...	...	...	...	7.75E+00
Slate	3.85E-01	...	...	...	...	...	3.85E-01
Other raw material	1.06E+01	...	...	...	...	...	1.06E+01
Gypsum, anhydrite	1.82E+01	...	...	...	...	...	1.82E+01
Water, process	3.02E+01	...	...	...	...	...	2.67E+02
Water, non-process	2.92E+02	...	no data	no data	1.30E+01	...	3.05E+02
Coarse aggregate, natural	...	...	1.41E+03	...	...	...	1.41E+03
Coarse aggregate, manufactured	...	...	...	4.94E+02	...	...	4.94E+02
Fine aggregate, natural	...	...	1.40E+03	...	...	...	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.11E-01	...	no data	no data	...	...	1.11E-01
Refractory	2.36E-01	...	...	...	...	...	2.36E-01
Grinding media	5.26E-02	...	...	...	...	...	5.26E-02
Grinding aids	1.35E-01	...	...	...	...	...	1.35E-01
Filter bags	7.24E-03	...	...	...	...	...	7.24E-03
Oil & grease	4.89E-02	...	...	...	no data	...	4.89E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	2.56E-01	...	...	...	...	...	2.56E-01
Chains	7.20E-03	...	...	...	...	...	7.20E-03
Fuel and electricity							
Coal (ton)	1.90E-02	...	...	...	...	…	1.90E-02
Gasoline (gallon)	1.89E-03	...	7.62E-03	2.32E-03	...	1.06E-01	1.17E-01
Liquefied petroleum gas (gallon)	1.27E-03	...	...	...	...	…	1.27E-03
Middle distillates (gallon)	4.20E-02	...	7.88E-02	2.30E-02	8.79E-02	2.73E-01	5.04E-01
Natural gas (thousand cu ft)	2.35E-02	...	1.87E-03	8.52E-04	7.91E-03	…	3.42E-02
Petroleum coke (ton)	4.23E-03	...	...	...	...	…	4.23E-03
Residual oil (gallon)	4.33E-03	...	1.77E-02	3.58E-03	...	2.02E-02	4.58E-02
Wastes (MBtu)	6.54E-02	...	...	...	...	…	6.54E-02
Electricity (kWh)	2.40E+01	...	3.38E+00	7.66E-01	3.15E+00	…	3.13E+01
Energy equivalent, MBtu							
Coal	3.98E-01	...	...	...	...	…	3.98E-01
Gasoline	2.36E-04	...	9.53E-04	2.90E-04	...	1.32E-02	1.47E-02
Liquefied petroleum gas	1.15E-04	...	...	...	...	…	1.15E-04
Middle distillates	5.82E-03	...	1.09E-02	3.19E-03	1.22E-02	3.78E-02	7.00E-02
Natural gas	2.42E-02	...	1.92E-03	8.75E-04	8.12E-03	…	3.51E-02
Petroleum coke	1.27E-01	...	...	...	...	…	1.27E-01
Residual oil	6.48E-04	...	2.65E-03	5.35E-04	...	3.02E-03	6.85E-03
Wastes	6.54E-02	...	...	...	...	…	6.54E-02
Electricity	8.18E-02	...	1.15E-02	2.61E-03	1.07E-02	…	1.07E-01
Subtotal	7.04E-01	...	2.80E-02	7.50E-03	3.10E-02	5.40E-02	8.24E-01
Emission to water							
Aluminum	3.23E-04	...	...	...	...	…	3.23E-04
Ammonia, ammonium	3.56E-04	...	...	...	...	…	3.56E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.74E-01	...	1.27E-09	2.56E-10	5.22E-09	…	2.74E-01
Copper	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	5.18E-03	...	...	...	...	…	5.18E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E3b. Ready Mix 3 (3,000-psi) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	2.22E-03	...	...	...	...	…	2.22E-03
Oil and grease	2.83E-03	...	9.50E-08	1.92E-08	3.91E-07	…	2.83E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	8.29E-06	...	...	...	...	…	8.29E-06
Phosphorus	2.07E-06	...	...	...	...	…	2.07E-06
Sulfates	2.31E-01	...	...	...	...	…	2.31E-01
Sulfides	2.49E-05	...	...	...	...	…	2.49E-05
Suspended solids	8.81E-02	...	1.90E-07	3.84E-08	7.82E-07	…	8.81E-02
Water (that leaves site) (gallon)	1.65E+02	...	...	...	7.04E+00	…	1.72E+02
Zinc	1.24E-05	...	...	...	...	…	1.24E-05
Emission to air							
1,3 Butadiene	...	...	8.21E-13	3.74E-13	...	…	1.19E-12
Acetaldehyde	...	...	7.64E-11	3.48E-11	...	…	1.11E-10
Acrolein	...	...	1.22E-11	5.56E-12	...	…	1.78E-11
Ammonia, NH_3	1.79E-03	...	...	...	2.99E-08	…	1.79E-03
Arsenic	...	...	2.34E-08	4.72E-09	6.10E-07	…	6.38E-07
Benzene	...	...	3.81E-09	7.76E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.92E-10	9.94E-11	8.45E-08	…	8.51E-08
Cadmium	...	...	7.04E-09	1.42E-09	5.05E-08	…	5.90E-08
Carbon dioxide, CO_2	3.40E+02	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	3.56E+02
Carbon dioxide, CO_2, calcination	2.07E+02	...	...	...	...	…	2.07E+02
Carbon dioxide, CO_2, combustion	1.33E+02	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	1.49E+02
Carbon monoxide, CO	4.01E-01	...	5.46E-03	1.62E-03	1.11E-03	4.84E-02	4.58E-01
Chromium	...	...	1.50E-08	3.02E-09	2.11E-06	…	2.13E-06
Cobalt	...	...	1.07E-07	2.15E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	3.68E-11	...	2.65E-13	5.30E-14	1.22E-12	…	3.83E-11
Ethylbenzene	...	...	6.11E-11	2.78E-11	...	…	8.89E-11
Formaldehyde	...	...	5.85E-07	1.19E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	2.75E-02	...	1.24E-05	2.50E-06	6.15E-05	…	2.76E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.67E-08	5.40E-09	8.69E-07	…	9.01E-07
Manganese	...	...	5.31E-08	1.07E-08	1.49E-05	…	1.49E-05
Mercury, Hg	2.29E-05	...	2.00E-09	4.04E-10	3.86E-08	…	2.29E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.40E-02	...	9.65E-05	2.69E-05	2.23E-05	6.13E-04	1.48E-02
Methylene chloride	...	...	8.53E-08	1.72E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	2.00E-08	4.04E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.50E-06	3.02E-07	2.60E-06	…	4.40E-06
Nitric oxide, NO (unspecified)	...	...	7.80E-05	2.26E-05	2.75E-05	2.81E-04	4.09E-04
Nitrogen oxides, NO_X	8.41E-01	...	1.56E-02	4.48E-03	2.90E-03	9.44E-02	9.59E-01
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.20E-12	1.91E-12	...	…	6.11E-12
Particulates, PM-2.5	3.41E-05	...	...	2.79E-05	...	…	6.20E-05
Particulates, PM-10	2.39E-01	...	5.50E-01	5.07E-02	2.88E-02	1.88E-03	8.71E-01
Particulates, total	1.04E+00	...	3.14E-01	4.43E-02	7.90E-02	…	1.48E+00
Perchloroethylene	...	...	1.24E-09	2.50E-10	6.70E-09	…	8.19E-09
Phenolic compounds	...	...	6.43E-08	1.30E-08	2.96E-07	…	3.73E-07
Phosphorus	...	...	...	...	7.31E-06	…	7.31E-06
Propylene oxide	...	...	5.54E-11	2.52E-11	...	…	8.06E-11
Radionuclides (kBq)	...	...	6.66E-03	1.35E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.21E-08	2.44E-09	2.35E-07	…	2.49E-07
Sulfur dioxide, SO_2	4.86E-01	...	...	...	1.76E-08	…	4.86E-01
Sulfur oxides, SO_X	...	...	1.21E-03	2.87E-04	4.44E-04	3.67E-03	5.62E-03
Toluene	...	...	2.48E-10	1.13E-10	...	…	3.61E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	1.77E-02	...	1.15E-03	3.37E-04	6.48E-05	6.41E-03	2.57E-02
Xylenes	...	...	1.22E-10	5.56E-11	...	…	1.78E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	1.46E+01	...	...	...	...	…	1.46E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.88E-04	3.79E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E4a. Ready Mix 4 (20-MPa, 20% Fly Ash) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	2.08E+02	...	...	...	...	...	2.08E+02
Cement rock, marl	3.56E+01	...	...	...	...	...	3.56E+01
Shale	8.98E+00	...	...	...	...	...	8.98E+00
Clay	1.10E+01	...	...	...	...	...	1.10E+01
Bottom ash	1.77E+00	...	...	...	...	...	1.77E+00
Fly ash	2.36E+00	...	...	...	...	...	4.69E+01
Foundry sand	7.11E-01	...	...	...	...	...	7.11E-01
Sand	7.16E+00	...	...	...	...	...	7.16E+00
Iron, iron ore	2.45E+00	...	...	...	...	...	2.45E+00
Blast furnace slag	3.68E+00	...	...	...	...	...	3.68E+00
Slate	1.83E-01	...	...	...	...	...	1.83E-01
Other raw material	5.04E+00	...	...	...	...	...	5.04E+00
Gypsum, anhydrite	8.67E+00	...	...	...	...	...	8.67E+00
Water, process	1.44E+01	...	...	...	...	...	1.55E+02
Water, non-process	1.39E+02	...	no data	no data	7.74E+00	...	1.46E+02
Coarse aggregate, natural	...	...	8.34E+02	...	...	...	8.34E+02
Coarse aggregate, manufactured	...	...	...	2.93E+02	...	...	2.93E+02
Fine aggregate, natural	...	...	8.31E+02	...	...	...	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	5.27E-02	...	no data	no data	...	...	5.27E-02
Refractory	1.12E-01	...	...	...	...	...	1.12E-01
Grinding media	2.50E-02	...	...	...	...	...	2.50E-02
Grinding aids	6.43E-02	...	...	...	...	...	6.43E-02
Filter bags	3.44E-03	...	...	...	...	...	3.44E-03
Oil & grease	2.32E-02	...	...	...	no data	...	2.32E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	1.21E-01	...	...	...	...	...	1.21E-01
Chains	3.42E-03	...	...	...	...	...	3.42E-03
Fuel and electricity							
Coal (metric ton)	1.80E-02	...	...	...	...	…	1.80E-02
Gasoline (L)	7.50E-03	...	3.77E-02	1.15E-02	...	5.22E-01	5.79E-01
Liquefied petroleum gas (L)	5.02E-03	...	...	...	...	…	5.02E-03
Middle distillates (L)	1.66E-01	...	3.90E-01	1.14E-01	4.35E-01	1.35E+00	2.46E+00
Natural gas (thousand m^3)	6.98E-04	...	6.93E-05	3.16E-05	2.93E-04	…	1.09E-03
Petroleum coke (metric ton)	4.01E-03	...	...	...	...	…	4.01E-03
Residual oil (L)	1.72E-02	...	8.76E-02	1.77E-02	...	9.98E-02	2.22E-01
Wastes (GJ)	7.22E-02	...	...	...	...	…	7.22E-02
Electricity (kWh)	2.51E+01	...	4.42E+00	1.00E+00	4.11E+00	…	3.46E+01
Energy equivalent, GJ							
Coal	4.40E-01	...	...	...	...	…	4.40E-01
Gasoline	2.61E-04	...	1.31E-03	4.00E-04	...	1.82E-02	2.02E-02
Liquefied petroleum gas	1.27E-04	...	...	...	...	…	1.27E-04
Middle distillates	6.43E-03	...	1.51E-02	4.40E-03	1.68E-02	5.22E-02	9.50E-02
Natural gas	2.67E-02	...	2.65E-03	1.21E-03	1.12E-02	…	4.18E-02
Petroleum coke	1.41E-01	...	...	...	...	…	1.41E-01
Residual oil	7.16E-04	...	3.65E-03	7.39E-04	...	4.16E-03	9.27E-03
Wastes	7.22E-02	...	...	...	...	…	7.22E-02
Electricity	9.04E-02	...	1.59E-02	3.61E-03	1.48E-02	…	1.25E-01
Subtotal	7.77E-01	...	3.86E-02	1.04E-02	4.28E-02	7.46E-02	9.44E-01
Emission to water							
Aluminum	1.54E-04	...	...	...	...	…	1.54E-04
Ammonia, ammonium	1.69E-04	...	...	...	...	…	1.69E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	1.30E-01	...	7.52E-10	1.52E-10	3.09E-09	…	1.30E-01
Copper	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	2.46E-03	...	...	...	...	…	2.46E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E4a. Ready Mix 4 (20-MPa, 20% Fly Ash) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	1.05E-03	...	...	...	...	…	1.05E-03
Oil and grease	1.34E-03	...	5.64E-08	1.14E-08	2.32E-07	…	1.34E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	3.94E-06	...	...	...	...	…	3.94E-06
Phosphorus	9.84E-07	...	...	...	...	…	9.84E-07
Sulfates	1.10E-01	...	...	...	...	…	1.10E-01
Sulfides	1.18E-05	...	...	...	...	…	1.18E-05
Suspended solids	4.19E-02	...	1.13E-07	2.28E-08	4.64E-07	…	4.19E-02
Water (that leaves site) (L)	6.55E+02	...	...	...	3.48E+01	…	6.90E+02
Zinc	5.91E-06	...	...	...	...	…	5.91E-06
Emission to air							
1,3 Butadiene	...	...	4.87E-13	2.22E-13	...	…	7.09E-13
Acetaldehyde	...	...	4.53E-11	2.06E-11	...	…	6.59E-11
Acrolein	...	...	7.25E-12	3.30E-12	...	…	1.05E-11
Ammonia, NH_3	8.50E-04	...	...	...	1.78E-08	…	8.50E-04
Arsenic	...	...	1.39E-08	2.80E-09	3.84E-07	…	4.01E-07
Benzene	...	...	2.26E-09	4.60E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.92E-10	5.90E-11	5.22E-08	…	5.25E-08
Cadmium	...	...	4.18E-09	8.44E-10	7.40E-08	…	7.90E-08
Carbon dioxide, CO_2	1.62E+02	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	1.71E+02
Carbon dioxide, CO_2, calcination	9.84E+01	...	...	...	...	…	9.84E+01
Carbon dioxide, CO_2, combustion	6.33E+01	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	7.24E+01
Carbon monoxide, CO	1.91E-01	...	3.24E-03	9.59E-04	6.59E-04	2.87E-02	2.24E-01
Chromium	...	...	8.87E-09	1.79E-09	1.28E-06	…	1.29E-06
Cobalt	...	...	6.32E-08	1.28E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.75E-11	...	1.57E-13	3.15E-14	7.23E-13	…	1.84E-11
Ethylbenzene	...	...	3.62E-11	1.65E-11	...	…	5.27E-11
Formaldehyde	...	...	3.47E-07	7.04E-08	3.52E-07	…	7.69E-07
Hydrogen chlorine, HCl	1.31E-02	...	7.34E-06	1.48E-06	3.65E-05	…	1.31E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.59E-08	3.20E-09	5.27E-07	…	5.46E-07
Manganese	...	...	3.15E-08	6.37E-09	8.82E-06	…	8.86E-06
Mercury, Hg	1.09E-05	...	1.19E-09	2.40E-10	2.29E-08	…	1.09E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	6.66E-03	...	5.72E-05	1.59E-05	1.32E-05	3.64E-04	7.11E-03
Methylene chloride	...	...	5.06E-08	1.02E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.19E-08	2.40E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.87E-07	1.79E-07	1.59E-06	…	2.66E-06
Nitric oxide, NO (unspecified)	...	...	4.62E-05	1.34E-05	1.63E-05	1.67E-04	2.43E-04
Nitrogen oxides, NO_X	4.00E-01	...	9.27E-03	2.66E-03	1.72E-03	5.60E-02	4.69E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.49E-12	1.13E-12	...	…	3.63E-12
Particulates, PM-2.5	1.62E-05	...	...	1.66E-05	...	…	3.28E-05
Particulates, PM-10	1.14E-01	...	3.26E-01	3.01E-02	1.71E-02	1.11E-03	4.88E-01
Particulates, total	4.94E-01	...	1.86E-01	2.63E-02	4.69E-02	…	7.54E-01
Perchloroethylene	...	...	7.35E-10	1.49E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.81E-08	7.71E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.41E-06	…	4.41E-06
Propylene oxide	...	...	3.28E-11	1.50E-11	...	…	4.78E-11
Radionuclides (kBq)	...	...	3.95E-03	7.98E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.17E-09	1.45E-09	1.41E-07	…	1.50E-07
Sulfur dioxide, SO_2	2.31E-01	...	...	...	1.04E-08	…	2.31E-01
Sulfur oxides, SO_X	...	...	7.21E-04	1.70E-04	2.63E-04	2.18E-03	3.33E-03
Toluene	...	...	1.47E-10	6.70E-11	...	…	2.14E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	8.42E-03	...	6.81E-04	2.00E-04	3.85E-05	3.80E-03	1.31E-02
Xylenes	...	...	7.25E-11	3.30E-11	...	…	1.05E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	6.92E+00	...	...	...	...	…	6.92E+00
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.11E-04	2.25E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E4b. Ready Mix 4 (3,000 psi, 20% Fly Ash) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	3.50E+02	...	...	...	...	...	3.50E+02
Cement rock, marl	6.00E+01	...	...	...	...	...	6.00E+01
Shale	1.51E+01	...	...	...	...	...	1.51E+01
Clay	1.85E+01	...	...	...	...	...	1.85E+01
Bottom ash	2.99E+00	...	...	...	...	...	2.99E+00
Fly ash	3.98E+00	...	...	...	...	...	7.90E+01
Foundry sand	1.20E+00	...	...	...	...	...	1.20E+00
Sand	1.21E+01	...	...	...	...	...	1.21E+01
Iron, iron ore	4.13E+00	...	...	...	...	...	4.13E+00
Blast furnace slag	6.21E+00	...	...	...	...	...	6.21E+00
Slate	3.08E-01	...	...	...	...	...	3.08E-01
Other raw material	8.50E+00	...	...	...	...	...	8.50E+00
Gypsum, anhydrite	1.46E+01	...	...	...	...	...	1.46E+01
Water, process	2.42E+01	...	...	...	...	...	2.61E+02
Water, non-process	2.34E+02	...	no data	no data	1.30E+01	...	2.47E+02
Coarse aggregate, natural	...	...	1.41E+03	...	...	...	1.41E+03
Coarse aggregate, manufactured	...	...	...	4.94E+02	...	...	4.98E+02
Fine aggregate, natural	...	...	1.40E+03	...	...	...	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	8.88E-02	...	no data	no data	...	...	8.88E-02
Refractory	1.89E-01	...	...	...	...	...	1.89E-01
Grinding media	4.21E-02	...	...	...	...	...	4.21E-02
Grinding aids	1.08E-01	...	...	...	...	...	1.08E-01
Filter bags	5.80E-03	...	...	...	...	...	5.80E-03
Oil & grease	3.91E-02	...	...	...	no data	...	3.91E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	2.05E-01	...	...	...	...	...	2.05E-01
Chains	5.77E-03	...	...	...	...	...	5.77E-03
Fuel and electricity							
Coal (ton)	1.52E-02	...	...	...	...	…	1.52E-02
Gasoline (gallon)	1.51E-03	...	7.62E-03	2.32E-03	...	1.06E-01	1.17E-01
Liquefied petroleum gas (gallon)	1.01E-03	...	...	...	...	…	1.01E-03
Middle distillates (gallon)	3.36E-02	...	7.88E-02	2.30E-02	8.79E-02	2.73E-01	4.96E-01
Natural gas (thousand cu ft)	1.88E-02	...	1.87E-03	8.52E-04	7.91E-03	…	2.95E-02
Petroleum coke (ton)	3.38E-03	...	...	...	...	…	3.38E-03
Residual oil (gallon)	3.47E-03	...	1.77E-02	3.58E-03	...	2.02E-02	4.49E-02
Wastes (MBtu)	5.23E-02	...	...	...	...	…	5.23E-02
Electricity (kWh)	1.92E+01	...	3.38E+00	7.66E-01	3.15E+00	…	2.65E+01
Energy equivalent, MBtu							
Coal	3.19E-01	...	...	...	...	…	3.19E-01
Gasoline	1.89E-04	...	9.53E-04	2.90E-04	...	1.32E-02	1.46E-02
