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August 11, 2003

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Life Cycle Inventory of Slag Cement Concrete
CTL Project No. 312012

Dear Mr. Prusinski,

As authorized by Mr. Randy Dunlap, President, Slag Cement Association, on June 28, 2002, Construction Technology Laboratories, Inc. (CTL) has completed a life cycle inventory of slag cement concrete. This report contains the basis, methodology, and summary of the life cycle inventory.

INTRODUCTION

A life cycle inventory (LCI) is a compilation of the materials and energy 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.

Background

Slag is waste material created during the production of pig iron in a blast furnace. Slag cement, also known as ground granulated blast furnace slag, is a supplementary cementitious material used as a partial replacement for portland cement in concrete. To process slag so it can be used as a supplementary cementitious material in concrete, hot slag is quenched with water and ground. Manufacturing slag cement consists of the following processes: (i) quenching and granulation, (ii) dewatering and/or drying, (iii) crushing, (iv) grinding, (v) storage, and (vi) shipping. The LCI for slag cement concrete assumes that slag comes into the system boundary with no environmental burdens since it is a waste product. Please refer to the LCI of slag cement for further details.[1]

[1] Marceau, M.L., and VanGeem, M.G, "Life Cycle Inventory of Slag Cement Manufacturing Process," CTL Project No. 312012, Letter-report to the Slag Cement Association, August 11, 2003.

LIFE CYCLE INVENTORY OF SLAG CEMENT CONCRETE

The functional unit is the basis for comparison in an LCI. In this report, the functional unit is defined as one cubic yard of concrete. Ten concrete mixes are compared in this LCI. Table 1 lists the mix designs for each of the mixes. The mixes are characterized by their intended use (ready-mix concrete for use in on-site forms, precast concrete for use in precast elements, and concrete for use in molding concrete blocks), compressive strength, and slag cement content. The mixes contain slag cement, portland cement, silica fume (high-strength precast mix only), coarse aggregate (except block mix), fine aggregate, water, and air. The mixes were provided by you in an e-mail dated December 20, 2002. They were designed to be consistent with those in the portland cement concrete LCI.[2] A copy of the report is attached to this letter for your convenience. As with any concrete mix, these mixes should not be used to produce concrete without verifying workability and performance according to applicable procedures and standards.

The system boundary defines the scope of an LCI. In this study, the system boundary is based on the system boundary for portland cement concrete in Reference 2. Figure 1 shows the system boundary for slag cement concrete. This LCI represents (i) ready-mix concrete exiting the plant gate, (ii) precast concrete ready for placement in forms, and (iii) concrete block exiting the manufacturing plant.

The system boundary does not include upstream profiles of energy sources, such as the energy and emissions associated with producing coal or generating electricity. However, the quantities of fuels used are included. In addition, the fuel used for transportation includes pre-combustion energy, that is, the energy used to acquire the fuels.

Methodology

The LCI of slag cement concrete was created by importing the data from the slag cement LCI into the portland cement concrete LCI. The basis for the slag cement concrete LCI is the same as that for the concrete LCI. Exceptions and additional assumptions are described below. This LCI is carried out in conformance with the requirement set by the International Organization for Standardization (ISO) in ISO 14040 and 14041.[3,4]

Transportation of slag and slag cement to granulators, grinding facilities, and distribution terminals is included in this LCI. This transportation data is from the slag cement LCI. In

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[2] Nisbet, M.A., Marceau, M.L., and VanGeem, M.G., "Environmental Life Cycle Inventory of Portland Cement Concrete," PCA R&D Serial No. 2095a, Portland Cement Association, Skokie, Illinois, 2002.

[3] "Environmental Management - Life Cycle Assessment - Principles and Framework," ANSI/ISO 14040, International Organization for Standardization, Geneva, Switzerland, 1997.

[4] "Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis," ISO 14041, International Organization for Standardization, Geneva, Switzerland, 1998.

addition, transportation of slag cement from the distribution terminals to the concrete plant is also included in this LCI, and it is assumed to be the same as for portland cement.[5]

Summary of Data

The LCI of slag cement concrete is presented in the following tables.

Table 2 lists the raw materials inputs for manufacturing portland cement, slag cement, and slag cement concrete. The LCI assumes that one ton of slag granules yields one ton of slag cement. Although some material is lost in the form of particulate matter and suspended solids, the amount is significantly less than 1 pound per ton slag cement. Note that the water used in manufacturing slag cement is not incorporated into slag cement, whereas the water used in producing portland cement and concrete is incorporated into the concrete.

Table 3 shows the amount of fuel and electricity used. Table 4 is a conversion of the fuel and electricity use to energy consumption. When compared to the portland cement concrete LCI, Table 4 shows that replacing 35 and 50% portland cement for slag cement reduces energy consumption per cubic yard of concrete for the 5,000 psi mix by 23 and 34%, respectively.