Liquefied petroleum gas	9.20E-05	...	...	...	...	…	9.20E-05
Middle distillates	4.66E-03	...	1.09E-02	3.19E-03	1.22E-02	3.78E-02	6.88E-02
Natural gas	1.94E-02	...	1.92E-03	8.75E-04	8.12E-03	…	3.03E-02
Petroleum coke	1.02E-01	...	...	...	...	…	1.02E-01
Residual oil	5.19E-04	...	2.65E-03	5.35E-04	...	3.02E-03	6.72E-03
Wastes	5.23E-02	...	...	...	...	…	5.23E-02
Electricity	6.55E-02	...	1.15E-02	2.61E-03	1.07E-02	…	9.04E-02
Subtotal	5.63E-01	...	2.80E-02	7.50E-03	3.10E-02	5.40E-02	6.84E-01
Emission to water							
Aluminum	2.59E-04	...	...	...	...	…	2.59E-04
Ammonia, ammonium	2.85E-04	...	...	...	...	…	2.85E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.19E-01	...	1.27E-09	2.56E-10	5.22E-09	…	2.19E-01
Copper	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	4.15E-03	...	...	...	...	…	4.15E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E4b. Ready Mix 4 (3,000 psi, 20% Fly Ash) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	1.78E-03	...	...	...	...	…	1.78E-03
Oil and grease	2.26E-03	...	9.50E-08	1.92E-08	3.91E-07	…	2.26E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	6.64E-06	...	...	...	...	…	6.64E-06
Phosphorus	1.66E-06	...	...	...	...	…	1.66E-06
Sulfates	1.85E-01	...	...	...	...	…	1.85E-01
Sulfides	1.99E-05	...	...	...	...	…	1.99E-05
Suspended solids	7.05E-02	...	1.90E-07	3.84E-08	7.82E-07	…	7.05E-02
Water (that leaves site) (gallon)	1.32E+02	...	...	...	7.04E+00	…	1.39E+02
Zinc	9.95E-06	...	...	...	...	…	9.95E-06
Emission to air							
1,3 Butadiene	...	...	8.21E-13	3.74E-13	...	…	1.19E-12
Acetaldehyde	...	...	7.64E-11	3.48E-11	...	…	1.11E-10
Acrolein	...	...	1.22E-11	5.56E-12	...	…	1.78E-11
Ammonia, NH_3	1.43E-03	...	...	...	2.99E-08	…	1.43E-03
Arsenic	...	...	2.34E-08	4.72E-09	6.47E-07	…	6.75E-07
Benzene	...	...	3.81E-09	7.76E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.92E-10	9.94E-11	8.79E-08	…	8.85E-08
Cadmium	...	...	7.04E-09	1.42E-09	1.25E-07	…	1.33E-07
Carbon dioxide, CO_2	2.73E+02	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	2.88E+02
Carbon dioxide, CO_2, calcination	1.66E+02	...	...	...	...	…	1.66E+02
Carbon dioxide, CO_2, combustion	1.07E+02	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	1.22E+02
Carbon monoxide, CO	3.21E-01	...	5.46E-03	1.62E-03	1.11E-03	4.84E-02	3.78E-01
Chromium	...	...	1.50E-08	3.02E-09	2.16E-06	…	2.17E-06
Cobalt	...	...	1.07E-07	2.15E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	2.94E-11	...	2.65E-13	5.30E-14	1.22E-12	…	3.10E-11
Ethylbenzene	...	...	6.11E-11	2.78E-11	...	…	8.89E-11
Formaldehyde	...	...	5.85E-07	1.19E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	2.20E-02	...	1.24E-05	2.50E-06	6.15E-05	…	2.21E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.67E-08	5.40E-09	8.88E-07	…	9.20E-07
Manganese	...	...	5.31E-08	1.07E-08	1.49E-05	…	1.49E-05
Mercury, Hg	1.83E-05	...	2.00E-09	4.04E-10	3.86E-08	…	1.84E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.12E-02	...	9.65E-05	2.69E-05	2.23E-05	6.13E-04	1.20E-02
Methylene chloride	...	...	8.53E-08	1.72E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	2.00E-08	4.04E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.50E-06	3.02E-07	2.68E-06	…	4.48E-06
Nitric oxide, NO (unspecified)	...	...	7.80E-05	2.26E-05	2.75E-05	2.81E-04	4.09E-04
Nitrogen oxides, NO_X	6.74E-01	...	1.56E-02	4.48E-03	2.90E-03	9.44E-02	7.91E-01
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.20E-12	1.91E-12	...	…	6.11E-12
Particulates, PM-2.5	2.73E-05	...	...	2.79E-05	...	…	5.52E-05
Particulates, PM-10	1.92E-01	...	5.50E-01	5.07E-02	2.88E-02	1.88E-03	8.23E-01
Particulates, total	8.33E-01	...	3.14E-01	4.43E-02	7.90E-02	…	1.27E+00
Perchloroethylene	...	...	1.24E-09	2.50E-10	6.70E-09	…	8.19E-09
Phenolic compounds	...	...	6.43E-08	1.30E-08	2.96E-07	…	3.73E-07
Phosphorus	...	...	...	...	7.44E-06	…	7.44E-06
Propylene oxide	...	...	5.54E-11	2.52E-11	...	…	8.06E-11
Radionuclides (kBq)	...	...	6.66E-03	1.35E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.21E-08	2.44E-09	2.38E-07	…	2.52E-07
Sulfur dioxide, SO_2	3.89E-01	...	...	...	1.76E-08	…	3.89E-01
Sulfur oxides, SO_X	...	...	1.21E-03	2.87E-04	4.44E-04	3.67E-03	5.62E-03
Toluene	...	...	2.48E-10	1.13E-10	...	…	3.61E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	1.42E-02	...	1.15E-03	3.37E-04	6.48E-05	6.41E-03	2.21E-02
Xylenes	...	...	1.22E-10	5.56E-11	...	…	1.78E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	1.17E+01	...	...	...	...	…	1.17E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.88E-04	3.79E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E5a. Ready Mix 5 (20-MPa, 25% Fly Ash) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	1.95E+02	...	...	...	...	...	1.95E+02
Cement rock, marl	3.33E+01	...	...	...	...	...	3.33E+01
Shale	8.42E+00	...	...	...	...	...	8.42E+00
Clay	1.03E+01	...	...	...	...	...	1.03E+01
Bottom ash	1.66E+00	...	...	...	...	...	1.66E+00
Fly ash	2.21E+00	...	...	...	...	...	5.80E+01
Foundry sand	6.66E-01	...	...	...	...	...	6.66E-01
Sand	6.71E+00	...	...	...	...	...	6.71E+00
Iron, iron ore	2.29E+00	...	...	...	...	...	2.29E+00
Blast furnace slag	3.45E+00	...	...	...	...	...	3.45E+00
Slate	1.71E-01	...	...	...	...	...	1.71E-01
Other raw material	4.72E+00	...	...	...	...	...	4.72E+00
Gypsum, anhydrite	8.12E+00	...	...	...	...	...	8.12E+00
Water, process	1.34E+01	...	...	...	...	...	1.54E+02
Water, non-process	1.30E+02	...	no data	no data	7.74E+00	...	1.38E+02
Coarse aggregate, natural	...	...	8.34E+02	...	...	...	8.34E+02
Coarse aggregate, manufactured	...	...	...	2.93E+02	...	...	2.93E+02
Fine aggregate, natural	...	...	8.31E+02	...	...	...	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	4.94E-02	...	no data	no data	...	...	4.94E-02
Refractory	1.05E-01	...	...	...	...	...	1.05E-01
Grinding media	2.34E-02	...	...	...	...	...	2.34E-02
Grinding aids	6.02E-02	...	...	...	...	...	6.02E-02
Filter bags	3.22E-03	...	...	...	...	...	3.22E-03
Oil & grease	2.17E-02	...	...	...	no data	...	2.17E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	1.14E-01	...	...	...	...	...	1.14E-01
Chains	3.20E-03	...	...	...	...	...	3.20E-03
Fuel and electricity							
Coal (metric ton)	1.69E-02	...	...	...	...	…	1.69E-02
Gasoline (L)	7.02E-03	...	3.77E-02	1.15E-02	...	5.22E-01	5.79E-01
Liquefied petroleum gas (L)	4.70E-03	...	...	...	...	…	4.70E-03
Middle distillates (L)	1.56E-01	...	3.90E-01	1.14E-01	4.35E-01	1.35E+00	2.45E+00
Natural gas (thousand m^3)	6.54E-04	...	6.93E-05	3.16E-05	2.93E-04	…	1.05E-03
Petroleum coke (metric ton)	3.76E-03	...	...	...	...	…	3.76E-03
Residual oil (L)	1.61E-02	...	8.76E-02	1.77E-02	...	9.98E-02	2.21E-01
Wastes (GJ)	6.76E-02	...	...	...	...	…	6.76E-02
Electricity (kWh)	2.35E+01	...	4.42E+00	1.00E+00	4.11E+00	…	3.31E+01
Energy equivalent, GJ							
Coal	4.12E-01	...	...	...	...	…	4.12E-01
Gasoline	2.45E-04	...	1.31E-03	4.00E-04	...	1.82E-02	2.02E-02
Liquefied petroleum gas	1.19E-04	...	...	...	...	…	1.19E-04
Middle distillates	6.02E-03	...	1.51E-02	4.40E-03	1.68E-02	5.22E-02	9.46E-02
Natural gas	2.50E-02	...	2.65E-03	1.21E-03	1.12E-02	…	4.01E-02
Petroleum coke	1.32E-01	...	...	...	...	…	1.32E-01
Residual oil	6.71E-04	...	3.65E-03	7.39E-04	...	4.16E-03	9.23E-03
Wastes	6.76E-02	...	...	...	...	…	6.76E-02
Electricity	8.47E-02	...	1.59E-02	3.61E-03	1.48E-02	…	1.19E-01
Subtotal	7.28E-01	...	3.86E-02	1.04E-02	4.28E-02	7.46E-02	8.95E-01
Emission to water							
Aluminum	1.44E-04	...	...	...	...	…	1.44E-04
Ammonia, ammonium	1.59E-04	...	...	...	...	…	1.59E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	1.22E-01	...	7.52E-10	1.52E-10	3.09E-09	…	1.22E-01
Copper	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	2.31E-03	...	...	...	...	…	2.31E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E5a. Ready Mix 5 (20-MPa, 25% Fly Ash) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	9.87E-04	...	...	...	...	…	9.87E-04
Oil and grease	1.26E-03	...	5.64E-08	1.14E-08	2.32E-07	…	1.26E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	3.69E-06	...	...	...	...	…	3.69E-06
Phosphorus	9.22E-07	...	...	...	...	…	9.22E-07
Sulfates	1.03E-01	...	...	...	...	…	1.03E-01
Sulfides	1.11E-05	...	...	...	...	…	1.11E-05
Suspended solids	3.92E-02	...	1.13E-07	2.28E-08	4.64E-07	…	3.92E-02
Water (that leaves site) (L)	6.14E+02	...	...	...	3.48E+01	…	6.48E+02
Zinc	5.53E-06	...	...	...	...	…	5.53E-06
Emission to air							
1,3 Butadiene	...	...	4.87E-13	2.22E-13	...	…	7.09E-13
Acetaldehyde	...	...	4.53E-11	2.06E-11	...	…	6.59E-11
Acrolein	...	...	7.25E-12	3.30E-12	...	…	1.05E-11
Ammonia, NH_3	7.96E-04	...	...	...	1.78E-08	…	7.96E-04
Arsenic	...	...	1.39E-08	2.80E-09	3.90E-07	…	4.06E-07
Benzene	...	...	2.26E-09	4.60E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.92E-10	5.90E-11	5.27E-08	…	5.30E-08
Cadmium	...	...	4.18E-09	8.44E-10	8.52E-08	…	9.02E-08
Carbon dioxide, CO_2	1.51E+02	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	1.61E+02
Carbon dioxide, CO_2, calcination	9.22E+01	...	...	...	...	…	9.22E+01
Carbon dioxide, CO_2, combustion	5.93E+01	...	1.52E+00	4.18E-01	1.76E+00	5.47E+00	6.85E+01
Carbon monoxide, CO	1.79E-01	...	3.24E-03	9.59E-04	6.59E-04	2.87E-02	2.12E-01
Chromium	...	...	8.87E-09	1.79E-09	1.29E-06	…	1.30E-06
Cobalt	...	...	6.32E-08	1.28E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.64E-11	...	1.57E-13	3.15E-14	7.23E-13	…	1.73E-11
Ethylbenzene	...	...	3.62E-11	1.65E-11	...	…	5.27E-11
Formaldehyde	...	...	3.47E-07	7.04E-08	3.52E-07	…	7.69E-07
Hydrogen chlorine, HCl	1.22E-02	...	7.34E-06	1.48E-06	3.65E-05	…	1.23E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.59E-08	3.20E-09	5.30E-07	…	5.49E-07
Manganese	...	...	3.15E-08	6.37E-09	8.82E-06	…	8.86E-06
Mercury, Hg	1.02E-05	...	1.19E-09	2.40E-10	2.29E-08	…	1.02E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	6.24E-03	...	5.72E-05	1.59E-05	1.32E-05	3.64E-04	6.69E-03
Methylene chloride	...	...	5.06E-08	1.02E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.19E-08	2.40E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.87E-07	1.79E-07	1.60E-06	…	2.67E-06
Nitric oxide, NO (unspecified)	...	...	4.62E-05	1.34E-05	1.63E-05	1.67E-04	2.43E-04
Nitrogen oxides, NO_X	3.74E-01	...	9.27E-03	2.66E-03	1.72E-03	5.60E-02	4.44E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.49E-12	1.13E-12	...	…	3.63E-12
Particulates, PM-2.5	1.52E-05	...	...	1.66E-05	...	…	3.17E-05
Particulates, PM-10	1.07E-01	...	3.26E-01	3.01E-02	1.71E-02	1.11E-03	4.81E-01
Particulates, total	4.63E-01	...	1.86E-01	2.63E-02	4.69E-02	…	7.23E-01
Perchloroethylene	...	...	7.35E-10	1.49E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.81E-08	7.71E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.43E-06	…	4.43E-06
Propylene oxide	...	...	3.28E-11	1.50E-11	...	…	4.78E-11
Radionuclides (kBq)	...	...	3.95E-03	7.98E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.17E-09	1.45E-09	1.41E-07	…	1.50E-07
Sulfur dioxide, SO_2	2.16E-01	...	...	...	1.04E-08	…	2.16E-01
Sulfur oxides, SO_X	...	...	7.21E-04	1.70E-04	2.63E-04	2.18E-03	3.33E-03
Toluene	...	...	1.47E-10	6.70E-11	...	…	2.14E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	7.89E-03	...	6.81E-04	2.00E-04	3.85E-05	3.80E-03	1.26E-02
Xylenes	...	...	7.25E-11	3.30E-11	...	…	1.05E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	6.48E+00	...	...	...	...	…	6.48E+00
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.11E-04	2.25E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E5b. Ready Mix 5 (3,000-psi, 25% Fly Ash) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	3.28E+02	...	...	...	...	...	3.28E+02
Cement rock, marl	5.62E+01	...	...	...	...	...	5.62E+01
Shale	1.42E+01	...	...	...	...	...	1.42E+01
Clay	1.73E+01	...	...	...	...	...	1.73E+01
Bottom ash	2.80E+00	...	...	...	...	...	2.80E+00
Fly ash	3.73E+00	...	...	...	...	...	9.77E+01
Foundry sand	1.12E+00	...	...	...	...	...	1.12E+00
Sand	1.13E+01	...	...	...	...	...	1.13E+01
Iron, iron ore	3.87E+00	...	...	...	...	...	3.87E+00
Blast furnace slag	5.81E+00	...	...	...	...	...	5.81E+00
Slate	2.88E-01	...	...	...	...	...	2.88E-01
Other raw material	7.96E+00	...	...	...	...	...	7.96E+00
Gypsum, anhydrite	1.37E+01	...	...	...	...	...	1.37E+01
Water, process	2.27E+01	...	...	...	...	...	2.60E+02
Water, non-process	2.19E+02	...	no data	no data	1.30E+01	...	2.32E+02
Coarse aggregate, natural	...	...	1.41E+03	...	...	...	1.41E+03
Coarse aggregate, manufactured	...	...	...	4.94E+02	...	...	4.94E+02
Fine aggregate, natural	...	...	1.40E+03	...	...	...	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	8.32E-02	...	no data	no data	...	...	8.32E-02
Refractory	1.77E-01	...	...	...	...	...	1.77E-01
Grinding media	3.95E-02	...	...	...	...	...	3.95E-02
Grinding aids	1.02E-01	...	...	...	...	...	1.02E-01
Filter bags	5.43E-03	...	...	...	...	...	5.43E-03
Oil & grease	3.67E-02	...	...	...	no data	...	3.67E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	1.92E-01	...	...	...	...	...	1.92E-01
Chains	5.40E-03	...	...	...	...	...	5.40E-03
Fuel and electricity							
Coal (ton)	1.42E-02	...	...	...	...	…	1.42E-02
Gasoline (gallon)	1.42E-03	...	7.62E-03	2.32E-03	...	1.06E-01	1.17E-01
Liquefied petroleum gas (gallon)	9.49E-04	...	...	...	...	…	9.49E-04
Middle distillates (gallon)	3.15E-02	...	7.88E-02	2.30E-02	8.79E-02	2.73E-01	4.94E-01
Natural gas (thousand cu ft)	1.77E-02	...	1.87E-03	8.52E-04	7.91E-03	…	2.83E-02
Petroleum coke (ton)	3.17E-03	...	...	...	...	…	3.17E-03
Residual oil (gallon)	3.25E-03	...	1.77E-02	3.58E-03	...	2.02E-02	4.47E-02
Wastes (MBtu)	4.90E-02	...	...	...	...	…	4.90E-02
Electricity (kWh)	1.80E+01	...	3.38E+00	7.66E-01	3.15E+00	…	2.53E+01
Energy equivalent, MBtu							
Coal	2.99E-01	...	...	...	...	…	2.99E-01
Gasoline	1.77E-04	...	9.53E-04	2.90E-04	...	1.32E-02	1.46E-02
Liquefied petroleum gas	8.62E-05	...	...	...	...	…	8.62E-05
Middle distillates	4.37E-03	...	1.09E-02	3.19E-03	1.22E-02	3.78E-02	6.85E-02
Natural gas	1.81E-02	...	1.92E-03	8.75E-04	8.12E-03	…	2.91E-02
Petroleum coke	9.55E-02	...	...	...	...	…	9.55E-02
Residual oil	4.86E-04	...	2.65E-03	5.35E-04	...	3.02E-03	6.69E-03
Wastes	4.90E-02	...	...	...	...	…	4.90E-02
Electricity	6.14E-02	...	1.15E-02	2.61E-03	1.07E-02	…	8.62E-02
Subtotal	5.28E-01	...	2.80E-02	7.50E-03	3.10E-02	5.40E-02	6.48E-01
Emission to water							
Aluminum	2.42E-04	...	...	...	...	…	2.42E-04
Ammonia, ammonium	2.67E-04	...	...	...	...	…	2.67E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.05E-01	...	1.27E-09	2.56E-10	5.22E-09	…	2.05E-01
Copper	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	3.89E-03	...	...	...	...	…	3.89E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E5b. Ready Mix 5 (3,000-psi, 25% Fly Ash) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	1.66E-03	...	...	...	...	…	1.66E-03
Oil and grease	2.12E-03	...	9.50E-08	1.92E-08	3.91E-07	…	2.12E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	6.22E-06	...	...	...	...	…	6.22E-06
Phosphorus	1.55E-06	...	...	...	...	…	1.55E-06
Sulfates	1.74E-01	...	...	...	...	…	1.74E-01
Sulfides	1.87E-05	...	...	...	...	…	1.87E-05
Suspended solids	6.61E-02	...	1.90E-07	3.84E-08	7.82E-07	…	6.61E-02
Water (that leaves site) (gallon)	1.24E+02	...	...	...	7.04E+00	…	1.31E+02
Zinc	9.33E-06	...	...	...	...	…	9.33E-06
Emission to air							
1,3 Butadiene	...	...	8.21E-13	3.74E-13	...	…	1.19E-12
Acetaldehyde	...	...	7.64E-11	3.48E-11	...	…	1.11E-10
Acrolein	...	...	1.22E-11	5.56E-12	...	…	1.78E-11
Ammonia, NH_3	1.34E-03	...	...	...	2.99E-08	…	1.34E-03
Arsenic	...	...	2.34E-08	4.72E-09	6.57E-07	…	6.85E-07
Benzene	...	...	3.81E-09	7.76E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.92E-10	9.94E-11	8.88E-08	…	8.94E-08
Cadmium	...	...	7.04E-09	1.42E-09	1.44E-07	…	1.52E-07
Carbon dioxide, CO_2	2.55E+02	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	2.71E+02
Carbon dioxide, CO_2, calcination	1.55E+02	...	...	...	...	…	1.55E+02
Carbon dioxide, CO_2, combustion	9.99E+01	...	2.56E+00	7.05E-01	2.97E+00	9.22E+00	1.15E+02
Carbon monoxide, CO	3.01E-01	...	5.46E-03	1.62E-03	1.11E-03	4.84E-02	3.58E-01
Chromium	...	...	1.50E-08	3.02E-09	2.17E-06	…	2.19E-06
Cobalt	...	...	1.07E-07	2.15E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	2.76E-11	...	2.65E-13	5.30E-14	1.22E-12	…	2.91E-11
Ethylbenzene	...	...	6.11E-11	2.78E-11	...	…	8.89E-11
Formaldehyde	...	...	5.85E-07	1.19E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	2.06E-02	...	1.24E-05	2.50E-06	6.15E-05	…	2.07E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.67E-08	5.40E-09	8.93E-07	…	9.25E-07
Manganese	...	...	5.31E-08	1.07E-08	1.49E-05	…	1.49E-05
Mercury, Hg	1.72E-05	...	2.00E-09	4.04E-10	3.86E-08	…	1.72E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.05E-02	...	9.65E-05	2.69E-05	2.23E-05	6.13E-04	1.13E-02
Methylene chloride	...	...	8.53E-08	1.72E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	2.00E-08	4.04E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.50E-06	3.02E-07	2.70E-06	…	4.50E-06
Nitric oxide, NO (unspecified)	...	...	7.80E-05	2.26E-05	2.75E-05	2.81E-04	4.09E-04
Nitrogen oxides, NO_X	6.31E-01	...	1.56E-02	4.48E-03	2.90E-03	9.44E-02	7.48E-01
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.20E-12	1.91E-12	...	…	6.11E-12
Particulates, PM-2.5	2.56E-05	...	...	2.79E-05	...	…	5.35E-05
Particulates, PM-10	1.80E-01	...	5.50E-01	5.07E-02	2.88E-02	1.88E-03	8.11E-01
Particulates, total	7.81E-01	...	3.14E-01	4.43E-02	7.90E-02	…	1.22E+00
Perchloroethylene	...	...	1.24E-09	2.50E-10	6.70E-09	…	8.19E-09
Phenolic compounds	...	...	6.43E-08	1.30E-08	2.96E-07	…	3.73E-07
Phosphorus	...	...	...	...	7.47E-06	…	7.47E-06
Propylene oxide	...	...	5.54E-11	2.52E-11	...	…	8.06E-11
Radionuclides (kBq)	...	...	6.66E-03	1.35E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.21E-08	2.44E-09	2.38E-07	…	2.53E-07
Sulfur dioxide, SO_2	3.64E-01	...	...	...	1.76E-08	…	3.64E-01
Sulfur oxides, SO_X	...	...	1.21E-03	2.87E-04	4.44E-04	3.67E-03	5.62E-03
Toluene	...	...	2.48E-10	1.13E-10	...	…	3.61E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	1.33E-02	...	1.15E-03	3.37E-04	6.48E-05	6.41E-03	2.13E-02
Xylenes	...	...	1.22E-10	5.56E-11	...	…	1.78E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	1.09E+01	...	...	...	...	…	1.09E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.88E-04	3.79E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E6a. Ready Mix 6 (20-MPa, 35% Slag Cement) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	1.68E+02	...	...	...	...	...	1.68E+02
Cement rock, marl	2.89E+01	...	...	...	...	...	2.89E+01
Shale	7.28E+00	...	...	...	...	...	7.28E+00
Clay	8.89E+00	...	...	...	...	...	8.89E+00
Bottom ash	1.44E+00	...	...	...	...	...	1.44E+00
Fly ash	1.91E+00	...	...	...	...	...	1.91E+00
Foundry sand	5.76E-01	...	...	...	...	...	5.76E-01
Sand	5.81E+00	...	...	...	...	...	5.81E+00
Iron, iron ore	1.98E+00	...	...	...	...	...	1.98E+00
Blast furnace slag	2.98E+00	7.83E+01	...	...	...	...	8.13E+01
Slate	1.48E-01	...	...	...	...	...	1.48E-01
Other raw material	4.09E+00	...	...	...	...	...	4.09E+00
Gypsum, anhydrite	7.03E+00	...	...	...	...	...	7.03E+00
Water, process	1.16E+01	...	...	...	...	...	1.52E+02
Water, non-process	1.12E+02	7.19E+01	no data	no data	7.74E+00	...	1.92E+02
Coarse aggregate, natural	...	...	8.34E+02	...	...	...	8.34E+02
Coarse aggregate, manufactured	...	...	...	2.93E+02	...	...	2.93E+02
Fine aggregate, natural	...	...	8.31E+02	...	...	...	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	7.83E+01	...	...	...	...	7.83E+01
Ancillary material							
Explosives	4.27E-02	...	no data	no data	...	...	4.27E-02
Refractory	9.08E-02	...	...	...	...	...	9.08E-02
Grinding media	2.03E-02	2.76E-02	...	...	...	...	4.79E-02
Grinding aids	5.21E-02	9.87E-05	...	...	...	...	5.22E-02
Filter bags	2.79E-03	3.30E-04	...	...	...	...	3.12E-03
Oil & grease	1.88E-02	...	...	...	no data	...	1.88E-02
Oil (L)	...	8.30E-04	...	...	no data	...	8.30E-04
Grease (L)	...	1.79E-03	...	...	no data	...	1.79E-03
Solvent (L)	...	7.19E-05	...	...	...	...	7.19E-05
Cement bags	9.84E-02	...	...	...	...	...	9.84E-02
Chains	2.77E-03	...	...	...	...	...	2.77E-03
Fuel and electricity							
Coal (metric ton)	1.46E-02	...	...	...	...	…	1.46E-02
Gasoline (L)	6.08E-03	...	3.77E-02	1.15E-02	...	5.22E-01	5.78E-01
Liquefied petroleum gas (L)	4.07E-03	...	...	...	...	…	4.07E-03
Middle distillates (L)	1.35E-01	9.87E-02	3.90E-01	1.14E-01	4.35E-01	1.35E+00	2.52E+00
Natural gas (thousand m^3)	5.66E-04	7.02E-04	6.93E-05	3.16E-05	2.93E-04	…	1.66E-03
Petroleum coke (metric ton)	3.25E-03	...	...	...	...	…	3.25E-03
Residual oil (L)	1.39E-02	...	8.76E-02	1.77E-02	...	9.98E-02	2.19E-01
Wastes (GJ)	5.85E-02	...	...	...	...	…	5.85E-02
Electricity (kWh)	2.03E+01	7.14E+00	4.42E+00	1.00E+00	4.11E+00	…	3.70E+01
Energy equivalent, GJ							
Coal	3.57E-01	...	...	...	...	…	3.57E-01
Gasoline	2.12E-04	...	1.31E-03	4.00E-04	...	1.82E-02	2.01E-02
Liquefied petroleum gas	1.03E-04	...	...	...	...	…	1.03E-04
Middle distillates	5.21E-03	3.81E-03	1.51E-02	4.40E-03	1.68E-02	5.22E-02	9.76E-02
Natural gas	2.17E-02	2.68E-02	2.65E-03	1.21E-03	1.12E-02	…	6.36E-02
Petroleum coke	1.14E-01	...	...	...	...	…	1.14E-01
Residual oil	5.81E-04	...	3.65E-03	7.39E-04	...	4.16E-03	9.14E-03
Wastes	5.85E-02	...	...	...	...	…	5.85E-02
Electricity	7.33E-02	2.57E-02	1.59E-02	3.61E-03	1.48E-02	…	1.33E-01
Subtotal	6.30E-01	5.64E-02	3.86E-02	1.04E-02	4.28E-02	7.46E-02	8.53E-01
Emission to water							
Aluminum	1.24E-04	...	...	...	...	…	1.24E-04
Ammonia, ammonium	1.37E-04	...	...	...	...	…	1.37E-04
Chemical oxygen demand, COD	...	2.27E-06	...	...	...	…	2.27E-06
Chlorides	1.05E-01	...	7.52E-10	1.52E-10	3.09E-09	…	1.05E-01
Copper	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	1.99E-03	...	...	...	...	…	1.99E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E6a. Ready Mix 6 (20-MPa, 35% Slag Cement) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	8.54E-04	...	...	...	...	…	8.54E-04
Oil and grease	1.09E-03	...	5.64E-08	1.14E-08	2.32E-07	…	1.09E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	3.19E-06	...	...	...	...	…	3.19E-06
Phosphorus	7.98E-07	...	...	...	...	…	7.98E-07
Sulfates	8.91E-02	...	...	...	...	…	8.91E-02
Sulfides	9.57E-06	...	...	...	...	…	9.57E-06
Suspended solids	3.39E-02	4.78E-04	1.13E-07	2.28E-08	4.64E-07	…	3.44E-02
Water (that leaves site) (L)	5.31E+02	2.76E+01	...	...	3.48E+01	…	5.93E+02
Zinc	4.79E-06	...	...	...	...	…	4.79E-06
Emission to air							
1,3 Butadiene	...	...	4.87E-13	2.22E-13	...	…	7.09E-13
Acetaldehyde	...	...	4.53E-11	2.06E-11	...	…	6.59E-11
Acrolein	...	...	7.25E-12	3.30E-12	...	…	1.05E-11
Ammonia, NH_3	6.89E-04	...	...	...	1.78E-08	…	6.89E-04
Arsenic	...	...	1.39E-08	2.80E-09	4.01E-07	…	4.18E-07
Benzene	...	...	2.26E-09	4.60E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.92E-10	5.90E-11	5.37E-08	…	5.40E-08
Cadmium	...	...	4.18E-09	8.44E-10	1.07E-07	…	1.12E-07
Carbon dioxide, CO_2	1.31E+02	1.64E+00	1.52E+00	4.18E-01	1.76E+00	5.47E+00	1.42E+02
Carbon dioxide, CO_2, calcination	7.98E+01	…	...	...	...	…	7.98E+01
Carbon dioxide, CO_2, combustion	5.13E+01	1.64E+00	1.52E+00	4.18E-01	1.76E+00	5.47E+00	6.21E+01
Carbon monoxide, CO	1.55E-01	5.40E-03	3.24E-03	9.59E-04	6.59E-04	2.87E-02	1.94E-01
Chromium	...	...	8.87E-09	1.79E-09	1.30E-06	…	1.31E-06
Cobalt	...	...	6.32E-08	1.28E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.42E-11	...	1.57E-13	3.15E-14	7.23E-13	…	1.51E-11
Ethylbenzene	...	...	3.62E-11	1.65E-11	...	…	5.27E-11
Formaldehyde	...	...	3.47E-07	7.04E-08	3.52E-07	…	7.69E-07
Hydrogen chlorine, HCl	1.06E-02	...	7.34E-06	1.48E-06	3.65E-05	…	1.06E-02
Hydrogen sulfide, H_2S	...	2.11E-02	...	...	...	…	2.11E-02
Lead	...	...	1.59E-08	3.20E-09	5.36E-07	…	5.55E-07
Manganese	...	...	3.15E-08	6.37E-09	8.83E-06	…	8.86E-06
Mercury, Hg	8.81E-06	...	1.19E-09	2.40E-10	2.29E-08	…	8.84E-06
Metals, not specified	...	5.13E-06	...	...	...	…	5.13E-06
Methane, CH_4	5.40E-03	1.16E-04	5.72E-05	1.59E-05	1.32E-05	3.64E-04	5.96E-03
Methylene chloride	...	...	5.06E-08	1.02E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.19E-08	2.40E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.87E-07	1.79E-07	1.63E-06	…	2.70E-06
Nitric oxide, NO (unspecified)	...	...	4.62E-05	1.34E-05	1.63E-05	1.67E-04	2.43E-04
Nitrogen oxides, NO_X	3.24E-01	2.46E-03	9.27E-03	2.66E-03	1.72E-03	5.60E-02	3.96E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.49E-12	1.13E-12	...	…	3.63E-12
Particulates, PM-2.5	1.31E-05	...	...	1.66E-05	...	…	2.97E-05
Particulates, PM-10	9.22E-02	...	3.26E-01	3.01E-02	1.71E-02	1.11E-03	4.67E-01
Particulates, total	4.01E-01	1.20E-02	1.86E-01	2.63E-02	4.69E-02	…	6.72E-01
Perchloroethylene	...	...	7.35E-10	1.49E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.81E-08	7.71E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.47E-06	…	4.47E-06
Propylene oxide	...	...	3.28E-11	1.50E-11	...	…	4.78E-11
Radionuclides (kBq)	...	...	3.95E-03	7.98E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.17E-09	1.45E-09	1.42E-07	…	1.51E-07
Sulfur dioxide, SO_2	1.87E-01	1.82E-02	...	...	1.04E-08	…	2.05E-01
Sulfur oxides, SO_X	...	...	7.21E-04	1.70E-04	2.63E-04	2.18E-03	3.33E-03
Toluene	...	...	1.47E-10	6.70E-11	...	…	2.14E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	6.82E-03	1.77E-04	6.81E-04	2.00E-04	3.85E-05	3.80E-03	1.17E-02
Xylenes	...	...	7.25E-11	3.30E-11	...	…	1.05E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	5.61E+00	...	...	...	...	…	5.61E+00
Slag reject	...	7.20E-02	...	...	...	…	7.20E-02
Other solid waste	...	1.57E-02	1.11E-04	2.25E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E6b. Ready Mix 6 (3,000-psi, 35% Slag Cement) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	2.84E+02	...	...	...	...	...	2.84E+02
Cement rock, marl	4.86E+01	...	...	...	...	...	4.86E+01
Shale	1.23E+01	...	...	...	...	...	1.23E+01
Clay	1.50E+01	...	...	...	...	...	1.50E+01
Bottom ash	2.42E+00	...	...	...	...	...	2.42E+00
Fly ash	3.22E+00	...	...	...	...	...	3.22E+00
Foundry sand	9.72E-01	...	...	...	...	...	9.72E-01
Sand	9.79E+00	...	...	...	...	...	9.79E+00
Iron, iron ore	3.34E+00	...	...	...	...	...	3.34E+00
Blast furnace slag	5.03E+00	1.32E+02	...	...	...	...	1.37E+02
Slate	2.50E-01	...	...	...	...	...	2.50E-01
Other raw material	6.89E+00	...	...	...	...	...	6.89E+00
Gypsum, anhydrite	1.18E+01	...	...	...	...	...	1.18E+01
Water, process	1.96E+01	...	...	...	...	...	2.57E+02
Water, non-process	1.89E+02	1.21E+02	no data	no data	1.30E+01	...	3.24E+02
Coarse aggregate, natural	...	...	1.41E+03	...	...	...	1.41E+03
Coarse aggregate, manufactured	...	...	...	4.94E+02	...	...	4.94E+02
Fine aggregate, natural	...	...	1.40E+03	...	...	...	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	1.32E+02	...	...	...	...	1.32E+02
Ancillary material							
Explosives	7.20E-02	...	no data	no data	...	...	7.20E-02
Refractory	1.53E-01	...	...	...	...	...	1.53E-01
Grinding media	3.42E-02	4.66E-02	...	...	...	...	8.08E-02
Grinding aids	8.78E-02	1.66E-04	...	...	...	...	8.80E-02
Filter bags	4.70E-03	5.56E-04	...	...	...	...	5.26E-03
Oil & grease	3.17E-02	...	...	...	no data	...	3.17E-02
Oil (gallon)	...	1.68E-04	...	...	no data	...	1.68E-04
Grease (gallon)	...	3.62E-04	...	...	no data	...	3.62E-04
Solvent (gallon)	...	1.45E-05	...	...	...	...	1.45E-05
Cement bags	1.66E-01	...	...	...	...	...	1.66E-01
Chains	4.67E-03	...	...	...	...	...	4.67E-03
Fuel and electricity							
Coal (ton)	1.23E-02	...	...	...	...	…	1.23E-02
Gasoline (gallon)	1.23E-03	...	7.62E-03	2.32E-03	...	1.06E-01	1.17E-01
Liquefied petroleum gas (gallon)	8.21E-04	...	...	...	...	…	8.21E-04
Middle distillates (gallon)	2.72E-02	1.99E-02	7.88E-02	2.30E-02	8.79E-02	2.73E-01	5.10E-01
Natural gas (thousand cu ft)	1.53E-02	1.89E-02	1.87E-03	8.52E-04	7.91E-03	…	4.49E-02
Petroleum coke (ton)	2.74E-03	...	...	...	...	…	2.74E-03
Residual oil (gallon)	2.81E-03	...	1.77E-02	3.58E-03	...	2.02E-02	4.42E-02
Wastes (MBtu)	4.24E-02	...	...	...	...	…	4.24E-02
Electricity (kWh)	1.56E+01	5.46E+00	3.38E+00	7.66E-01	3.15E+00	…	2.83E+01
Energy equivalent, MBtu							
Coal	2.59E-01	...	...	...	...	…	2.59E-01
Gasoline	1.53E-04	...	9.53E-04	2.90E-04	...	1.32E-02	1.46E-02
Liquefied petroleum gas	7.46E-05	...	...	...	...	…	7.46E-05
Middle distillates	3.78E-03	2.76E-03	1.09E-02	3.19E-03	1.22E-02	3.78E-02	7.07E-02
Natural gas	1.57E-02	1.95E-02	1.92E-03	8.75E-04	8.12E-03	…	4.61E-02
Petroleum coke	8.26E-02	...	...	...	...	…	8.26E-02
Residual oil	4.21E-04	...	2.65E-03	5.35E-04	...	3.02E-03	6.62E-03
Wastes	4.24E-02	...	...	...	...	…	4.24E-02
Electricity	5.31E-02	1.86E-02	1.15E-02	2.61E-03	1.07E-02	…	9.66E-02
Subtotal	4.57E-01	4.08E-02	2.80E-02	7.50E-03	3.10E-02	5.40E-02	6.18E-01
Emission to water							
Aluminum	2.10E-04	...	...	...	...	…	2.10E-04
Ammonia, ammonium	2.31E-04	...	...	...	...	…	2.31E-04
Chemical oxygen demand, COD	...	3.83E-06	...	...	...	…	3.83E-06
Chlorides	1.78E-01	...	1.27E-09	2.56E-10	5.22E-09	…	1.78E-01
Copper	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	3.36E-03	...	...	...	...	…	3.36E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E6b. Ready Mix 6 (3,000-psi, 35% Slag Cement) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	1.44E-03	...	...	...	...	…	1.44E-03
Oil and grease	1.83E-03	...	9.50E-08	1.92E-08	3.91E-07	…	1.83E-03
pH	8.5	no data	no data	no data	no data	…	8.45
Phenolics	5.38E-06	...	...	...	...	…	5.38E-06
Phosphorus	1.34E-06	...	...	...	...	…	1.34E-06
Sulfates	1.50E-01	...	...	...	...	…	1.50E-01
Sulfides	1.61E-05	...	...	...	...	…	1.61E-05
Suspended solids	5.72E-02	8.07E-04	1.90E-07	3.84E-08	7.82E-07	…	5.80E-02
Water (that leaves site) (gallon)	1.07E+02	5.57E+00	...	...	7.04E+00	…	1.20E+02
Zinc	8.07E-06	...	...	...	...	…	8.07E-06
Emission to air							
1,3 Butadiene	...	...	8.21E-13	3.74E-13	...	…	1.19E-12
Acetaldehyde	...	...	7.64E-11	3.48E-11	...	…	1.11E-10
Acrolein	...	...	1.22E-11	5.56E-12	...	…	1.78E-11
Ammonia, NH_3	1.16E-03	...	...	...	2.99E-08	…	1.16E-03
Arsenic	...	...	2.34E-08	4.72E-09	6.76E-07	…	7.04E-07
Benzene	...	...	3.81E-09	7.76E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.92E-10	9.94E-11	9.05E-08	…	9.11E-08
Cadmium	...	...	7.04E-09	1.42E-09	1.81E-07	…	1.90E-07
Carbon dioxide, CO_2	2.21E+02	2.77E+00	2.56E+00	7.05E-01	2.97E+00	9.22E+00	2.39E+02
Carbon dioxide, CO_2, calcination	1.34E+02	…	...	...	...	…	1.34E+02
Carbon dioxide, CO_2, combustion	8.65E+01	2.77E+00	2.56E+00	7.05E-01	2.97E+00	9.22E+00	1.05E+02
Carbon monoxide, CO	2.61E-01	9.10E-03	5.46E-03	1.62E-03	1.11E-03	4.84E-02	3.26E-01
Chromium	...	...	1.50E-08	3.02E-09	2.19E-06	…	2.21E-06
Cobalt	...	...	1.07E-07	2.15E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	2.39E-11	...	2.65E-13	5.30E-14	1.22E-12	…	2.54E-11
Ethylbenzene	...	...	6.11E-11	2.78E-11	...	…	8.89E-11
Formaldehyde	...	...	5.85E-07	1.19E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	1.79E-02	...	1.24E-05	2.50E-06	6.15E-05	…	1.79E-02
Hydrogen sulfide, H_2S	...	3.56E-02	...	...	...	…	3.56E-02
Lead	...	...	2.67E-08	5.40E-09	9.03E-07	…	9.35E-07
Manganese	...	...	5.31E-08	1.07E-08	1.49E-05	…	1.49E-05