Table 5 summarizes the emissions to air from transporting finished goods to the concrete plant. Table 6 summarizes the emissions to air by process step for slag cement concrete production. The emissions to air consist of carbon dioxide (CO_2), carbon monoxide (CO), hydrogen sulfide (H_2S), metals, methane (CH_4), nitrogen oxides (NO_X), volatile organic compounds (VOC), particulate matter, and sulfur dioxide (SO_2). The emissions from fuel combustion during manufacturing of slag cement are based on the slag cement LCI except for CO_2 emissions. The CO_2 emissions are calculated from EPA AP-42 emission factors.[6] Table 7 summarizes the total emissions to air, land, and water for all the steps of concrete production. Although H_2S and metals emissions are not included in the portland cement and portland cement concrete LCIs, these emissions from the manufacture of slag cement are shown here for completeness. In general, emissions to air decrease with increasing level of slag cement replacement. When compared to the portland cement concrete LCI, Table 7 shows that replacing 35 and 50% portland cement with slag cement reduces CO_2 emissions per cubic yard of concrete for the 5,000 psi mix by 31 and 45%, respectively.

SUMMARY AND CONCLUSIONS

The life cycle inventories of portland cement concrete and slag cement were used to develop this life cycle inventory for concrete with slag cement used as a partial replacement for portland cement. The LCI includes materials, energy, and emissions through the manufacture of one cubic

[5] 60 miles.

[6] *Compilation of Air Pollutant Emission Factors*, Chapter 1: "External Combustion Sources," Table 1.3-12. Default CO_2 Emission Factors for Liquid Fuel, and Table 1.4-2. Emission Factors for Criteria Pollutants and Green House Gases from Natural Gas Combustion, AP-42, Fifth Edition, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 1995.

yard of concrete. It does not include the upstream profiles of the fuels, although it includes the quantity of fuel used. Energy and emissions to air are significantly reduced when slag is used as a partial replacement for portland cement.

We appreciate the opportunity to be of service to the Slag Cement Association. Please contact one of us if you have any questions.

Sincerely,

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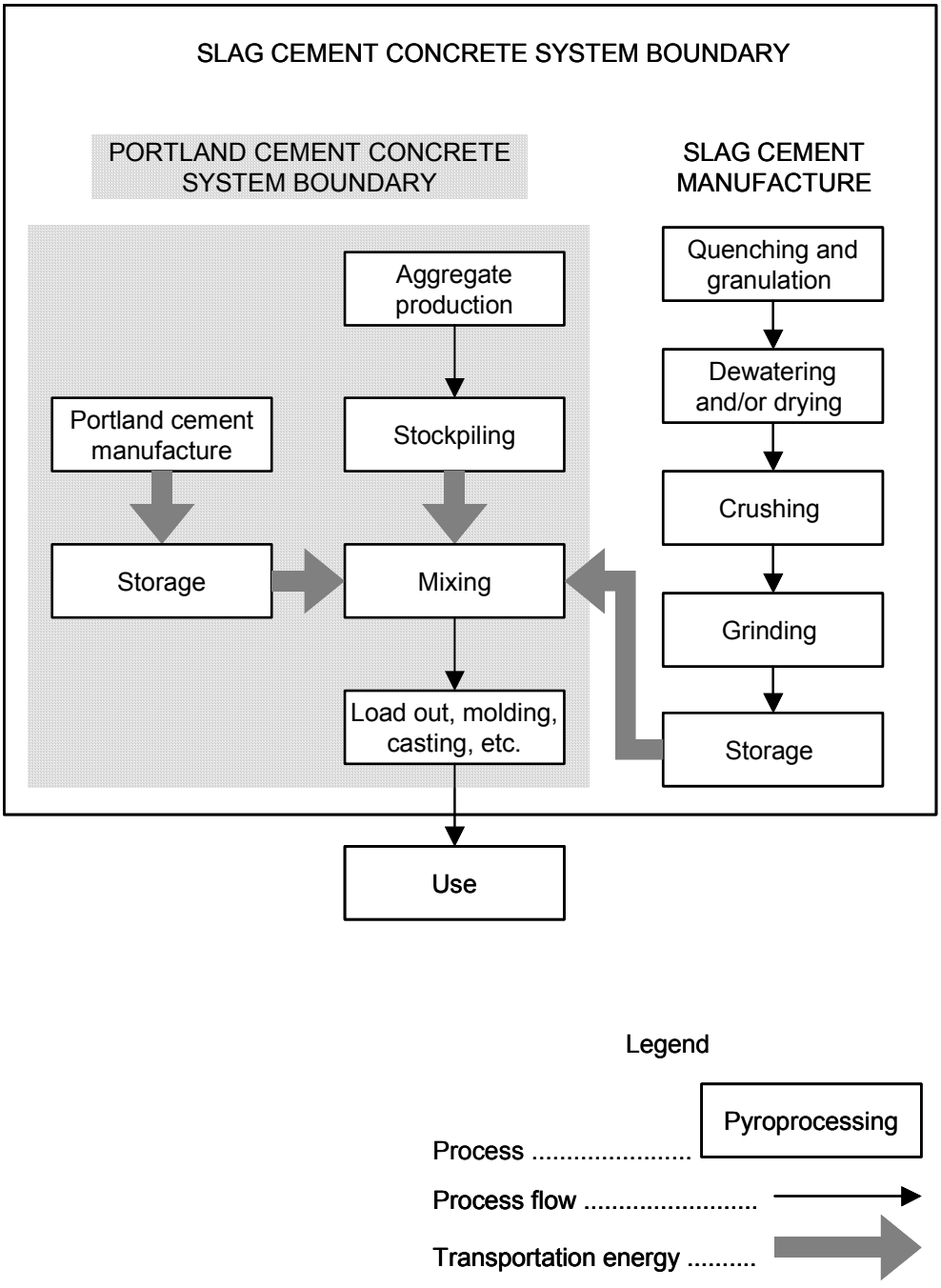