Mercury, Hg	1.49E-05	...	2.00E-09	4.04E-10	3.86E-08	…	1.49E-05
Metals, not specified	...	8.65E-06	...	...	...	…	8.65E-06
Methane, CH_4	9.09E-03	1.96E-04	9.65E-05	2.69E-05	2.23E-05	6.13E-04	1.00E-02
Methylene chloride	...	...	8.53E-08	1.72E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	2.00E-08	4.04E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.50E-06	3.02E-07	2.75E-06	…	4.54E-06
Nitric oxide, NO (unspecified)	...	...	7.80E-05	2.26E-05	2.75E-05	2.81E-04	4.09E-04
Nitrogen oxides, NO_X	5.46E-01	4.15E-03	1.56E-02	4.48E-03	2.90E-03	9.44E-02	6.68E-01
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.20E-12	1.91E-12	...	…	6.11E-12
Particulates, PM-2.5	2.21E-05	...	...	2.79E-05	...	…	5.00E-05
Particulates, PM-10	1.55E-01	...	5.50E-01	5.07E-02	2.88E-02	1.88E-03	7.87E-01
Particulates, total	6.76E-01	2.03E-02	3.14E-01	4.43E-02	7.90E-02	…	1.13E+00
Perchloroethylene	...	...	1.24E-09	2.50E-10	6.70E-09	…	8.19E-09
Phenolic compounds	...	...	6.43E-08	1.30E-08	2.96E-07	…	3.73E-07
Phosphorus	...	...	...	...	7.54E-06	…	7.54E-06
Propylene oxide	...	...	5.54E-11	2.52E-11	...	…	8.06E-11
Radionuclides (kBq)	...	...	6.66E-03	1.35E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.21E-08	2.44E-09	2.40E-07	…	2.54E-07
Sulfur dioxide, SO_2	3.15E-01	3.06E-02	...	...	1.76E-08	…	3.46E-01
Sulfur oxides, SO_X	...	...	1.21E-03	2.87E-04	4.44E-04	3.67E-03	5.62E-03
Toluene	...	...	2.48E-10	1.13E-10	...	…	3.61E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	1.15E-02	2.98E-04	1.15E-03	3.37E-04	6.48E-05	6.41E-03	1.98E-02
Xylenes	...	...	1.22E-10	5.56E-11	...	…	1.78E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	9.45E+00	...	...	...	...	…	9.45E+00
Slag reject	...	1.21E-01	...	...	...	…	1.21E-01
Other solid waste	...	2.65E-02	1.88E-04	3.79E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E7a. Ready Mix 7 (20-MPa, 50% Slag Cement) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	1.30E+02	...	...	...	...	...	1.30E+02
Cement rock, marl	2.22E+01	...	...	...	...	...	2.22E+01
Shale	5.61E+00	...	...	...	...	...	5.61E+00
Clay	6.85E+00	...	...	...	...	...	6.85E+00
Bottom ash	1.11E+00	...	...	...	...	...	1.11E+00
Fly ash	1.47E+00	...	...	...	...	...	1.47E+00
Foundry sand	4.44E-01	...	...	...	...	...	4.44E-01
Sand	4.47E+00	...	...	...	...	...	4.47E+00
Iron, iron ore	1.53E+00	...	...	...	...	...	1.53E+00
Blast furnace slag	2.30E+00	1.12E+02	...	...	...	...	1.14E+02
Slate	1.14E-01	...	...	...	...	...	1.14E-01
Other raw material	3.15E+00	...	...	...	...	...	3.15E+00
Gypsum, anhydrite	5.41E+00	...	...	...	...	...	5.41E+00
Water, process	8.96E+00	...	...	...	...	...	1.50E+02
Water, non-process	8.65E+01	1.02E+02	no data	no data	7.74E+00	...	1.97E+02
Coarse aggregate, natural	...	...	8.34E+02	...	...	...	8.34E+02
Coarse aggregate, manufactured	...	...	...	2.93E+02	...	...	2.93E+02
Fine aggregate, natural	...	...	8.31E+02	...	...	...	8.31E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	1.12E+02	...	...	...	...	1.12E+02
Ancillary material							
Explosives	3.29E-02	...	no data	no data	...	...	3.29E-02
Refractory	6.99E-02	...	...	...	...	...	6.99E-02
Grinding media	1.56E-02	3.94E-02	...	...	...	...	5.50E-02
Grinding aids	4.02E-02	1.41E-04	...	...	...	...	4.03E-02
Filter bags	2.15E-03	4.70E-04	...	...	...	...	2.62E-03
Oil & grease	1.45E-02	...	...	...	no data	...	1.45E-02
Oil (L)	...	1.18E-03	...	...	no data	...	1.18E-03
Grease (L)	...	2.56E-03	...	...	no data	...	2.56E-03
Solvent (L)	...	1.02E-04	...	...	...	...	1.02E-04
Cement bags	7.58E-02	...	...	...	...	...	7.58E-02
Chains	2.14E-03	...	...	...	...	...	2.14E-03
Fuel and electricity							
Coal (metric ton)	1.12E-02	...	...	...	...	…	1.12E-02
Gasoline (L)	4.68E-03	...	3.77E-02	1.15E-02	...	5.22E-01	5.76E-01
Liquefied petroleum gas (L)	3.13E-03	...	...	...	...	…	3.13E-03
Middle distillates (L)	1.04E-01	1.41E-01	3.90E-01	1.14E-01	4.35E-01	1.35E+00	2.53E+00
Natural gas (thousand m^3)	4.36E-04	9.99E-04	6.93E-05	3.16E-05	2.93E-04	…	1.83E-03
Petroleum coke (metric ton)	2.51E-03	...	...	...	...	…	2.51E-03
Residual oil (L)	1.07E-02	...	8.76E-02	1.77E-02	...	9.98E-02	2.16E-01
Wastes (GJ)	4.51E-02	...	...	...	...	…	4.51E-02
Electricity (kWh)	1.57E+01	1.02E+01	4.42E+00	1.00E+00	4.11E+00	…	3.54E+01
Energy equivalent, GJ							
Coal	2.75E-01	...	...	...	...	…	2.75E-01
Gasoline	1.63E-04	...	1.31E-03	4.00E-04	...	1.82E-02	2.01E-02
Liquefied petroleum gas	7.93E-05	...	...	...	...	…	7.93E-05
Middle distillates	4.02E-03	5.43E-03	1.51E-02	4.40E-03	1.68E-02	5.22E-02	9.80E-02
Natural gas	1.67E-02	3.82E-02	2.65E-03	1.21E-03	1.12E-02	…	7.00E-02
Petroleum coke	8.78E-02	...	...	...	...	…	8.78E-02
Residual oil	4.47E-04	...	3.65E-03	7.39E-04	...	4.16E-03	9.00E-03
Wastes	4.51E-02	...	...	...	...	…	4.51E-02
Electricity	5.64E-02	3.66E-02	1.59E-02	3.61E-03	1.48E-02	…	1.27E-01
Subtotal	4.86E-01	8.03E-02	3.86E-02	1.04E-02	4.28E-02	7.46E-02	7.32E-01
Emission to water							
Aluminum	9.59E-05	...	...	...	...	…	9.59E-05
Ammonia, ammonium	1.06E-04	...	...	...	...	…	1.06E-04
Chemical oxygen demand, COD	...	3.24E-06	...	...	...	…	3.24E-06
Chlorides	8.11E-02	...	7.52E-10	1.52E-10	3.09E-09	…	8.11E-02
Copper	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Dissolved organic compounds	1.54E-03	...	...	...	...	…	1.54E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E7a. Ready Mix 7 (20-MPa, 50% Slag Cement) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.76E-09	7.60E-10	1.55E-08	…	2.00E-08
Nitric, nitrites	6.58E-04	...	...	...	...	…	6.58E-04
Oil and grease	8.39E-04	...	5.64E-08	1.14E-08	2.32E-07	…	8.39E-04
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	2.46E-06	...	...	...	...	…	2.46E-06
Phosphorus	6.15E-07	...	...	...	...	…	6.15E-07
Sulfates	6.87E-02	...	...	...	...	…	6.87E-02
Sulfides	7.38E-06	...	...	...	...	…	7.38E-06
Suspended solids	2.61E-02	6.81E-04	1.13E-07	2.28E-08	4.64E-07	…	2.68E-02
Water (that leaves site) (L)	4.09E+02	3.93E+01	...	...	3.48E+01	…	4.83E+02
Zinc	3.69E-06	...	...	...	...	…	3.69E-06
Emission to air							
1,3 Butadiene	...	...	4.87E-13	2.22E-13	...	…	7.09E-13
Acetaldehyde	...	...	4.53E-11	2.06E-11	...	…	6.59E-11
Acrolein	...	...	7.25E-12	3.30E-12	...	…	1.05E-11
Ammonia, NH_3	5.31E-04	...	...	...	1.78E-08	…	5.31E-04
Arsenic	...	...	1.39E-08	2.80E-09	4.17E-07	…	4.34E-07
Benzene	...	...	2.26E-09	4.60E-10	9.85E-09	…	1.26E-08
Beryllium	...	...	2.92E-10	5.90E-11	5.52E-08	…	5.55E-08
Cadmium	...	...	4.18E-09	8.44E-10	1.40E-07	…	1.45E-07
Carbon dioxide, CO_2	1.01E+02	2.34E+00	1.52E+00	4.18E-01	1.76E+00	5.47E+00	1.12E+02
Carbon dioxide, CO_2, calcination	6.15E+01	…	...	...	...	…	6.15E+01
Carbon dioxide, CO_2, combustion	3.95E+01	2.34E+00	1.52E+00	4.18E-01	1.76E+00	5.47E+00	5.10E+01
Carbon monoxide, CO	1.19E-01	7.69E-03	3.24E-03	9.59E-04	6.59E-04	2.87E-02	1.60E-01
Chromium	...	...	8.87E-09	1.79E-09	1.32E-06	…	1.33E-06
Cobalt	...	...	6.32E-08	1.28E-08	3.94E-10	…	7.64E-08
Copper	...	...	...	...	4.34E-08	…	4.34E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.09E-11	...	1.57E-13	3.15E-14	7.23E-13	…	1.18E-11
Ethylbenzene	...	...	3.62E-11	1.65E-11	...	…	5.27E-11
Formaldehyde	...	...	3.47E-07	7.04E-08	3.52E-07	…	7.69E-07
Hydrogen chlorine, HCl	8.16E-03	...	7.34E-06	1.48E-06	3.65E-05	…	8.21E-03
Hydrogen sulfide, H_2S	...	3.01E-02	...	...	...	…	3.01E-02
Lead	...	...	1.59E-08	3.20E-09	5.44E-07	…	5.63E-07
Manganese	...	...	3.15E-08	6.37E-09	8.83E-06	…	8.87E-06
Mercury, Hg	6.79E-06	...	1.19E-09	2.40E-10	2.29E-08	…	6.81E-06
Metals, not specified	...	7.31E-06	...	...	...	…	7.31E-06
Methane, CH_4	4.16E-03	1.66E-04	5.72E-05	1.59E-05	1.32E-05	3.64E-04	4.77E-03
Methylene chloride	...	...	5.06E-08	1.02E-08	2.33E-07	…	2.94E-07
Naphthalene	...	...	1.19E-08	2.40E-09	2.86E-09	…	1.71E-08
Nickel	...	...	8.87E-07	1.79E-07	1.67E-06	…	2.73E-06
Nitric oxide, NO (unspecified)	...	...	4.62E-05	1.34E-05	1.63E-05	1.67E-04	2.43E-04
Nitrogen oxides, NO_X	2.50E-01	3.51E-03	9.27E-03	2.66E-03	1.72E-03	5.60E-02	3.23E-01
Non-methane organic gases, NMOG	...	...	...	...	2.10E-06	…	2.10E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	2.49E-12	1.13E-12	...	…	3.63E-12
Particulates, PM-2.5	1.01E-05	...	...	1.66E-05	...	…	2.67E-05
Particulates, PM-10	7.10E-02	...	3.26E-01	3.01E-02	1.71E-02	1.11E-03	4.46E-01
Particulates, total	3.09E-01	1.71E-02	1.86E-01	2.63E-02	4.69E-02	…	5.85E-01
Perchloroethylene	...	...	7.35E-10	1.49E-10	3.98E-09	…	4.86E-09
Phenolic compounds	...	...	3.81E-08	7.71E-09	1.76E-07	…	2.22E-07
Phosphorus	...	...	...	...	4.53E-06	…	4.53E-06
Propylene oxide	...	...	3.28E-11	1.50E-11	...	…	4.78E-11
Radionuclides (kBq)	...	...	3.95E-03	7.98E-04	2.18E-02	…	2.66E-02
Selenium	...	...	7.17E-09	1.45E-09	1.43E-07	…	1.52E-07
Sulfur dioxide, SO_2	1.44E-01	2.59E-02	...	...	1.04E-08	…	1.70E-01
Sulfur oxides, SO_X	...	...	7.21E-04	1.70E-04	2.63E-04	2.18E-03	3.33E-03
Toluene	...	...	1.47E-10	6.70E-11	...	…	2.14E-10
Total hydrocarbon, THC	...	...	...	...	2.04E-06	…	2.04E-06
Volatile organic compounds, VOC	5.26E-03	2.52E-04	6.81E-04	2.00E-04	3.85E-05	3.80E-03	1.02E-02
Xylenes	...	...	7.25E-11	3.30E-11	...	…	1.05E-10
Zinc	...	...	...	...	2.89E-08	…	2.89E-08
Emission to land							
Cement kiln dust, CKD	4.32E+00	...	...	...	...	…	4.32E+00
Slag reject	...	1.03E-01	...	...	...	…	1.03E-01
Other solid waste	...	2.24E-02	1.11E-04	2.25E-05	2.45E+01	…	2.45E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E7b. Ready Mix 7 (3,000-psi, 50% Slag Cement) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	2.19E+02	...	...	...	...	...	2.19E+02
Cement rock, marl	3.75E+01	...	...	...	...	...	3.75E+01
Shale	9.46E+00	...	...	...	...	...	9.46E+00
Clay	1.15E+01	...	...	...	...	...	1.15E+01
Bottom ash	1.87E+00	...	...	...	...	...	1.87E+00
Fly ash	2.48E+00	...	...	...	...	...	2.48E+00
Foundry sand	7.49E-01	...	...	...	...	...	7.49E-01
Sand	7.54E+00	...	...	...	...	...	7.54E+00
Iron, iron ore	2.58E+00	...	...	...	...	...	2.58E+00
Blast furnace slag	3.88E+00	1.88E+02	...	...	...	...	1.92E+02
Slate	1.92E-01	...	...	...	...	...	1.92E-01
Other raw material	5.31E+00	...	...	...	...	...	5.31E+00
Gypsum, anhydrite	9.12E+00	...	...	...	...	...	9.12E+00
Water, process	1.51E+01	...	...	...	...	...	2.52E+02
Water, non-process	1.46E+02	1.73E+02	no data	no data	1.30E+01	...	3.32E+02
Coarse aggregate, natural	...	...	1.41E+03	...	...	...	1.41E+03
Coarse aggregate, manufactured	...	...	...	4.94E+02	...	...	4.94E+02
Fine aggregate, natural	...	...	1.40E+03	...	...	...	1.40E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	1.88E+02	...	...	...	...	1.88E+02
Ancillary material							
Explosives	5.55E-02	...	no data	no data	...	...	5.55E-02
Refractory	1.18E-01	...	...	...	...	...	1.18E-01
Grinding media	2.63E-02	6.64E-02	...	...	...	...	9.27E-02
Grinding aids	6.77E-02	2.37E-04	...	...	...	...	6.79E-02
Filter bags	3.62E-03	7.92E-04	...	...	...	...	4.41E-03
Oil & grease	2.44E-02	...	...	...	no data	...	2.44E-02
Oil (gallon)	...	2.39E-04	...	...	no data	...	2.39E-04
Grease (gallon)	...	5.16E-04	...	...	no data	...	5.16E-04
Solvent (gallon)	...	2.07E-05	...	...	...	...	2.07E-05
Cement bags	1.28E-01	...	...	...	...	...	1.28E-01
Chains	3.60E-03	...	...	...	...	...	3.60E-03
Fuel and electricity							
Coal (ton)	9.48E-03	...	...	...	...	…	9.48E-03
Gasoline (gallon)	9.46E-04	...	7.62E-03	2.32E-03	...	1.06E-01	1.16E-01
Liquefied petroleum gas (gallon)	6.33E-04	...	...	...	...	…	6.33E-04
Middle distillates (gallon)	2.10E-02	2.84E-02	7.88E-02	2.30E-02	8.79E-02	2.73E-01	5.12E-01
Natural gas (thousand cu ft)	1.18E-02	2.70E-02	1.87E-03	8.52E-04	7.91E-03	…	4.94E-02
Petroleum coke (ton)	2.11E-03	...	...	...	...	…	2.11E-03
Residual oil (gallon)	2.17E-03	...	1.77E-02	3.58E-03	...	2.02E-02	4.36E-02
Wastes (MBtu)	3.27E-02	...	...	...	...	…	3.27E-02
Electricity (kWh)	1.20E+01	7.77E+00	3.38E+00	7.66E-01	3.15E+00	…	2.70E+01
Energy equivalent, MBtu							
Coal	1.99E-01	...	...	...	...	…	1.99E-01
Gasoline	1.18E-04	...	9.53E-04	2.90E-04	...	1.32E-02	1.46E-02
Liquefied petroleum gas	5.75E-05	...	...	...	...	…	5.75E-05
Middle distillates	2.91E-03	3.94E-03	1.09E-02	3.19E-03	1.22E-02	3.78E-02	7.10E-02
Natural gas	1.21E-02	2.77E-02	1.92E-03	8.75E-04	8.12E-03	…	5.07E-02
Petroleum coke	6.37E-02	...	...	...	...	…	6.37E-02
Residual oil	3.24E-04	...	2.65E-03	5.35E-04	...	3.02E-03	6.53E-03
Wastes	3.27E-02	...	...	...	...	…	3.27E-02
Electricity	4.09E-02	2.65E-02	1.15E-02	2.61E-03	1.07E-02	…	9.23E-02
Subtotal	3.52E-01	5.82E-02	2.80E-02	7.50E-03	3.10E-02	5.40E-02	5.31E-01
Emission to water							
Aluminum	1.62E-04	...	...	...	...	…	1.62E-04
Ammonia, ammonium	1.78E-04	...	...	...	...	…	1.78E-04
Chemical oxygen demand, COD	...	5.46E-06	...	...	...	…	5.46E-06
Chlorides	1.37E-01	...	1.27E-09	2.56E-10	5.22E-09	…	1.37E-01
Copper	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Dissolved organic compounds	2.59E-03	...	...	...	...	…	2.59E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table E7b. Ready Mix 7 (3,000-psi, 50% Slag Cement) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	6.34E-09	1.28E-09	2.61E-08	…	3.37E-08
Nitric, nitrites	1.11E-03	...	...	...	...	…	1.11E-03
Oil and grease	1.41E-03	...	9.50E-08	1.92E-08	3.91E-07	…	1.41E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	4.14E-06	...	...	...	...	…	4.14E-06
Phosphorus	1.04E-06	...	...	...	...	…	1.04E-06
Sulfates	1.16E-01	...	...	...	...	…	1.16E-01
Sulfides	1.24E-05	...	...	...	...	…	1.24E-05
Suspended solids	4.41E-02	1.15E-03	1.90E-07	3.84E-08	7.82E-07	…	4.52E-02
Water (that leaves site) (gallon)	8.26E+01	7.93E+00	...	...	7.04E+00	…	9.76E+01
Zinc	6.22E-06	...	...	...	...	…	6.22E-06
Emission to air							
1,3 Butadiene	...	...	8.21E-13	3.74E-13	...	…	1.19E-12
Acetaldehyde	...	...	7.64E-11	3.48E-11	...	…	1.11E-10
Acrolein	...	...	1.22E-11	5.56E-12	...	…	1.78E-11
Ammonia, NH_3	8.94E-04	...	...	...	2.99E-08	…	8.94E-04
Arsenic	...	...	2.34E-08	4.72E-09	7.04E-07	…	7.32E-07
Benzene	...	...	3.81E-09	7.76E-10	1.66E-08	…	2.12E-08
Beryllium	...	...	4.92E-10	9.94E-11	9.30E-08	…	9.36E-08
Cadmium	...	...	7.04E-09	1.42E-09	2.37E-07	…	2.45E-07
Carbon dioxide, CO_2	1.70E+02	3.95E+00	2.56E+00	7.05E-01	2.97E+00	9.22E+00	1.90E+02
Carbon dioxide, CO_2, calcination	1.04E+02	…	...	...	...	…	1.04E+02
Carbon dioxide, CO_2, combustion	6.66E+01	3.95E+00	2.56E+00	7.05E-01	2.97E+00	9.22E+00	8.60E+01
Carbon monoxide, CO	2.01E-01	1.30E-02	5.46E-03	1.62E-03	1.11E-03	4.84E-02	2.70E-01
Chromium	...	...	1.50E-08	3.02E-09	2.22E-06	…	2.24E-06
Cobalt	...	...	1.07E-07	2.15E-08	6.64E-10	…	1.29E-07
Copper	...	...	...	...	7.31E-08	…	7.31E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.84E-11	...	2.65E-13	5.30E-14	1.22E-12	…	1.99E-11
Ethylbenzene	...	...	6.11E-11	2.78E-11	...	…	8.89E-11
Formaldehyde	...	...	5.85E-07	1.19E-07	5.93E-07	…	1.30E-06
Hydrogen chlorine, HCl	1.38E-02	...	1.24E-05	2.50E-06	6.15E-05	…	1.38E-02
Hydrogen sulfide, H_2S	...	5.07E-02	...	...	...	…	5.07E-02
Lead	...	...	2.67E-08	5.40E-09	9.17E-07	…	9.49E-07
Manganese	...	...	5.31E-08	1.07E-08	1.49E-05	…	1.49E-05
Mercury, Hg	1.14E-05	...	2.00E-09	4.04E-10	3.86E-08	…	1.15E-05
Metals, not specified	...	1.23E-05	...	...	...	…	1.23E-05
Methane, CH_4	7.01E-03	2.79E-04	9.65E-05	2.69E-05	2.23E-05	6.13E-04	8.04E-03
Methylene chloride	...	...	8.53E-08	1.72E-08	3.93E-07	…	4.96E-07
Naphthalene	...	...	2.00E-08	4.04E-09	4.82E-09	…	2.89E-08
Nickel	...	...	1.50E-06	3.02E-07	2.81E-06	…	4.61E-06
Nitric oxide, NO (unspecified)	...	...	7.80E-05	2.26E-05	2.75E-05	2.81E-04	4.09E-04
Nitrogen oxides, NO_X	4.21E-01	5.91E-03	1.56E-02	4.48E-03	2.90E-03	9.44E-02	5.44E-01
Non-methane organic gases, NMOG	...	...	...	...	3.53E-06	…	3.53E-06
Polycyclic aromatic hydrocarbons, PAH	...	...	4.20E-12	1.91E-12	...	…	6.11E-12
Particulates, PM-2.5	1.71E-05	...	...	2.79E-05	...	…	4.50E-05
Particulates, PM-10	1.20E-01	...	5.50E-01	5.07E-02	2.88E-02	1.88E-03	7.51E-01
Particulates, total	5.20E-01	2.89E-02	3.14E-01	4.43E-02	7.90E-02	…	9.87E-01
Perchloroethylene	...	...	1.24E-09	2.50E-10	6.70E-09	…	8.19E-09
Phenolic compounds	...	...	6.43E-08	1.30E-08	2.96E-07	…	3.73E-07
Phosphorus	...	...	...	...	7.64E-06	…	7.64E-06
Propylene oxide	...	...	5.54E-11	2.52E-11	...	…	8.06E-11
Radionuclides (kBq)	...	...	6.66E-03	1.35E-03	3.68E-02	…	4.48E-02
Selenium	...	...	1.21E-08	2.44E-09	2.42E-07	…	2.56E-07
Sulfur dioxide, SO_2	2.43E-01	4.36E-02	...	...	1.76E-08	…	2.87E-01
Sulfur oxides, SO_X	...	...	1.21E-03	2.87E-04	4.44E-04	3.67E-03	5.62E-03
Toluene	...	...	2.48E-10	1.13E-10	...	…	3.61E-10
Total hydrocarbon, THC	...	...	...	...	3.43E-06	…	3.43E-06
Volatile organic compounds, VOC	8.86E-03	4.25E-04	1.15E-03	3.37E-04	6.48E-05	6.41E-03	1.72E-02
Xylenes	...	...	1.22E-10	5.56E-11	...	…	1.78E-10
Zinc	...	...	...	...	4.88E-08	…	4.88E-08
Emission to land							
Cement kiln dust, CKD	7.28E+00	...	...	...	...	…	7.28E+00
Slag reject	...	1.73E-01	...	...	...	…	1.73E-01
Other solid waste	...	3.78E-02	1.88E-04	3.79E-05	4.13E+01	…	4.13E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

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APPENDIX F – CONCRETE MASONRY LCI RESULTS

Table F1a. CMU Mix LCI Results (SI Units)*

Inputs and outputs per 100 CMU (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	1.85E+02	...	...	...	...	...	1.85E+02
Cement rock, marl	3.16E+01	...	...	...	...	...	3.16E+01
Shale	7.99E+00	...	...	...	...	...	7.99E+00
Clay	9.75E+00	...	...	...	...	...	9.75E+00
Bottom ash	1.58E+00	...	...	...	...	...	1.58E+00
Fly ash	2.10E+00	...	...	...	...	...	2.10E+00
Foundry sand	6.32E-01	...	...	...	...	...	6.32E-01
Sand	6.37E+00	...	...	...	...	...	6.37E+00
Iron, iron ore	2.18E+00	...	...	...	...	...	2.18E+00
Blast furnace slag	3.27E+00	...	...	...	...	...	3.27E+00
Slate	1.62E-01	...	...	...	...	...	1.62E-01
Other raw material	4.48E+00	...	...	...	...	...	4.48E+00
Gypsum, anhydrite	7.70E+00	...	...	...	...	...	7.70E+00
Water, process	1.28E+01	...	...	...	...	...	1.22E+02
Water, non-process	1.23E+02	...	no data	no data	1.07E+01	...	1.34E+02
Coarse aggregate, natural	...	...	3.50E+02	...	...	...	3.50E+02
Coarse aggregate, manufactured	...	...	...	1.23E+02	...	...	1.23E+02
Fine aggregate, natural	...	...	1.08E+03	...	...	...	1.08E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	4.68E-02	...	no data	no data	...	...	4.68E-02
Refractory	9.96E-02	...	...	...	...	...	9.96E-02
Grinding media	2.22E-02	...	...	...	...	...	2.22E-02
Grinding aids	5.72E-02	...	...	...	...	...	5.72E-02
Filter bags	3.06E-03	...	...	...	...	...	3.06E-03
Oil & grease	2.06E-02	...	...	...	no data	...	2.06E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	1.08E-01	...	...	...	...	...	1.08E-01
Chains	3.04E-03	...	...	...	...	...	3.04E-03
Fuel and electricity							
Coal (metric ton)	1.60E-02	...	...	...	...	…	1.60E-02
Gasoline (L)	6.66E-03	...	3.24E-02	4.82E-03	...	4.52E-01	4.96E-01
Liquefied petroleum gas (L)	4.46E-03	...	...	...	1.57E+00	…	1.57E+00
Middle distillates (L)	1.48E-01	...	3.36E-01	4.78E-02	...	1.03E+00	1.56E+00
Natural gas (thousand m^3)	6.21E-04	...	5.96E-05	1.32E-05	4.03E-03	…	4.73E-03
Petroleum coke (metric ton)	3.57E-03	...	...	...	...	…	3.57E-03
Residual oil (L)	1.53E-02	...	7.53E-02	7.43E-03	...	8.43E-02	1.82E-01
Wastes (GJ)	6.42E-02	...	...	...	...	…	6.42E-02
Electricity (kWh)	2.23E+01	...	3.80E+00	4.20E-01	9.19E+00	…	3.57E+01
Energy equivalent, GJ							
Coal	3.91E-01	...	...	...	...	…	3.91E-01
Gasoline	2.32E-04	...	1.13E-03	1.68E-04	...	1.57E-02	1.73E-02
Liquefied petroleum gas	1.13E-04	...	...	...	3.97E-02	…	3.98E-02
Middle distillates	5.72E-03	...	1.30E-02	1.85E-03	...	3.97E-02	6.02E-02
Natural gas	2.37E-02	...	2.28E-03	5.07E-04	1.54E-01	…	1.81E-01
Petroleum coke	1.25E-01	...	...	...	...	…	1.25E-01
Residual oil	6.37E-04	...	3.14E-03	3.10E-04	...	3.52E-03	7.61E-03
Wastes	6.42E-02	...	...	...	...	…	6.42E-02
Electricity	8.03E-02	...	1.37E-02	1.51E-03	3.31E-02	…	1.29E-01
Subtotal	6.91E-01	...	3.32E-02	4.35E-03	2.27E-01	5.90E-02	1.01E+00
Emission to water							
Aluminum	1.37E-04	...	...	...	...	…	1.37E-04
Ammonia, ammonium	1.51E-04	...	...	...	...	…	1.51E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	1.15E-01	...	6.46E-10	6.38E-11	...	…	1.15E-01
Copper	...	...	3.23E-09	3.19E-10	...	…	3.55E-09
Dissolved organic compounds	2.19E-03	...	...	...	...	…	2.19E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table F1a. CMU Mix LCI Results (SI Units) (Continued)*

Inputs and outputs per 100 CMU (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.23E-09	3.19E-10	...	…	3.55E-09
Nitric, nitrites	9.36E-04	...	...	...	...	…	9.36E-04
Oil and grease	1.19E-03	...	4.85E-08	4.78E-09	...	…	1.19E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	3.50E-06	...	...	...	...	…	3.50E-06
Phosphorus	8.75E-07	...	...	...	...	…	8.75E-07
Sulfates	9.77E-02	...	...	...	...	…	9.77E-02
Sulfides	1.05E-05	...	...	...	...	…	1.05E-05
Suspended solids	3.72E-02	...	9.70E-08	9.57E-09	...	…	3.72E-02
Water (that leaves site) (L)	5.82E+02	...	...	...	4.52E+00	…	5.87E+02
Zinc	5.25E-06	...	...	...	...	…	5.25E-06
Emission to air							
1,3 Butadiene	...	...	4.19E-13	9.31E-14	...	…	5.12E-13
Acetaldehyde	...	...	3.90E-11	8.66E-12	...	…	4.76E-11
Acrolein	...	...	6.23E-12	1.39E-12	...	…	7.62E-12
Ammonia, NH_3	7.55E-04	...	...	...	1.60E-07	…	7.55E-04
Arsenic	...	...	1.19E-08	1.18E-09	2.74E-07	…	2.87E-07
Benzene	...	...	1.94E-09	1.93E-10	1.36E-07	…	1.38E-07
Beryllium	...	...	2.51E-10	2.48E-11	2.31E-08	…	2.34E-08
Cadmium	...	...	3.59E-09	3.54E-10	7.35E-08	…	7.75E-08
Carbon dioxide, CO_2	1.44E+02	...	1.30E+00	1.75E-01	7.92E+00	4.31E+00	1.57E+02
Carbon dioxide, CO_2, calcination	8.75E+01	...	...	...	...	…	8.75E+01
Carbon dioxide, CO_2, combustion	5.63E+01	...	1.30E+00	1.75E-01	7.92E+00	4.31E+00	7.00E+01
Carbon monoxide, CO	1.70E-01	...	2.78E-03	4.02E-04	5.46E-03	2.40E-02	2.02E-01
Chromium	...	...	7.63E-09	7.52E-10	1.05E-06	…	1.06E-06
Cobalt	...	...	5.43E-08	5.36E-09	5.43E-09	…	6.51E-08
Copper	...	...	...	...	...	…	...
Dioxins and furans, TEQ 2,3,7,8-TCDD	1.55E-11	...	1.35E-13	1.33E-14	…	…	1.57E-11
Ethylbenzene	...	...	3.12E-11	6.93E-12	...	…	3.81E-11
Formaldehyde	...	...	2.99E-07	2.95E-08	4.85E-06	…	5.17E-06
Hydrogen chlorine, HCl	1.16E-02	...	6.31E-06	6.23E-07	...	…	1.16E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.36E-08	1.34E-09	3.84E-07	…	3.99E-07
Manganese	...	...	2.71E-08	2.67E-09	6.92E-06	…	6.95E-06
Mercury, Hg	9.66E-06	...	1.02E-09	1.01E-10	1.68E-08	…	9.68E-06
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	5.92E-03	...	4.92E-05	6.69E-06	1.45E-04	3.04E-04	6.42E-03
Methylene chloride	...	...	4.35E-08	4.29E-09	...	…	4.78E-08
Naphthalene	...	...	1.02E-08	1.01E-09	3.94E-08	…	5.06E-08
Nickel	...	...	7.63E-07	7.52E-08	1.32E-06	…	2.16E-06
Nitric oxide, NO (unspecified)	...	...	3.98E-05	5.64E-06	1.45E-04	1.34E-04	3.24E-04
Nitrogen oxides, NO_X	3.55E-01	...	7.97E-03	1.12E-03	6.49E-03	4.34E-02	4.14E-01
Non-methane organic gases, NMOG	...	...	...	...	1.89E-05	…	1.89E-05
Polycyclic aromatic hydrocarbons, PAH	...	...	2.14E-12	4.76E-13	...	…	2.62E-12
Particulates, PM-2.5	1.44E-05	...	...	6.95E-06	...	…	2.14E-05
Particulates, PM-10	1.01E-01	...	2.81E-01	1.26E-02	1.35E-02	8.52E-04	4.09E-01
Particulates, total	4.40E-01	...	1.60E-01	1.10E-02	3.58E-02	…	6.47E-01
Perchloroethylene	...	...	6.32E-10	6.24E-11	...	…	6.94E-10
Phenolic compounds	...	...	3.28E-08	3.23E-09	...	…	3.60E-08
Phosphorus	...	...	...	...	3.41E-06	…	3.41E-06
Propylene oxide	...	...	2.82E-11	6.28E-12	...	…	3.45E-11
Radionuclides (kBq)	...	...	3.40E-03	3.35E-04	6.27E-03	…	1.00E-02
Selenium	...	...	6.16E-09	6.08E-10	2.57E-08	…	3.25E-08
Sulfur dioxide, SO_2	2.05E-01	...	...	...	9.42E-08	…	2.05E-01
Sulfur oxides, SO_X	...	...	6.20E-04	7.15E-05	4.08E-05	1.77E-03	2.50E-03
Toluene	...	...	1.27E-10	2.81E-11	...	…	1.55E-10
Total hydrocarbon, THC	...	...	...	...	1.84E-05	…	1.84E-05
Volatile organic compounds, VOC	7.48E-03	...	5.86E-04	8.39E-05	3.75E-04	3.08E-03	1.16E-02
Xylenes	...	...	6.23E-11	1.39E-11	...	…	7.62E-11
Zinc	...	...	...	...	...	…	...
Emission to land							
Cement kiln dust, CKD	6.15E+00	...	...	...	...	…	6.15E+00
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	9.57E-05	9.44E-06	5.11E+01	…	5.11E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table F1b. CMU Mix LCI Results (U.S. Customary Units)*

Inputs and outputs per 100 CMU (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	4.07E+02	...	...	...	...	...	4.07E+02
Cement rock, marl	6.98E+01	...	...	...	...	...	6.98E+01
Shale	1.76E+01	...	...	...	...	...	1.76E+01
Clay	2.15E+01	...	...	...	...	...	2.15E+01
Bottom ash	3.48E+00	...	...	...	...	...	3.48E+00
Fly ash	4.62E+00	...	...	...	...	...	4.62E+00
Foundry sand	1.39E+00	...	...	...	...	...	1.39E+00
Sand	1.40E+01	...	...	...	...	...	1.40E+01
Iron, iron ore	4.80E+00	...	...	...	...	...	4.80E+00
Blast furnace slag	7.22E+00	...	...	...	...	...	7.22E+00
Slate	3.58E-01	...	...	...	...	...	3.58E-01
Other raw material	9.88E+00	...	...	...	...	...	9.88E+00
Gypsum, anhydrite	1.70E+01	...	...	...	...	...	1.70E+01
Water, process	2.81E+01	...	...	...	...	...	2.68E+02
Water, non-process	2.72E+02	...	no data	no data	2.37E+01	...	2.95E+02
Coarse aggregate, natural	...	...	7.72E+02	...	...	...	7.72E+02
Coarse aggregate, manufactured	...	...	...	2.71E+02	...	...	2.71E+02
Fine aggregate, natural	...	...	2.38E+03	...	...	...	2.38E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.03E-01	...	no data	no data	...	...	1.03E-01
Refractory	2.19E-01	...	...	...	...	...	2.19E-01
Grinding media	4.90E-02	...	...	...	...	...	4.90E-02
Grinding aids	1.26E-01	...	...	...	...	...	1.26E-01
Filter bags	6.74E-03	...	...	...	...	...	6.74E-03
Oil & grease	4.55E-02	...	...	...	no data	...	4.55E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	2.38E-01	...	...	...	...	...	2.38E-01
Chains	6.70E-03	...	...	...	...	...	6.70E-03
Fuel and electricity							
Coal (ton)	1.76E-02	...	...	...	...	…	1.76E-02
Gasoline (gallon)	1.76E-03	...	8.57E-03	1.27E-03	...	1.19E-01	1.31E-01
Liquefied petroleum gas (gallon)	1.18E-03	...	...	...	4.14E-01	…	4.16E-01
Middle distillates (gallon)	3.91E-02	...	8.87E-02	1.26E-02	...	2.71E-01	4.12E-01
Natural gas (thousand cu ft)	2.19E-02	...	2.11E-03	4.68E-04	1.42E-01	…	1.67E-01
Petroleum coke (ton)	3.93E-03	...	...	...	...	…	3.93E-03
Residual oil (gallon)	4.03E-03	...	1.99E-02	1.96E-03	...	2.23E-02	4.82E-02
Wastes (MBtu)	6.08E-02	...	...	...	...	…	6.08E-02
Electricity (kWh)	2.23E+01	...	3.80E+00	4.20E-01	9.19E+00	…	3.57E+01
Energy equivalent, MBtu							
Coal	3.71E-01	...	...	...	...	…	3.71E-01
Gasoline	2.20E-04	...	1.07E-03	1.59E-04	...	1.49E-02	1.64E-02
Liquefied petroleum gas	1.07E-04	...	...	...	3.76E-02	…	3.77E-02
Middle distillates	5.42E-03	...	1.23E-02	1.75E-03	...	3.76E-02	5.71E-02
Natural gas	2.25E-02	...	2.16E-03	4.80E-04	1.46E-01	…	1.71E-01
Petroleum coke	1.18E-01	...	...	...	...	…	1.18E-01
Residual oil	6.04E-04	...	2.98E-03	2.94E-04	...	3.33E-03	7.21E-03
Wastes	6.08E-02	...	...	...	...	…	6.08E-02
Electricity	7.61E-02	...	1.30E-02	1.43E-03	3.14E-02	…	1.22E-01
Subtotal	6.55E-01	...	3.15E-02	4.12E-03	2.15E-01	5.59E-02	9.62E-01
Emission to water							
Aluminum	3.01E-04	...	...	...	...	…	3.01E-04
Ammonia, ammonium	3.32E-04	...	...	...	...	…	3.32E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.55E-01	...	1.43E-09	1.41E-10	...	…	2.55E-01
Copper	...	...	7.13E-09	7.03E-10	...	…	7.83E-09
Dissolved organic compounds	4.82E-03	...	...	...	...	…	4.82E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table F1b. CMU Mix LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per 100 CMU (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	7.13E-09	7.03E-10	...	…	7.83E-09
Nitric, nitrites	2.06E-03	...	...	...	...	…	2.06E-03
Oil and grease	2.63E-03	...	1.07E-07	1.05E-08	...	…	2.63E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	7.72E-06	...	...	...	...	…	7.72E-06
Phosphorus	1.93E-06	...	...	...	...	…	1.93E-06
Sulfates	2.15E-01	...	...	...	...	…	2.15E-01
Sulfides	2.31E-05	...	...	...	...	…	2.31E-05
Suspended solids	8.20E-02	...	2.14E-07	2.11E-08	...	…	8.20E-02
Water (that leaves site) (gallon)	1.54E+02	...	...	...	1.19E+00	…	1.55E+02
Zinc	1.16E-05	...	...	...	...	…	1.16E-05
Emission to air							
1,3 Butadiene	...	...	9.23E-13	2.05E-13	...	…	1.13E-12
Acetaldehyde	...	...	8.59E-11	1.91E-11	...	…	1.05E-10
Acrolein	...	...	1.37E-11	3.05E-12	...	…	1.68E-11
Ammonia, NH_3	1.67E-03	...	...	...	3.53E-07	…	1.67E-03
Arsenic	...	...	2.63E-08	2.59E-09	6.03E-07	…	6.32E-07
Benzene	...	...	4.28E-09	4.26E-10	2.99E-07	…	3.04E-07
Beryllium	...	...	5.53E-10	5.46E-11	5.09E-08	…	5.15E-08
Cadmium	...	...	7.92E-09	7.81E-10	1.62E-07	…	1.71E-07
Carbon dioxide, CO_2	3.17E+02	...	2.87E+00	3.87E-01	1.75E+01	9.50E+00	3.47E+02
Carbon dioxide, CO_2, calcination	1.93E+02	...	...	...	...	…	1.93E+02
Carbon dioxide, CO_2, combustion	1.24E+02	...	2.87E+00	3.87E-01	1.75E+01	9.50E+00	1.54E+02
Carbon monoxide, CO	3.74E-01	...	6.14E-03	8.87E-04	1.20E-02	5.30E-02	4.46E-01
Chromium	...	...	1.68E-08	1.66E-09	2.32E-06	…	2.34E-06
Cobalt	...	...	1.20E-07	1.18E-08	1.20E-08	…	1.44E-07
Copper	...	...	...	...	...	…	...
Dioxins and furans, TEQ 2,3,7,8-TCDD	3.42E-11	...	2.98E-13	2.93E-14	...	…	3.45E-11
Ethylbenzene	...	...	6.87E-11	1.53E-11	...	…	8.40E-11
Formaldehyde	...	...	6.58E-07	6.51E-08	1.07E-05	…	1.14E-05
Hydrogen chlorine, HCl	2.56E-02	...	1.39E-05	1.37E-06	...	…	2.56E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	3.00E-08	2.96E-09	8.47E-07	…	8.80E-07
Manganese	...	...	5.97E-08	5.89E-09	1.52E-05	…	1.53E-05
Mercury, Hg	2.13E-05	...	2.25E-09	2.22E-10	3.70E-08	…	2.13E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.30E-02	...	1.09E-04	1.47E-05	3.20E-04	6.71E-04	1.42E-02
Methylene chloride	...	...	9.59E-08	9.47E-09	...	…	1.05E-07
Naphthalene	...	...	2.25E-08	2.22E-09	8.69E-08	…	1.12E-07
Nickel	...	...	1.68E-06	1.66E-07	2.91E-06	…	4.76E-06
Nitric oxide, NO (unspecified)	...	...	8.77E-05	1.24E-05	3.20E-04	2.95E-04	7.15E-04
Nitrogen oxides, NO_X	7.83E-01	...	1.76E-02	2.46E-03	1.43E-02	9.57E-02	9.13E-01
Non-methane organic gases, NMOG	...	...	...	...	4.16E-05	…	4.16E-05
Polycyclic aromatic hydrocarbons, PAH	...	...	4.72E-12	1.05E-12	...	…	5.77E-12
Particulates, PM-2.5	3.18E-05	...	...	1.53E-05	...	…	4.71E-05
Particulates, PM-10	2.23E-01	...	6.19E-01	2.78E-02	2.98E-02	1.88E-03	9.01E-01
Particulates, total	9.69E-01	...	3.53E-01	2.43E-02	7.90E-02	…	1.43E+00
Perchloroethylene	...	...	1.39E-09	1.37E-10	...	…	1.53E-09
Phenolic compounds	...	...	7.23E-08	7.13E-09	...	…	7.94E-08
Phosphorus	...	...	...	...	7.51E-06	…	7.51E-06
Propylene oxide	...	...	6.23E-11	1.38E-11	...	…	7.61E-11
Radionuclides (kBq)	...	...	7.49E-03	7.39E-04	1.38E-02	…	2.20E-02
Selenium	...	...	1.36E-08	1.34E-09	5.68E-08	…	7.17E-08
Sulfur dioxide, SO_2	4.52E-01	...	...	...	2.08E-07	…	4.52E-01
Sulfur oxides, SO_X	...	...	1.37E-03	1.58E-04	9.01E-05	3.91E-03	5.52E-03
Toluene	...	...	2.79E-10	6.20E-11	...	…	3.41E-10
Total hydrocarbon, THC	...	...	...	...	4.05E-05	…	4.05E-05
Volatile organic compounds, VOC	1.65E-02	...	1.29E-03	1.85E-04	8.28E-04	6.78E-03	2.56E-02
Xylenes	...	...	1.37E-10	3.05E-11	...	…	1.68E-10
Zinc	...	...	...	...	...	…	...