Figure 1. The LCI data from manufacturing slag cement is imported into the portland cement concrete LCI to develop an LCI for slag cement concrete.

Table 1. Mix Designs and Properties of Slag Cement Concrete[1,2]

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31[3]	44[4]	35	50
Unit weight, lb/cu ft	145	145	148	148	143	143	147	147	149	149
Concrete raw material, lb/cu yd concrete										
Portland cement	244	188	367	282	552	425	488	375	228	175
Slag cement	132	188	197	282	298	425	262	375	122	175
Silica fume	0	0	0	0	0	0	95	95	0	0
Water	237	237	237	237	300	300	230	230	240	240
Coarse aggregate	1,900	1,900	2,000	2,000	1,770	1,770	1,875	1,875	0	0
Fine aggregate	1,400	1,400	1,200	1,200	935	935	1,030	1,030	3,427[5]	3,427
Total	**3,913**	**3,913**	**4,001**	**4,001**	**3,855**	**3,855**	**3,980**	**3,980**	**4,017**	**4,017**

[1] Concretes with different compressive strengths represent different broad use-categories. Structural concrete for beams, columns, floors, slabs, and other uses often specify 4,000 or 5,000 psi. Residential and other general use concrete is often 3,000 psi or less.

[2] The Slag Cement Association provided the mix designs.

[3] Slag cement is a 35% replacement for portland cement and 31% of the total cementitious materials.

[4] Slag cement is a 50% replacement for portland cement and 44% of the total cementitious materials.

[5] Fine aggregate is assumed to be 1,043 lb/cu yd of crushed stone and 2,384 lb/cu yd of sand. This is consistent with the portland cement concrete LCI.

Table 2. Raw Materials Inputs for Manufacturing Portland Cement, Slag Cement, and Slag Cement Concrete

Concrete mix description	**Ready mix concrete**				**Precast concrete**				**Concrete block**	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Portland cement, lb/cu yd concrete	244	188	367	282	552	425	488	375	228	175
Slag cement, lb/cu yd concrete	132	188	197	282	298	425	262	375	122	175
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Portland cement raw material*, lb/cu yd concrete										
Limestone	291	224	437	336	658	507	582	447	272	209
Cement rock, marl	55	42	82	63	123	95	109	84	51	39
Shale	13	10	20	15	30	23	26	20	12	9
Clay	16	13	25	19	37	29	33	25	15	12
Bottom ash	0	0	0	0	1	0	0	0	0	0
Fly ash	1	1	2	2	3	2	3	2	1	1
Foundry sand	1	1	1	1	2	1	1	1	1	1
Sand	3	2	4	3	6	5	6	4	3	2
Iron, iron ore	2	1	3	2	4	3	3	3	2	1
Gypsum, anhydrite	12	10	19	14	28	22	25	19	12	9
Water	43	33	65	50	97	75	86	66	40	31
Subtotal**	**394**	**304**	**593**	**455**	**892**	**687**	**788**	**605**	**369**	**283**
Slag Cement										
Blast furnace slag	132	188	197	282	298	425	262	375	122	175
Water***	15	21	22	31	33	47	29	41	13	19
Subtotal	**147**	**209**	**219**	**313**	**331**	**472**	**291**	**416**	**135**	**194**

Table 2. Raw Materials Inputs for Manufacturing Portland Cement, Slag Cement, and Slag Cement Concrete (Continued)

Concrete mix description	**Ready mix concrete**				**Precast concrete**				**Concrete block**	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Other concrete raw material, lb/cu yd concrete										
Silica fume	0	0	0	0	0	0	95	95	0	0
Water	237	237	237	237	300	300	230	230	240	240
Coarse aggregate	1,900	1,900	2,000	2,000	1,770	1,770	1,875	1,875	0	0
Fine aggregate	1,400	1,400	1,200	1,200	935	935	1,030	1,030	3,427	3,427
Subtotal	**3,537**	**3,537**	**3,437**	**3,437**	**3,005**	**3,005**	**3,230**	**3,230**	**3,667**	**3,667**
Total	**4,078**	**4,050**	**4,249**	**4,205**	**4,228**	**4,164**	**4,309**	**4,251**	**4,171**	**4,144**

*U.S. and Canadian Labor-Energy Input Survey, Portland Cement Association, Skokie IL, January 2001.