Emission to land							
Cement kiln dust, CKD	1.36E+01	...	...	...	...	…	1.36E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	2.11E-04	2.08E-05	1.13E+02	…	1.13E+02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

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APPENDIX G – PRECAST CONCRETE LCI RESULTS

Table G1a. Precast Mix 1 (50-MPa) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	5.87E+02	...	...	...	...	...	5.87E+02
Cement rock, marl	1.01E+02	...	...	...	...	...	1.01E+02
Shale	2.54E+01	...	...	...	...	...	2.54E+01
Clay	3.10E+01	...	...	...	...	...	3.10E+01
Bottom ash	5.01E+00	...	...	...	...	...	5.01E+00
Fly ash	6.66E+00	...	...	...	...	...	6.66E+00
Foundry sand	2.01E+00	...	...	...	...	...	2.01E+00
Sand	2.02E+01	...	...	...	...	...	2.02E+01
Iron, iron ore	6.91E+00	...	...	...	...	...	6.91E+00
Blast furnace slag	1.04E+01	...	...	...	...	...	1.04E+01
Slate	5.16E-01	...	...	...	...	...	5.16E-01
Other raw material	1.42E+01	...	...	...	...	...	1.42E+01
Gypsum, anhydrite	2.45E+01	...	...	...	...	...	2.45E+01
Water, process	4.05E+01	...	...	...	...	...	2.19E+02
Water, non-process	3.91E+02	...	no data	no data	1.01E+02	...	4.92E+02
Coarse aggregate, natural	...	...	7.77E+02	...	...	...	7.77E+02
Coarse aggregate, manufactured	...	...	...	2.73E+02	...	...	2.73E+02
Fine aggregate, natural	...	...	5.55E+02	...	...	...	5.55E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.49E-01	...	no data	no data	...	...	1.49E-01
Refractory	3.16E-01	...	...	...	...	...	3.16E-01
Grinding media	7.06E-02	...	...	...	...	...	7.06E-02
Grinding aids	1.82E-01	...	...	...	...	...	1.82E-01
Filter bags	9.71E-03	...	...	...	...	...	9.71E-03
Oil & grease	6.56E-02	...	...	...	no data	...	6.56E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	3.43E-01	...	...	...	...	...	3.43E-01
Chains	9.66E-03	...	...	...	...	...	9.66E-03
Fuel and electricity							
Coal (metric ton)	5.09E-02	...	...	...	...	…	5.09E-02
Gasoline (L)	2.12E-02	...	3.02E-02	1.07E-02	9.32E-01	4.17E-01	1.41E+00
Liquefied petroleum gas (L)	1.42E-02	...	...	...	2.29E+00	…	2.30E+00
Middle distillates (L)	4.70E-01	...	3.12E-01	1.06E-01	6.26E+00	2.08E+00	9.23E+00
Natural gas (thousand m^3)	1.97E-03	...	5.55E-05	2.94E-05	9.14E-03	…	1.12E-02
Petroleum coke (metric ton)	1.13E-02	...	...	...	...	…	1.13E-02
Residual oil (L)	4.85E-02	...	7.01E-02	1.65E-02	...	8.93E-02	2.24E-01
Wastes (GJ)	2.04E-01	...	...	...	...	…	2.04E-01
Electricity (kWh)	7.09E+01	...	3.53E+00	9.33E-01	3.81E+01	…	1.13E+02
Energy equivalent, GJ							
Coal	1.24E+00	...	...	...	...	…	1.24E+00
Gasoline	7.37E-04	...	1.05E-03	3.73E-04	3.25E-02	1.45E-02	4.92E-02
Liquefied petroleum gas	3.59E-04	...	...	...	5.79E-02	…	5.82E-02
Middle distillates	1.82E-02	...	1.21E-02	4.10E-03	2.42E-01	8.04E-02	3.57E-01
Natural gas	7.54E-02	...	2.12E-03	1.13E-03	3.50E-01	…	4.28E-01
Petroleum coke	3.97E-01	...	...	...	...	…	3.97E-01
Residual oil	2.02E-03	...	2.92E-03	6.88E-04	...	3.72E-03	9.36E-03
Wastes	2.04E-01	...	...	...	...	…	2.04E-01
Electricity	2.55E-01	...	1.27E-02	3.36E-03	1.37E-01	…	4.08E-01
Subtotal	2.20E+00	...	3.09E-02	9.65E-03	8.19E-01	9.86E-02	3.15E+00
Emission to water							
Aluminum	4.34E-04	...	...	...	...	…	4.34E-04
Ammonia, ammonium	4.78E-04	...	...	...	...	…	4.78E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	3.67E-01	...	6.01E-10	1.42E-10	1.64E-09	…	3.67E-01
Copper	...	...	3.01E-09	7.08E-10	8.21E-09	…	1.19E-08
Dissolved organic compounds	6.95E-03	...	...	...	...	…	6.95E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G1a. Precast Mix 1 (50-MPa) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.01E-09	7.08E-10	8.21E-09	…	1.19E-08
Nitric, nitrites	2.97E-03	...	...	...	...	…	2.97E-03
Oil and grease	3.79E-03	...	4.51E-08	1.06E-08	1.23E-07	…	3.79E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	1.11E-05	...	...	...	...	…	1.11E-05
Phosphorus	2.78E-06	...	...	...	...	…	2.78E-06
Sulfates	3.10E-01	...	...	...	...	…	3.10E-01
Sulfides	3.34E-05	...	...	...	...	…	3.34E-05
Suspended solids	1.18E-01	...	9.02E-08	2.12E-08	2.46E-07	…	1.18E-01
Water (that leaves site) (L)	1.85E+03	...	...	...	4.99E+02	…	2.35E+03
Zinc	1.67E-05	...	...	...	...	…	1.67E-05
Emission to air							
1,3 Butadiene	...	...	3.90E-13	2.07E-13	...	…	5.96E-13
Acetaldehyde	...	...	3.62E-11	1.92E-11	...	…	5.55E-11
Acrolein	...	...	5.80E-12	3.07E-12	...	…	8.87E-12
Ammonia, NH_3	2.40E-03	...	...	...	3.47E-04	…	2.75E-03
Arsenic	...	...	1.11E-08	2.61E-09	3.68E-07	…	3.81E-07
Benzene	...	...	1.81E-09	4.29E-10	3.08E-07	…	3.10E-07
Beryllium	...	...	2.33E-10	5.49E-11	4.18E-08	…	4.21E-08
Cadmium	...	...	3.34E-09	7.87E-10	1.77E-07	…	1.81E-07
Carbon dioxide, CO_2	4.57E+02	...	1.21E+00	3.89E-01	2.48E+01	7.33E+00	4.90E+02
Carbon dioxide, CO_2, calcination	2.78E+02	...	...	...	...	…	2.78E+02
Carbon dioxide, CO_2, combustion	1.79E+02	...	1.21E+00	3.89E-01	2.48E+01	7.33E+00	2.12E+02
Carbon monoxide, CO	5.38E-01	...	2.59E-03	8.93E-04	9.11E-02	2.77E-02	6.61E-01
Chromium	...	...	7.10E-09	1.67E-09	1.41E-06	…	1.41E-06
Cobalt	...	...	5.06E-08	1.19E-08	1.23E-08	…	7.48E-08
Copper	...	...	...	...	2.49E-08	…	2.49E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	4.93E-11	...	1.26E-13	2.95E-14	4.16E-13	…	4.99E-11
Ethylbenzene	...	...	2.90E-11	1.54E-11	...	…	4.44E-11
Formaldehyde	...	...	2.78E-07	6.56E-08	1.10E-05	…	1.13E-05
Hydrogen chlorine, HCl	3.69E-02	...	5.87E-06	1.38E-06	2.10E-05	…	3.69E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.27E-08	2.98E-09	5.46E-07	…	5.61E-07
Manganese	...	...	2.52E-08	5.93E-09	8.58E-06	…	8.61E-06
Mercury, Hg	3.07E-05	...	9.49E-10	2.23E-10	5.05E-08	…	3.08E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.88E-02	...	4.58E-05	1.48E-05	5.35E-04	3.41E-04	1.97E-02
Methylene chloride	...	...	4.05E-08	9.53E-09	1.34E-07	…	1.84E-07
Naphthalene	...	...	9.49E-09	2.23E-09	8.93E-08	…	1.01E-07
Nickel	...	...	7.10E-07	1.67E-07	1.79E-06	…	2.66E-06
Nitric oxide, NO (unspecified)	...	...	3.70E-05	1.25E-05	6.00E-04	2.07E-04	8.57E-04
Nitrogen oxides, NO_X	1.13E+00	...	7.42E-03	2.48E-03	2.69E-02	6.60E-02	1.23E+00
Non-methane organic gases, NMOG	...	...	...	...	6.51E-03	…	6.51E-03
Polycyclic aromatic hydrocarbons, PAH	...	...	1.99E-12	1.06E-12	...	…	3.05E-12
Particulates, PM-2.5	4.57E-05	...	...	1.54E-05	...	…	6.12E-05
Particulates, PM-10	3.21E-01	...	2.61E-01	2.80E-02	1.83E-02	1.27E-03	6.30E-01
Particulates, total	1.40E+00	...	1.49E-01	2.45E-02	4.69E-02	…	1.62E+00
Perchloroethylene	...	...	5.88E-10	1.38E-10	2.29E-09	…	3.01E-09
Phenolic compounds	...	...	3.05E-08	7.18E-09	1.01E-07	…	1.39E-07
Phosphorus	...	...	...	...	4.19E-06	…	4.19E-06
Propylene oxide	...	...	2.63E-11	1.39E-11	...	…	4.02E-11
Radionuclides (kBq)	...	...	3.16E-03	7.44E-04	2.65E-02	…	3.04E-02
Selenium	...	...	5.74E-09	1.35E-09	9.57E-08	…	1.03E-07
Sulfur dioxide, SO_2	6.52E-01	...	...	...	4.45E-05	…	6.52E-01
Sulfur oxides, SO_X	...	...	5.77E-04	1.59E-04	2.42E-04	2.48E-03	3.46E-03
Toluene	...	...	1.18E-10	6.24E-11	...	…	1.80E-10
Total hydrocarbon, THC	...	...	...	...	6.65E-03	…	6.65E-03
Volatile organic compounds, VOC	2.38E-02	...	5.45E-04	1.86E-04	7.38E-03	4.06E-03	3.59E-02
Xylenes	...	...	5.80E-11	3.07E-11	...	…	8.87E-11
Zinc	...	...	...	...	1.66E-08	…	1.66E-08
Emission to land							
Cement kiln dust, CKD	1.95E+01	...	...	...	...	…	1.95E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	8.90E-05	2.10E-05	7.60E+01	…	7.60E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G1b. Precast Mix 1 (7,500 psi) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	9.89E+02	...	...	...	...	...	9.89E+02
Cement rock, marl	1.69E+02	...	...	...	...	...	1.69E+02
Shale	4.28E+01	...	...	...	...	...	4.28E+01
Clay	5.22E+01	...	...	...	...	...	5.22E+01
Bottom ash	8.45E+00	...	...	...	...	...	8.45E+00
Fly ash	1.12E+01	...	...	...	...	...	1.12E+01
Foundry sand	3.38E+00	...	...	...	...	...	3.38E+00
Sand	3.41E+01	...	...	...	...	...	3.41E+01
Iron, iron ore	1.17E+01	...	...	...	...	...	1.17E+01
Blast furnace slag	1.75E+01	...	...	...	...	...	1.75E+01
Slate	8.69E-01	...	...	...	...	...	8.69E-01
Other raw material	2.40E+01	...	...	...	...	...	2.40E+01
Gypsum, anhydrite	4.13E+01	...	...	...	...	...	4.13E+01
Water, process	6.83E+01	...	...	...	...	...	3.68E+02
Water, non-process	6.60E+02	...	no data	no data	1.70E+02	...	8.30E+02
Coarse aggregate, natural	...	...	1.31E+03	...	...	...	1.31E+03
Coarse aggregate, manufactured	...	...	...	4.60E+02	...	...	4.60E+02
Fine aggregate, natural	...	...	9.35E+02	...	...	...	9.35E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	2.51E-01	...	no data	no data	...	...	2.51E-01
Refractory	5.33E-01	...	...	...	...	...	5.33E-01
Grinding media	1.19E-01	...	...	...	...	...	1.19E-01
Grinding aids	3.06E-01	...	...	...	...	...	3.06E-01
Filter bags	1.64E-02	...	...	...	...	...	1.64E-02
Oil & grease	1.11E-01	...	...	...	no data	...	1.11E-01
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	5.78E-01	...	...	...	...	...	5.78E-01
Chains	1.63E-02	...	...	...	...	...	1.63E-02
Fuel and electricity							
Coal (ton)	4.29E-02	...	...	...	...	…	4.29E-02
Gasoline (gallon)	4.28E-03	...	6.10E-03	2.16E-03	1.88E-01	8.43E-02	2.85E-01
Liquefied petroleum gas (gallon)	2.86E-03	...	...	...	4.62E-01	…	4.65E-01
Middle distillates (gallon)	9.49E-02	...	6.31E-02	2.14E-02	1.26E+00	4.20E-01	1.86E+00
Natural gas (thousand cu ft)	5.32E-02	...	1.50E-03	7.94E-04	2.47E-01	…	3.02E-01
Petroleum coke (ton)	9.55E-03	...	...	...	...	…	9.55E-03
Residual oil (gallon)	9.79E-03	...	1.42E-02	3.33E-03	...	1.80E-02	4.53E-02
Wastes (MBtu)	1.48E-01	...	...	...	...	…	1.48E-01
Electricity (kWh)	5.42E+01	...	2.70E+00	7.13E-01	2.91E+01	…	8.67E+01
Energy equivalent, MBtu							
Coal	9.01E-01	...	...	...	...	…	9.01E-01
Gasoline	5.34E-04	...	7.62E-04	2.70E-04	2.35E-02	1.05E-02	3.56E-02
Liquefied petroleum gas	2.60E-04	...	...	...	4.20E-02	…	4.22E-02
Middle distillates	1.32E-02	...	8.75E-03	2.97E-03	1.75E-01	5.82E-02	2.58E-01
Natural gas	5.47E-02	...	1.54E-03	8.15E-04	2.53E-01	…	3.11E-01
Petroleum coke	2.88E-01	...	...	...	...	…	2.88E-01
Residual oil	1.47E-03	...	2.12E-03	4.99E-04	...	2.70E-03	6.78E-03
Wastes	1.48E-01	...	...	...	...	…	1.48E-01
Electricity	1.85E-01	...	9.21E-03	2.43E-03	9.94E-02	…	2.96E-01
Subtotal	1.59E+00	...	2.24E-02	6.99E-03	5.94E-01	7.15E-02	2.29E+00
Emission to water							
Aluminum	7.31E-04	...	...	...	...	…	7.31E-04
Ammonia, ammonium	8.06E-04	...	...	...	...	…	8.06E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	6.18E-01	...	1.01E-09	2.39E-10	2.77E-09	…	6.18E-01
Copper	...	...	5.07E-09	1.19E-09	1.38E-08	…	2.01E-08
Dissolved organic compounds	1.17E-02	...	...	...	...	…	1.17E-02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G1b. Precast Mix 1 (7,500 psi) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	5.07E-09	1.19E-09	1.38E-08	…	2.01E-08
Nitric, nitrites	5.01E-03	...	...	...	...	…	5.01E-03
Oil and grease	6.39E-03	...	7.60E-08	1.79E-08	2.08E-07	…	6.39E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	1.87E-05	...	...	...	...	…	1.87E-05
Phosphorus	4.68E-06	...	...	...	...	…	4.68E-06
Sulfates	5.23E-01	...	...	...	...	…	5.23E-01
Sulfides	5.62E-05	...	...	...	...	…	5.62E-05
Suspended solids	1.99E-01	...	1.52E-07	3.58E-08	4.15E-07	…	1.99E-01
Water (that leaves site) (gallon)	3.73E+02	...	...	...	1.01E+02	…	4.74E+02
Zinc	2.81E-05	...	...	...	...	…	2.81E-05
Emission to air							
1,3 Butadiene	...	...	6.57E-13	3.48E-13	...	…	1.00E-12
Acetaldehyde	...	...	6.11E-11	3.24E-11	...	…	9.35E-11
Acrolein	...	...	9.77E-12	5.18E-12	...	…	1.50E-11
Ammonia, NH_3	4.04E-03	...	...	...	5.86E-04	…	4.63E-03
Arsenic	...	...	1.87E-08	4.40E-09	6.20E-07	…	6.43E-07
Benzene	...	...	3.05E-09	7.23E-10	5.18E-07	…	5.22E-07
Beryllium	...	...	3.94E-10	9.26E-11	7.04E-08	…	7.09E-08
Cadmium	...	...	5.63E-09	1.33E-09	2.98E-07	…	3.05E-07
Carbon dioxide, CO_2	7.70E+02	...	2.04E+00	6.56E-01	4.18E+01	1.24E+01	8.26E+02
Carbon dioxide, CO_2, calcination	4.68E+02	...	...	...	...	…	4.68E+02
Carbon dioxide, CO_2, combustion	3.01E+02	...	2.04E+00	6.56E-01	4.18E+01	1.24E+01	3.58E+02
Carbon monoxide, CO	9.08E-01	...	4.36E-03	1.51E-03	1.54E-01	4.67E-02	1.11E+00
Chromium	...	...	1.20E-08	2.82E-09	2.37E-06	…	2.38E-06
Cobalt	...	...	8.52E-08	2.01E-08	2.07E-08	…	1.26E-07
Copper	...	...	...	...	4.20E-08	…	4.20E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	8.31E-11	...	2.12E-13	4.98E-14	7.01E-13	…	8.41E-11
Ethylbenzene	...	...	4.89E-11	2.59E-11	...	…	7.48E-11
Formaldehyde	...	...	4.68E-07	1.11E-07	1.85E-05	…	1.91E-05
Hydrogen chlorine, HCl	6.22E-02	...	9.90E-06	2.33E-06	3.53E-05	…	6.23E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.14E-08	5.03E-09	9.20E-07	…	9.46E-07
Manganese	...	...	4.25E-08	9.99E-09	1.45E-05	…	1.45E-05
Mercury, Hg	5.17E-05	...	1.60E-09	3.76E-10	8.52E-08	…	5.18E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	3.17E-02	...	7.72E-05	2.50E-05	9.02E-04	5.74E-04	3.33E-02
Methylene chloride	...	...	6.82E-08	1.61E-08	2.26E-07	…	3.10E-07
Naphthalene	...	...	1.60E-08	3.77E-09	1.51E-07	…	1.70E-07
Nickel	...	...	1.20E-06	2.82E-07	3.01E-06	…	4.49E-06
Nitric oxide, NO (unspecified)	...	...	6.24E-05	2.11E-05	1.01E-03	3.49E-04	1.44E-03
Nitrogen oxides, NO_X	1.90E+00	...	1.25E-02	4.17E-03	4.53E-02	1.11E-01	2.08E+00
Non-methane organic gases, NMOG	...	...	...	...	1.10E-02	…	1.10E-02
Polycyclic aromatic hydrocarbons, PAH	...	...	3.36E-12	1.78E-12	...	…	5.14E-12
Particulates, PM-2.5	7.71E-05	...	...	2.60E-05	...	…	1.03E-04
Particulates, PM-10	5.41E-01	...	4.40E-01	4.72E-02	3.09E-02	2.15E-03	1.06E+00
Particulates, total	2.35E+00	...	2.51E-01	4.12E-02	7.91E-02	…	2.72E+00
Perchloroethylene	...	...	9.91E-10	2.33E-10	3.85E-09	…	5.08E-09
Phenolic compounds	...	...	5.14E-08	1.21E-08	1.70E-07	…	2.34E-07
Phosphorus	...	...	...	...	7.07E-06	…	7.07E-06
Propylene oxide	...	...	4.43E-11	2.35E-11	...	…	6.78E-11
Radionuclides (kBq)	...	...	5.33E-03	1.25E-03	4.46E-02	…	5.12E-02
Selenium	...	...	9.67E-09	2.28E-09	1.61E-07	…	1.73E-07
Sulfur dioxide, SO_2	1.10E+00	...	...	...	7.51E-05	…	1.10E+00
Sulfur oxides, SO_X	...	...	9.72E-04	2.68E-04	4.08E-04	4.19E-03	5.83E-03
Toluene	...	...	1.99E-10	1.05E-10	...	…	3.04E-10
Total hydrocarbon, THC	...	...	...	...	1.12E-02	…	1.12E-02
Volatile organic compounds, VOC	4.01E-02	...	9.18E-04	3.14E-04	1.24E-02	6.84E-03	6.06E-02
Xylenes	...	...	9.77E-11	5.18E-11	...	…	1.50E-10
Zinc	...	...	...	...	2.80E-08	…	2.80E-08
Emission to land							
Cement kiln dust, CKD	3.29E+01	...	...	...	...	…	3.29E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.50E-04	3.53E-05	1.28E+02	…	1.28E+02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G2a. Precast Mix 2 (75-MPa) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	5.18E+02	...	...	...	...	...	5.18E+02
Cement rock, marl	8.87E+01	...	...	...	...	...	8.87E+01
Shale	2.24E+01	...	...	...	...	...	2.24E+01
Clay	2.73E+01	...	...	...	...	...	2.73E+01
Bottom ash	4.42E+00	...	...	...	...	...	4.42E+00
Fly ash	5.88E+00	...	...	...	...	...	5.88E+00
Foundry sand	1.77E+00	...	...	...	...	...	1.77E+00
Sand	1.79E+01	...	...	...	...	...	1.79E+01
Iron, iron ore	6.10E+00	...	...	...	...	...	6.10E+00
Blast furnace slag	9.17E+00	...	...	...	...	...	9.17E+00
Slate	4.55E-01	...	...	...	...	...	4.55E-01
Other raw material	1.26E+01	...	...	...	...	...	1.26E+01
Gypsum, anhydrite	2.16E+01	...	...	...	...	...	2.16E+01
Water, process	3.58E+01	...	...	...	...	...	1.72E+02
Water, non-process	3.45E+02	...	no data	no data	1.01E+02	...	4.46E+02
Coarse aggregate, natural	...	...	8.23E+02	...	...	...	8.23E+02
Coarse aggregate, manufactured	...	...	...	2.89E+02	...	...	2.89E+02
Fine aggregate, natural	...	...	6.11E+02	...	...	...	6.11E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	5.64E+01
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.31E-01	...	no data	no data	...	...	1.31E-01
Refractory	2.79E-01	...	...	...	...	...	2.79E-01
Grinding media	6.23E-02	...	...	...	...	...	6.23E-02
Grinding aids	1.60E-01	...	...	...	...	...	1.60E-01
Filter bags	8.57E-03	...	...	...	...	...	8.57E-03
Oil & grease	5.78E-02	...	...	...	no data	...	5.78E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	3.03E-01	...	...	...	...	...	3.03E-01
Chains	8.52E-03	...	...	...	...	...	8.52E-03
Fuel and electricity							
Coal (metric ton)	4.49E-02	...	...	...	...	…	4.49E-02
Gasoline (L)	1.87E-02	...	3.25E-02	1.13E-02	9.32E-01	4.49E-01	1.44E+00
Liquefied petroleum gas (L)	1.25E-02	...	...	...	2.29E+00	…	2.30E+00
Middle distillates (L)	4.14E-01	...	3.36E-01	1.12E-01	6.26E+00	2.11E+00	9.23E+00
Natural gas (thousand m^3)	1.74E-03	...	5.97E-05	3.11E-05	9.14E-03	…	1.10E-02
Petroleum coke (metric ton)	1.00E-02	...	...	...	...	…	1.00E-02
Residual oil (L)	4.28E-02	...	7.55E-02	1.75E-02	...	9.49E-02	2.31E-01
Wastes (GJ)	1.80E-01	...	...	...	...	…	1.80E-01
Electricity (kWh)	6.26E+01	...	3.80E+00	9.88E-01	3.81E+01	…	1.05E+02
Energy equivalent, GJ							
Coal	1.10E+00	...	...	...	...	…	1.10E+00
Gasoline	6.51E-04	...	1.13E-03	3.95E-04	3.25E-02	1.57E-02	5.03E-02
Liquefied petroleum gas	3.16E-04	...	...	...	5.79E-02	…	5.82E-02
Middle distillates	1.60E-02	...	1.30E-02	4.35E-03	2.42E-01	8.16E-02	3.57E-01
Natural gas	6.65E-02	...	2.29E-03	1.19E-03	3.50E-01	…	4.20E-01
Petroleum coke	3.50E-01	...	...	...	...	…	3.50E-01
Residual oil	1.78E-03	...	3.15E-03	7.29E-04	...	3.96E-03	9.62E-03
Wastes	1.80E-01	...	...	...	...	…	1.80E-01
Electricity	2.25E-01	...	1.37E-02	3.56E-03	1.37E-01	…	3.80E-01
Subtotal	1.94E+00	...	3.33E-02	1.02E-02	8.19E-01	1.01E-01	2.90E+00
Emission to water							
Aluminum	3.83E-04	...	...	...	...	…	3.83E-04
Ammonia, ammonium	4.22E-04	...	...	...	...	…	4.22E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	3.24E-01	...	6.48E-10	1.50E-10	1.64E-09	…	3.24E-01
Copper	...	...	3.24E-09	7.50E-10	8.21E-09	…	1.22E-08
Dissolved organic compounds	6.13E-03	...	...	...	...	…	6.13E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G2a. Precast Mix 2 (75-MPa) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.24E-09	7.50E-10	8.21E-09	…	1.22E-08
Nitric, nitrites	2.62E-03	...	...	...	...	…	2.62E-03
Oil and grease	3.35E-03	...	4.86E-08	1.12E-08	1.23E-07	…	3.35E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	9.81E-06	...	...	...	...	…	9.81E-06
Phosphorus	2.45E-06	...	...	...	...	…	2.45E-06
Sulfates	2.74E-01	...	...	...	...	…	2.74E-01
Sulfides	2.94E-05	...	...	...	...	…	2.94E-05
Suspended solids	1.04E-01	...	9.71E-08	2.25E-08	2.46E-07	…	1.04E-01
Water (that leaves site) (L)	1.63E+03	...	...	...	4.99E+02	…	2.13E+03
Zinc	1.47E-05	...	...	...	...	…	1.47E-05
Emission to air							
1,3 Butadiene	...	...	4.20E-13	2.19E-13	...	…	6.38E-13
Acetaldehyde	...	...	3.90E-11	2.04E-11	...	…	5.94E-11
Acrolein	...	...	6.25E-12	3.26E-12	...	…	9.50E-12
Ammonia, NH_3	2.12E-03	...	...	...	3.47E-04	…	2.46E-03
Arsenic	...	...	1.19E-08	2.76E-09	4.13E-07	…	4.28E-07
Benzene	...	...	1.95E-09	4.54E-10	3.08E-07	…	3.10E-07
Beryllium	...	...	2.51E-10	5.82E-11	4.58E-08	…	4.61E-08
Cadmium	...	...	3.60E-09	8.33E-10	2.33E-07	…	2.37E-07
Carbon dioxide, CO_2	4.03E+02	...	1.31E+00	4.13E-01	2.48E+01	7.52E+00	4.37E+02
Carbon dioxide, CO_2, calcination	2.45E+02	...	...	...	...	…	2.45E+02
Carbon dioxide, CO_2, combustion	1.58E+02	...	1.31E+00	4.13E-01	2.48E+01	7.52E+00	1.92E+02
Carbon monoxide, CO	4.75E-01	...	2.79E-03	9.46E-04	9.11E-02	2.92E-02	5.99E-01
Chromium	...	...	7.64E-09	1.77E-09	1.50E-06	…	1.51E-06
Cobalt	...	...	5.44E-08	1.26E-08	1.23E-08	…	7.93E-08
Copper	...	...	...	...	2.49E-08	…	2.49E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	4.35E-11	...	1.35E-13	3.11E-14	4.16E-13	…	4.41E-11
Ethylbenzene	...	...	3.12E-11	1.63E-11	...	…	4.75E-11
Formaldehyde	...	...	2.99E-07	6.95E-08	1.10E-05	…	1.14E-05
Hydrogen chlorine, HCl	3.26E-02	...	6.33E-06	1.46E-06	2.10E-05	…	3.26E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.37E-08	3.16E-09	5.84E-07	…	6.01E-07
Manganese	...	...	2.71E-08	6.28E-09	9.05E-06	…	9.09E-06
Mercury, Hg	2.71E-05	...	1.02E-09	2.37E-10	5.05E-08	…	2.71E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.66E-02	...	4.93E-05	1.57E-05	5.35E-04	3.61E-04	1.75E-02
Methylene chloride	...	...	4.36E-08	1.01E-08	1.34E-07	…	1.88E-07
Naphthalene	...	...	1.02E-08	2.37E-09	8.93E-08	…	1.02E-07
Nickel	...	...	7.64E-07	1.77E-07	1.93E-06	…	2.87E-06
Nitric oxide, NO (unspecified)	...	...	3.98E-05	1.33E-05	6.00E-04	2.14E-04	8.67E-04
Nitrogen oxides, NO_X	9.96E-01	...	7.99E-03	2.62E-03	2.69E-02	6.84E-02	1.10E+00
Non-methane organic gases, NMOG	...	...	...	...	6.51E-03	…	6.51E-03
Polycyclic aromatic hydrocarbons, PAH	...	...	2.15E-12	1.12E-12	...	…	3.27E-12
Particulates, PM-2.5	4.04E-05	...	...	1.63E-05	...	…	5.67E-05
Particulates, PM-10	2.83E-01	...	2.81E-01	2.97E-02	1.83E-02	1.32E-03	6.14E-01
Particulates, total	1.23E+00	...	1.60E-01	2.59E-02	4.69E-02	…	1.47E+00
Perchloroethylene	...	...	6.33E-10	1.47E-10	2.29E-09	…	3.07E-09
Phenolic compounds	...	...	3.29E-08	7.61E-09	1.01E-07	…	1.41E-07
Phosphorus	...	...	...	...	4.52E-06	…	4.52E-06
Propylene oxide	...	...	2.83E-11	1.48E-11	...	…	4.31E-11
Radionuclides (kBq)	...	...	3.40E-03	7.88E-04	2.65E-02	…	3.07E-02
Selenium	...	...	6.18E-09	1.43E-09	9.93E-08	…	1.07E-07
Sulfur dioxide, SO_2	5.75E-01	...	...	...	4.45E-05	…	5.75E-01
Sulfur oxides, SO_X	...	...	6.21E-04	1.68E-04	2.42E-04	2.58E-03	3.61E-03
Toluene	...	...	1.27E-10	6.62E-11	...	…	1.93E-10
Total hydrocarbon, THC	...	...	...	...	6.65E-03	…	6.65E-03
Volatile organic compounds, VOC	2.10E-02	...	5.87E-04	1.97E-04	7.38E-03	4.24E-03	3.34E-02
Xylenes	...	...	6.25E-11	3.26E-11	...	…	9.50E-11
Zinc	...	...	...	...	1.66E-08	…	1.66E-08
Emission to land							
Cement kiln dust, CKD	1.72E+01	...	...	...	...	…	1.72E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	9.59E-05	2.22E-05	7.60E+01	…	7.60E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G2b. Precast Mix 2 (10,000-psi) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	8.73E+02	...	...	...	...	...	8.73E+02
Cement rock, marl	1.49E+02	...	...	...	...	...	1.49E+02
Shale	3.77E+01	...	...	...	...	...	3.77E+01
Clay	4.60E+01	...	...	...	...	...	4.60E+01
Bottom ash	7.45E+00	...	...	...	...	...	7.45E+00
Fly ash	9.91E+00	...	...	...	...	...	9.91E+00
Foundry sand	2.99E+00	...	...	...	...	...	2.99E+00
Sand	3.01E+01	...	...	...	...	...	3.01E+01
Iron, iron ore	1.03E+01	...	...	...	...	...	1.03E+01
Blast furnace slag	1.55E+01	...	...	...	...	...	1.55E+01
Slate	7.67E-01	...	...	...	...	...	7.67E-01
Other raw material	2.12E+01	...	...	...	...	...	2.12E+01
Gypsum, anhydrite	3.64E+01	...	...	...	...	...	3.64E+01
Water, process	6.03E+01	...	...	...	...	...	2.90E+02
Water, non-process	5.82E+02	...	no data	no data	1.70E+02	...	7.52E+02
Coarse aggregate, natural	...	...	1.39E+03	...	...	...	1.39E+03
Coarse aggregate, manufactured	...	...	...	4.88E+02	...	...	4.88E+02
Fine aggregate, natural	...	...	1.03E+03	...	...	...	1.03E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	9.50E+01
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	2.21E-01	...	no data	no data	...	...	2.21E-01
Refractory	4.70E-01	...	...	...	...	...	4.70E-01
Grinding media	1.05E-01	...	...	...	...	...	1.05E-01
Grinding aids	2.70E-01	...	...	...	...	...	2.70E-01
Filter bags	1.44E-02	...	...	...	...	...	1.44E-02
Oil & grease	9.75E-02	...	...	...	no data	...	9.75E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	5.10E-01	...	...	...	...	...	5.10E-01
Chains	1.44E-02	...	...	...	...	...	1.44E-02
Fuel and electricity							
Coal (ton)	3.78E-02	...	...	...	...	…	3.78E-02
Gasoline (gallon)	3.77E-03	...	6.57E-03	2.29E-03	1.88E-01	9.08E-02	2.92E-01
Liquefied petroleum gas (gallon)	2.52E-03	...	...	...	4.62E-01	…	4.65E-01
Middle distillates (gallon)	8.37E-02	...	6.79E-02	2.27E-02	1.26E+00	4.26E-01	1.87E+00
Natural gas (thousand cu ft)	4.70E-02	...	1.61E-03	8.41E-04	2.47E-01	…	2.96E-01
Petroleum coke (ton)	8.43E-03	...	...	...	...	…	8.43E-03
Residual oil (gallon)	8.64E-03	...	1.52E-02	3.53E-03	...	1.92E-02	4.66E-02
Wastes (MBtu)	1.30E-01	...	...	...	...	…	1.30E-01
Electricity (kWh)	4.78E+01	...	2.91E+00	7.56E-01	2.91E+01	…	8.06E+01
Energy equivalent, MBtu							
Coal	7.95E-01	...	...	...	...	…	7.95E-01
Gasoline	4.72E-04	...	8.21E-04	2.86E-04	2.35E-02	1.13E-02	3.65E-02
Liquefied petroleum gas	2.29E-04	...	...	...	4.20E-02	…	4.22E-02
Middle distillates	1.16E-02	...	9.42E-03	3.15E-03	1.75E-01	5.91E-02	2.59E-01
Natural gas	4.82E-02	...	1.66E-03	8.64E-04	2.53E-01	…	3.04E-01
Petroleum coke	2.54E-01	...	...	...	...	…	2.54E-01
Residual oil	1.29E-03	...	2.28E-03	5.28E-04	...	2.87E-03	6.97E-03
Wastes	1.30E-01	...	...	...	...	…	1.30E-01
Electricity	1.63E-01	...	9.92E-03	2.58E-03	9.94E-02	…	2.75E-01
Subtotal	1.40E+00	...	2.41E-02	7.41E-03	5.94E-01	7.33E-02	2.10E+00
Emission to water							
Aluminum	6.45E-04	...	...	...	...	…	6.45E-04
Ammonia, ammonium	7.11E-04	...	...	...	...	…	7.11E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	5.46E-01	...	1.09E-09	2.53E-10	2.77E-09	…	5.46E-01
Copper	...	...	5.46E-09	1.26E-09	1.38E-08	…	2.06E-08
Dissolved organic compounds	1.03E-02	...	...	...	...	…	1.03E-02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G2b. Precast Mix 2 (10,000-psi) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	5.46E-09	1.26E-09	1.38E-08	…	2.06E-08
Nitric, nitrites	4.42E-03	...	...	...	...	…	4.42E-03
Oil and grease	5.64E-03	...	8.19E-08	1.90E-08	2.08E-07	…	5.64E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	1.65E-05	...	...	...	...	…	1.65E-05
Phosphorus	4.13E-06	...	...	...	...	…	4.13E-06
Sulfates	4.62E-01	...	...	...	...	…	4.62E-01
Sulfides	4.96E-05	...	...	...	...	…	4.96E-05
Suspended solids	1.76E-01	...	1.64E-07	3.79E-08	4.15E-07	…	1.76E-01
Water (that leaves site) (gallon)	3.30E+02	...	...	...	1.01E+02	…	4.30E+02
Zinc	2.48E-05	...	...	...	...	…	2.48E-05
Emission to air							
1,3 Butadiene	...	...	7.07E-13	3.69E-13	...	…	1.08E-12
Acetaldehyde	...	...	6.58E-11	3.43E-11	...	…	1.00E-10
Acrolein	...	...	1.05E-11	5.49E-12	...	…	1.60E-11
Ammonia, NH_3	3.57E-03	...	...	...	5.86E-04	…	4.15E-03
Arsenic	...	...	2.01E-08	4.66E-09	6.97E-07	…	7.21E-07
Benzene	...	...	3.28E-09	7.66E-10	5.18E-07	…	5.22E-07
Beryllium	...	...	4.24E-10	9.81E-11	7.72E-08	…	7.77E-08
Cadmium	...	...	6.07E-09	1.40E-09	3.92E-07	…	3.99E-07
Carbon dioxide, CO_2	6.79E+02	...	2.20E+00	6.95E-01	4.18E+01	1.27E+01	7.36E+02
Carbon dioxide, CO_2, calcination	4.13E+02	...	...	...	...	…	4.13E+02
Carbon dioxide, CO_2, combustion	2.66E+02	...	2.20E+00	6.95E-01	4.18E+01	1.27E+01	3.23E+02
Carbon monoxide, CO	8.01E-01	...	4.70E-03	1.60E-03	1.54E-01	4.92E-02	1.01E+00
Chromium	...	...	1.29E-08	2.98E-09	2.54E-06	…	2.55E-06
Cobalt	...	...	9.18E-08	2.12E-08	2.07E-08	…	1.34E-07
Copper	...	...	...	...	4.20E-08	…	4.20E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	7.33E-11	...	2.28E-13	5.25E-14	7.01E-13	…	7.43E-11
Ethylbenzene	...	...	5.26E-11	2.74E-11	...	…	8.01E-11
Formaldehyde	...	...	5.04E-07	1.17E-07	1.85E-05	…	1.91E-05
Hydrogen chlorine, HCl	5.49E-02	...	1.07E-05	2.47E-06	3.53E-05	…	5.49E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.30E-08	5.33E-09	9.84E-07	…	1.01E-06
Manganese	...	...	4.57E-08	1.06E-08	1.53E-05	…	1.53E-05
Mercury, Hg	4.57E-05	...	1.72E-09	3.99E-10	8.52E-08	…	4.57E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	2.80E-02	...	8.31E-05	2.65E-05	9.02E-04	6.08E-04	2.96E-02
Methylene chloride	...	...	7.35E-08	1.70E-08	2.26E-07	…	3.17E-07
Naphthalene	...	...	1.72E-08	3.99E-09	1.51E-07	…	1.72E-07
Nickel	...	...	1.29E-06	2.98E-07	3.25E-06	…	4.84E-06
Nitric oxide, NO (unspecified)	...	...	6.72E-05	2.23E-05	1.01E-03	3.60E-04	1.46E-03
Nitrogen oxides, NO_X	1.68E+00	...	1.35E-02	4.42E-03	4.53E-02	1.15E-01	1.86E+00
Non-methane organic gases, NMOG	...	...	...	...	1.10E-02	…	1.10E-02
Polycyclic aromatic hydrocarbons, PAH	...	...	3.62E-12	1.89E-12	...	…	5.51E-12
Particulates, PM-2.5	6.80E-05	...	...	2.75E-05	...	…	9.56E-05
Particulates, PM-10	4.78E-01	...	4.74E-01	5.00E-02	3.09E-02	2.23E-03	1.03E+00
Particulates, total	2.08E+00	...	2.70E-01	4.37E-02	7.91E-02	…	2.47E+00
Perchloroethylene	...	...	1.07E-09	2.47E-10	3.85E-09	…	5.17E-09
Phenolic compounds	...	...	5.54E-08	1.28E-08	1.70E-07	…	2.39E-07
Phosphorus	...	...	...	...	7.62E-06	…	7.62E-06
Propylene oxide	...	...	4.77E-11	2.49E-11	...	…	7.26E-11
Radionuclides (kBq)	...	...	5.74E-03	1.33E-03	4.46E-02	…	5.17E-02
Selenium	...	...	1.04E-08	2.41E-09	1.67E-07	…	1.80E-07
Sulfur dioxide, SO_2	9.69E-01	...	...	...	7.51E-05	…	9.69E-01
Sulfur oxides, SO_X	...	...	1.05E-03	2.83E-04	4.08E-04	4.35E-03	6.09E-03
Toluene	...	...	2.14E-10	1.12E-10	...	…	3.25E-10
Total hydrocarbon, THC	...	...	...	...	1.12E-02	…	1.12E-02
Volatile organic compounds, VOC	3.54E-02	...	9.89E-04	3.33E-04	1.24E-02	7.15E-03	5.63E-02
Xylenes	...	...	1.05E-10	5.49E-11	...	…	1.60E-10
Zinc	...	...	...	...	2.80E-08	…	2.80E-08
Emission to land							
Cement kiln dust, CKD	2.90E+01	...	...	...	...	…	2.90E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.62E-04	3.74E-05	1.28E+02	…	1.28E+02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G3a. Precast Mix 3 (Architectural) LCI Results (SI Units)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	4.49E+02	...	...	...	...	...	4.49E+02
Cement rock, marl	7.69E+01	...	...	...	...	...	7.69E+01
Shale	1.94E+01	...	...	...	...	...	1.94E+01
Clay	2.37E+01	...	...	...	...	...	2.37E+01
Bottom ash	3.83E+00	...	...	...	...	...	3.83E+00
Fly ash	5.10E+00	...	...	...	...	...	5.10E+00
Foundry sand	1.54E+00	...	...	...	...	...	1.54E+00
Sand	1.55E+01	...	...	...	...	...	1.55E+01
Iron, iron ore	5.29E+00	...	...	...	...	...	5.29E+00
Blast furnace slag	7.95E+00	...	...	...	...	...	7.95E+00
Slate	3.94E-01	...	...	...	...	...	3.94E-01
Other raw material	1.09E+01	...	...	...	...	...	1.09E+01
Gypsum, anhydrite	1.87E+01	...	...	...	...	...	1.87E+01
Water, process	3.10E+01	...	...	...	...	...	1.85E+02
Water, non-process	2.99E+02	...	no data	no data	1.01E+02	...	4.00E+02
Coarse aggregate, natural	...	...	7.90E+02	...	...	...	7.90E+02
Coarse aggregate, manufactured	...	...	...	2.78E+02	...	...	2.78E+02
Fine aggregate, natural	...	...	7.42E+02	...	...	...	7.42E+02
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.14E-01	...	no data	no data	...	...	1.14E-01
Refractory	2.42E-01	...	...	...	...	...	2.42E-01
Grinding media	5.40E-02	...	...	...	...	...	5.40E-02
Grinding aids	1.39E-01	...	...	...	...	...	1.39E-01
Filter bags	7.43E-03	...	...	...	...	...	7.43E-03
Oil & grease	5.01E-02	...	...	...	no data	...	5.01E-02
Oil (L)	...	...	...	...	no data	...	...
Grease (L)	...	...	...	...	no data	...	...
Solvent (L)	...	...	...	...	...	...	...
Cement bags	2.62E-01	...	...	...	...	...	2.62E-01
Chains	7.39E-03	...	...	...	...	...	7.39E-03
Fuel and electricity							
Coal (metric ton)	3.89E-02	...	...	...	...	…	3.89E-02
Gasoline (L)	1.62E-02	...	3.47E-02	1.09E-02	9.32E-01	4.81E-01	1.47E+00
Liquefied petroleum gas (L)	1.08E-02	...	...	...	2.29E+00	…	2.30E+00
Middle distillates (L)	3.59E-01	...	3.59E-01	1.08E-01	6.26E+00	1.79E+00	8.88E+00
Natural gas (thousand m^3)	1.51E-03	...	6.38E-05	2.99E-05	9.14E-03	…	1.07E-02
Petroleum coke (metric ton)	8.67E-03	...	...	...	...	…	8.67E-03
Residual oil (L)	3.71E-02	...	8.06E-02	1.68E-02	...	9.70E-02	2.31E-01
Wastes (GJ)	1.56E-01	...	...	...	...	…	1.56E-01
Electricity (kWh)	5.42E+01	...	4.06E+00	9.49E-01	3.81E+01	…	9.73E+01
Energy equivalent, GJ							
Coal	9.50E-01	...	...	...	...	…	9.50E-01
Gasoline	5.64E-04	...	1.21E-03	3.79E-04	3.25E-02	1.67E-02	5.14E-02
Liquefied petroleum gas	2.74E-04	...	...	...	5.79E-02	…	5.82E-02
Middle distillates	1.39E-02	...	1.39E-02	4.17E-03	2.42E-01	6.93E-02	3.43E-01
Natural gas	5.77E-02	...	2.44E-03	1.14E-03	3.50E-01	…	4.11E-01
Petroleum coke	3.04E-01	...	...	...	...	…	3.04E-01
Residual oil	1.55E-03	...	3.36E-03	7.00E-04	...	4.05E-03	9.66E-03
Wastes	1.56E-01	...	...	...	...	…	1.56E-01
Electricity	1.95E-01	...	1.46E-02	3.42E-03	1.37E-01	…	3.50E-01
Subtotal	1.68E+00	...	3.55E-02	9.81E-03	8.19E-01	9.01E-02	2.63E+00
Emission to water							
Aluminum	3.32E-04	...	...	...	...	…	3.32E-04
Ammonia, ammonium	3.66E-04	...	...	...	...	…	3.66E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	2.81E-01	...	6.92E-10	1.44E-10	1.64E-09	…	2.81E-01
Copper	...	...	3.46E-09	7.20E-10	8.21E-09	…	1.24E-08
Dissolved organic compounds	5.31E-03	...	...	...	...	…	5.31E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G3a. Precast Mix 3 (Architectural) LCI Results (SI Units) (Continued)*

Inputs and outputs per m^3 concrete (kg unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	3.46E-09	7.20E-10	8.21E-09	…	1.24E-08
Nitric, nitrites	2.27E-03	...	...	...	...	…	2.27E-03
Oil and grease	2.90E-03	...	5.19E-08	1.08E-08	1.23E-07	…	2.90E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	8.50E-06	...	...	...	...	…	8.50E-06
Phosphorus	2.13E-06	...	...	...	...	…	2.13E-06
Sulfates	2.37E-01	...	...	...	...	…	2.37E-01
Sulfides	2.55E-05	...	...	...	...	…	2.55E-05
Suspended solids	9.04E-02	...	1.04E-07	2.16E-08	2.46E-07	…	9.04E-02
Water (that leaves site) (L)	1.41E+03	...	...	...	4.99E+02	…	1.91E+03
Zinc	1.28E-05	...	...	...	...	…	1.28E-05
Emission to air							
1,3 Butadiene	...	...	4.48E-13	2.10E-13	...	…	6.58E-13
Acetaldehyde	...	...	4.17E-11	1.95E-11	...	…	6.12E-11
Acrolein	...	...	6.67E-12	3.13E-12	...	…	9.80E-12
Ammonia, NH_3	1.83E-03	...	...	...	3.47E-04	…	2.18E-03
Arsenic	...	...	1.28E-08	2.65E-09	3.80E-07	…	3.96E-07
Benzene	...	...	2.08E-09	4.36E-10	3.08E-07	…	3.10E-07
Beryllium	...	...	2.69E-10	5.59E-11	4.29E-08	…	4.32E-08
Cadmium	...	...	3.84E-09	8.00E-10	1.77E-07	…	1.81E-07
Carbon dioxide, CO_2	3.49E+02	...	1.40E+00	3.96E-01	2.48E+01	6.66E+00	3.82E+02
Carbon dioxide, CO_2, calcination	2.12E+02	...	...	...	...	…	2.12E+02
Carbon dioxide, CO_2, combustion	1.37E+02	...	1.40E+00	3.96E-01	2.48E+01	6.66E+00	1.70E+02
Carbon monoxide, CO	4.12E-01	...	2.98E-03	9.08E-04	9.11E-02	2.90E-02	5.36E-01
Chromium	...	...	8.16E-09	1.70E-09	1.45E-06	…	1.46E-06
Cobalt	...	...	5.81E-08	1.21E-08	1.23E-08	…	8.25E-08
Copper	...	...	...	...	2.49E-08	…	2.49E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	3.77E-11	...	1.44E-13	3.02E-14	4.16E-13	…	3.83E-11
Ethylbenzene	...	...	3.34E-11	1.56E-11	...	…	4.90E-11
Formaldehyde	...	...	3.19E-07	6.67E-08	1.10E-05	…	1.14E-05
Hydrogen chlorine, HCl	2.82E-02	...	6.76E-06	1.41E-06	2.10E-05	…	2.83E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	1.46E-08	3.04E-09	5.63E-07	…	5.80E-07
Manganese	...	...	2.90E-08	6.03E-09	8.92E-06	…	8.96E-06
Mercury, Hg	2.35E-05	...	1.09E-09	2.27E-10	5.05E-08	…	2.35E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	1.44E-02	...	5.27E-05	1.51E-05	5.35E-04	3.62E-04	1.53E-02
Methylene chloride	...	...	4.66E-08	9.69E-09	1.34E-07	…	1.90E-07
Naphthalene	...	...	1.09E-08	2.27E-09	8.93E-08	…	1.03E-07
Nickel	...	...	8.16E-07	1.70E-07	1.84E-06	…	2.83E-06
Nitric oxide, NO (unspecified)	...	...	4.26E-05	1.27E-05	6.00E-04	1.94E-04	8.50E-04
Nitrogen oxides, NO_X	8.63E-01	...	8.53E-03	2.52E-03	2.69E-02	6.30E-02	9.64E-01
Non-methane organic gases, NMOG	...	...	...	...	6.51E-03	…	6.51E-03
Polycyclic aromatic hydrocarbons, PAH	...	...	2.29E-12	1.07E-12	...	…	3.37E-12
Particulates, PM-2.5	3.50E-05	...	...	1.57E-05	...	…	5.07E-05
Particulates, PM-10	2.46E-01	...	3.00E-01	2.85E-02	1.83E-02	1.23E-03	5.94E-01
Particulates, total	1.07E+00	...	1.71E-01	2.49E-02	4.69E-02	…	1.31E+00
Perchloroethylene	...	...	6.76E-10	1.41E-10	2.29E-09	…	3.10E-09
Phenolic compounds	...	...	3.51E-08	7.30E-09	1.01E-07	…	1.43E-07
Phosphorus	...	...	...	...	4.36E-06	…	4.36E-06
Propylene oxide	...	...	3.02E-11	1.42E-11	...	…	4.44E-11
Radionuclides (kBq)	...	...	3.63E-03	7.56E-04	2.65E-02	…	3.09E-02
Selenium	...	...	6.60E-09	1.37E-09	9.69E-08	…	1.05E-07
Sulfur dioxide, SO_2	4.98E-01	...	...	...	4.45E-05	…	4.98E-01
Sulfur oxides, SO_X	...	...	6.63E-04	1.61E-04	2.42E-04	2.41E-03	3.48E-03
Toluene	...	...	1.35E-10	6.35E-11	...	…	1.99E-10
Total hydrocarbon, THC	...	...	...	...	6.65E-03	…	6.65E-03
Volatile organic compounds, VOC	1.82E-02	...	6.27E-04	1.89E-04	7.38E-03	4.05E-03	3.04E-02
Xylenes	...	...	6.67E-11	3.13E-11	...	…	9.80E-11
Zinc	...	...	...	...	1.66E-08	…	1.66E-08
Emission to land							
Cement kiln dust, CKD	1.49E+01	...	...	...	...	…	1.49E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.02E-04	2.13E-05	7.60E+01	…	7.60E+01

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G3b. Precast Mix 3 (Architectural) LCI Results (U.S. Customary Units)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Raw material							
Limestone	7.56E+02	...	...	...	...	...	7.56E+02
Cement rock, marl	1.30E+02	...	...	...	...	...	1.30E+02
Shale	3.27E+01	...	...	...	...	...	3.27E+01
Clay	3.99E+01	...	...	...	...	...	3.99E+01
Bottom ash	6.46E+00	...	...	...	...	...	6.46E+00
Fly ash	8.59E+00	...	...	...	...	...	8.59E+00
Foundry sand	2.59E+00	...	...	...	...	...	2.59E+00
Sand	2.61E+01	...	...	...	...	...	2.61E+01
Iron, iron ore	8.91E+00	...	...	...	...	...	8.91E+00
Blast furnace slag	1.34E+01	...	...	...	...	...	1.34E+01
Slate	6.65E-01	...	...	...	...	...	6.65E-01
Other raw material	1.83E+01	...	...	...	...	...	1.83E+01
Gypsum, anhydrite	3.15E+01	...	...	...	...	...	3.15E+01
Water, process	5.22E+01	...	...	...	...	...	3.12E+02
Water, non-process	5.04E+02	...	no data	no data	1.70E+02	...	6.75E+02
Coarse aggregate, natural	...	...	1.33E+03	...	...	...	1.33E+03
Coarse aggregate, manufactured	...	...	...	4.68E+02	...	...	4.68E+02
Fine aggregate, natural	...	...	1.25E+03	...	...	...	1.25E+03
Fine aggregate, manufactured	...	...	...	...	...	...	...
Silica fume	...	...	...	...	...	...	...
Slag cement, i.e., GGBFS	...	...	...	...	...	...	...
Ancillary material							
Explosives	1.92E-01	...	no data	no data	...	...	1.92E-01
Refractory	4.08E-01	...	...	...	...	...	4.08E-01
Grinding media	9.10E-02	...	...	...	...	...	9.10E-02
Grinding aids	2.34E-01	...	...	...	...	...	2.34E-01
Filter bags	1.25E-02	...	...	...	...	...	1.25E-02
Oil & grease	8.45E-02	...	...	...	no data	...	8.45E-02
Oil (gallon)	...	...	...	...	no data	...	...
Grease (gallon)	...	...	...	...	no data	...	...
Solvent (gallon)	...	...	...	...	...	...	...
Cement bags	4.42E-01	...	...	...	...	...	4.42E-01
Chains	1.25E-02	...	...	...	...	...	1.25E-02
Fuel and electricity							
Coal (ton)	3.28E-02	...	...	...	...	…	3.28E-02
Gasoline (gallon)	3.27E-03	...	7.01E-03	2.20E-03	1.88E-01	9.71E-02	2.98E-01
Liquefied petroleum gas (gallon)	2.19E-03	...	...	...	4.62E-01	…	4.64E-01
Middle distillates (gallon)	7.25E-02	...	7.25E-02	2.18E-02	1.26E+00	3.62E-01	1.79E+00
Natural gas (thousand cu ft)	4.07E-02	...	1.72E-03	8.07E-04	2.47E-01	…	2.90E-01
Petroleum coke (ton)	7.31E-03	...	...	...	...	…	7.31E-03
Residual oil (gallon)	7.49E-03	...	1.63E-02	3.39E-03	...	1.96E-02	4.67E-02
Wastes (MBtu)	1.13E-01	...	...	...	...	…	1.13E-01
Electricity (kWh)	4.14E+01	...	3.11E+00	7.25E-01	2.91E+01	…	7.44E+01
Energy equivalent, MBtu							
Coal	6.89E-01	...	...	...	...	…	6.89E-01
Gasoline	4.09E-04	...	8.77E-04	2.75E-04	2.35E-02	1.21E-02	3.72E-02
Liquefied petroleum gas	1.99E-04	...	...	...	4.20E-02	…	4.21E-02
Middle distillates	1.01E-02	...	1.01E-02	3.02E-03	1.75E-01	5.02E-02	2.49E-01
Natural gas	4.18E-02	...	1.77E-03	8.29E-04	2.53E-01	…	2.98E-01
Petroleum coke	2.20E-01	...	...	...	...	…	2.20E-01
Residual oil	1.12E-03	...	2.44E-03	5.07E-04	...	2.93E-03	7.00E-03
Wastes	1.13E-01	...	...	...	...	…	1.13E-01
Electricity	1.41E-01	...	1.06E-02	2.48E-03	9.94E-02	…	2.54E-01
Subtotal	1.22E+00	...	2.57E-02	7.11E-03	5.94E-01	6.53E-02	1.91E+00
Emission to water							
Aluminum	5.59E-04	...	...	...	...	…	5.59E-04
Ammonia, ammonium	6.16E-04	...	...	...	...	…	6.16E-04
Chemical oxygen demand, COD	...	...	...	...	...	…	...
Chlorides	4.73E-01	...	1.17E-09	2.43E-10	2.77E-09	…	4.73E-01
Copper	...	...	5.83E-09	1.21E-09	1.38E-08	…	2.09E-08
Dissolved organic compounds	8.96E-03	...	...	...	...	…	8.96E-03

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.

Table G3b. Precast Mix 3 (Architectural) LCI Results (U.S. Customary Units) (Continued)*

Inputs and outputs per cu yd concrete (lb unless otherwise specified)	Portland cement	Slag cement	Aggregates		Plant operations	Transport	Total
			Natural	Manuf.			
Iron	...	...	5.83E-09	1.21E-09	1.38E-08	…	2.09E-08
Nitric, nitrites	3.83E-03	...	...	...	...	…	3.83E-03
Oil and grease	4.89E-03	...	8.74E-08	1.82E-08	2.08E-07	…	4.89E-03
pH	8.45	no data	no data	no data	no data	…	8.45
Phenolics	1.43E-05	...	...	...	...	…	1.43E-05
Phosphorus	3.58E-06	...	...	...	...	…	3.58E-06
Sulfates	4.00E-01	...	...	...	...	…	4.00E-01
Sulfides	4.30E-05	...	...	...	...	…	4.30E-05
Suspended solids	1.52E-01	...	1.75E-07	3.64E-08	4.15E-07	…	1.52E-01
Water (that leaves site) (gallon)	2.86E+02	...	...	...	1.01E+02	…	3.86E+02
Zinc	2.15E-05	...	...	...	...	…	2.15E-05
Emission to air							
1,3 Butadiene	...	...	7.55E-13	3.54E-13	...	…	1.11E-12
Acetaldehyde	...	...	7.03E-11	3.29E-11	...	…	1.03E-10
Acrolein	...	...	1.12E-11	5.27E-12	...	…	1.65E-11
Ammonia, NH_3	3.09E-03	...	...	...	5.86E-04	…	3.68E-03
Arsenic	...	...	2.15E-08	4.47E-09	6.41E-07	…	6.67E-07
Benzene	...	...	3.51E-09	7.35E-10	5.18E-07	…	5.23E-07
Beryllium	...	...	4.53E-10	9.42E-11	7.22E-08	…	7.28E-08
Cadmium	...	...	6.48E-09	1.35E-09	2.98E-07	…	3.06E-07
Carbon dioxide, CO_2	5.89E+02	...	2.35E+00	6.68E-01	4.18E+01	1.12E+01	6.45E+02
Carbon dioxide, CO_2, calcination	3.58E+02	...	...	...	...	…	3.58E+02
Carbon dioxide, CO_2, combustion	2.30E+02	...	2.35E+00	6.68E-01	4.18E+01	1.12E+01	2.86E+02
Carbon monoxide, CO	6.94E-01	...	5.02E-03	1.53E-03	1.54E-01	4.89E-02	9.03E-01
Chromium	...	...	1.38E-08	2.86E-09	2.45E-06	…	2.47E-06
Cobalt	...	...	9.80E-08	2.04E-08	2.07E-08	…	1.39E-07
Copper	...	...	...	...	4.20E-08	…	4.20E-08
Dioxins and furans, TEQ 2,3,7,8-TCDD	6.35E-11	...	2.43E-13	5.09E-14	7.01E-13	…	6.45E-11
Ethylbenzene	...	...	5.62E-11	2.63E-11	...	…	8.26E-11
Formaldehyde	...	...	5.39E-07	1.12E-07	1.85E-05	…	1.92E-05
Hydrogen chlorine, HCl	4.76E-02	...	1.14E-05	2.37E-06	3.53E-05	…	4.76E-02
Hydrogen sulfide, H_2S	...	...	...	...	...	…	...
Lead	...	...	2.46E-08	5.12E-09	9.48E-07	…	9.78E-07
Manganese	...	...	4.88E-08	1.02E-08	1.50E-05	…	1.51E-05
Mercury, Hg	3.96E-05	...	1.84E-09	3.83E-10	8.52E-08	…	3.97E-05
Metals, not specified	...	...	...	...	...	…	...
Methane, CH_4	2.42E-02	...	8.88E-05	2.54E-05	9.02E-04	6.10E-04	2.59E-02
Methylene chloride	...	...	7.85E-08	1.63E-08	2.26E-07	…	3.21E-07
Naphthalene	...	...	1.84E-08	3.83E-09	1.51E-07	…	1.73E-07
Nickel	...	...	1.38E-06	2.86E-07	3.11E-06	…	4.77E-06
Nitric oxide, NO (unspecified)	...	...	7.17E-05	2.15E-05	1.01E-03	3.27E-04	1.43E-03
Nitrogen oxides, NO_X	1.45E+00	...	1.44E-02	4.24E-03	4.53E-02	1.06E-01	1.62E+00
Non-methane organic gases, NMOG	...	...	...	...	1.10E-02	…	1.10E-02
Polycyclic aromatic hydrocarbons, PAH	...	...	3.86E-12	1.81E-12	...	…	5.68E-12
Particulates, PM-2.5	5.90E-05	...	...	2.64E-05	...	…	8.54E-05
Particulates, PM-10	4.14E-01	...	5.06E-01	4.80E-02	3.09E-02	2.07E-03	1.00E+00
Particulates, total	1.80E+00	...	2.89E-01	4.19E-02	7.91E-02	…	2.21E+00
Perchloroethylene	...	...	1.14E-09	2.37E-10	3.85E-09	…	5.23E-09
Phenolic compounds	...	...	5.91E-08	1.23E-08	1.70E-07	…	2.42E-07
Phosphorus	...	...	...	...	7.35E-06	…	7.35E-06
Propylene oxide	...	...	5.09E-11	2.39E-11	...	…	7.48E-11
Radionuclides (kBq)	...	...	6.13E-03	1.27E-03	4.46E-02	…	5.20E-02
Selenium	...	...	1.11E-08	2.31E-09	1.63E-07	…	1.77E-07
Sulfur dioxide, SO_2	8.40E-01	...	...	...	7.51E-05	…	8.40E-01
Sulfur oxides, SO_X	...	...	1.12E-03	2.72E-04	4.08E-04	4.07E-03	5.86E-03
Toluene	...	...	2.28E-10	1.07E-10	...	…	3.35E-10
Total hydrocarbon, THC	...	...	...	...	1.12E-02	…	1.12E-02
Volatile organic compounds, VOC	3.06E-02	...	1.06E-03	3.19E-04	1.24E-02	6.83E-03	5.13E-02
Xylenes	...	...	1.12E-10	5.27E-11	...	…	1.65E-10
Zinc	...	...	...	...	2.80E-08	…	2.80E-08
Emission to land							
Cement kiln dust, CKD	2.52E+01	...	...	...	...	…	2.52E+01
Slag reject	...	...	...	...	...	…	...
Other solid waste	...	...	1.73E-04	3.59E-05	1.28E+02	…	1.28E+02

*The notation in the table is a modified scientific notation, for example 1.234E-02 means 1.234×10^{-2} which is equal to 0.01234. Three dots "…" mean zero.