**Approximately 1.6 tons of raw materials (excluding water) are needed to make 1 ton of cement due primarily to calcination of the limestone. Subtotal does not include water.

***Water used in manufacturing slag cement is not incorporated into the slag cement wheras the water used in producing portland cement and concrete is incorporated into the concrete.

Table 3. Fuel and Electricity Use for Slag Cement Concrete

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Portland cement manufacturing, fuel unit/cu yd concrete										
Coal, lb	28.2	21.7	42.4	32.6	63.8	49.1	56.4	43.4	26.4	20.2
Gasoline, gal	0.00191	0.00147	0.00287	0.00221	0.00432	0.00332	0.00382	0.00293	0.00178	0.00137
LPG, gal	0.000409	0.000315	0.000615	0.000472	0.000924	0.000712	0.000817	0.000628	0.000382	0.000293
Middle distillates, gal	0.0358	0.0276	0.0538	0.0414	0.0810	0.0624	0.0716	0.0550	0.0335	0.0257
Natural gas, cu ft	35.4	27.3	53.2	40.9	80.1	61.6	70.8	54.4	33.1	25.4
Petroleum coke, lb	5.73	4.42	8.62	6.62	13.0	10.0	11.5	8.81	5.35	4.11
Residual oil, gallon	0.00271	0.00209	0.00408	0.00313	0.00614	0.00472	0.00542	0.00417	0.00253	0.00194
Wastes, lb	4.50	3.47	6.77	5.20	10.2	7.84	9.00	6.92	4.20	3.23
Electricity, kWh	16.9	13.0	25.4	19.5	38.2	29.4	33.8	25.9	15.8	12.1
Slag cement manufacturing, fuel unit/cu yd concrete										
Diesel fuel, gal	0.00191	0.00272	0.00285	0.00407	0.00431	0.00614	0.00379	0.00542	0.00176	0.00253
Natural gas, cu ft	18.9	27.0	28.3	40.5	42.8	61.0	37.6	53.8	17.5	25.1
No. 2 fuel oil, gal	0.0180	0.0257	0.0269	0.0385	0.0407	0.0580	0.0358	0.0512	0.0167	0.0239
Electricity, kWh	5.46	7.77	8.15	11.7	12.3	17.6	10.8	15.5	5.04	7.24
Aggregate production, fuel unit/cu yd concrete										
Crushed stone										
Diesel fuel, gal	0.255	0.255	0.247	0.247	0.209	0.209	0.224	0.224	0.132	0.132
Electricity, kWh	10.3	10.3	10.0	10.0	8.46	8.46	9.09	9.09	5.35	5.35
Sand and gravel										
Diesel fuel, gal	0.0931	0.0931	0.0903	0.0903	0.0763	0.0763	0.0819	0.0819	0.172	0.172
Electricity, kWh	3.77	3.77	3.66	3.66	3.09	3.09	3.32	3.32	6.99	6.99

Table 3. Fuel and Electricity Use for Slag Cement Concrete (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Transporting materials to plant, fuel unit/cu yd concrete										
Diesel fuel, gal										
Cement	0.0776	0.0598	0.117	0.0896	0.175	0.135	0.155	0.119	0.0725	0.0556
Slag cement	0.0420	0.0598	0.0626	0.0896	0.0947	0.135	0.0833	0.119	0.0388	0.0556
Silica fume	0	0	0	0	0	0	0.0302	0.0302	0	0
Coarse aggregate	0.302	0.302	0.318	0.318	0.281	0.281	0.298	0.298	0	0
Fine aggregate	0.223	0.223	0.191	0.191	0.149	0.149	0.164	0.164	0.545	0.545
Concrete plant operations, fuel unit/cu yd concrete										
Diesel fuel, gal	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Natural gas, cu ft	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5
Electricity, kWh	3.02	3.02	3.02	3.02	3.02	3.02	3.02	3.02	3.02	3.02
Concrete block curing, fuel unit/cu yd concrete										
Middle distillates, gal	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.176	0.176
Natural gas, cu ft	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	23.7	23.7
Electricity, kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0

Table 4. Energy Inputs for Slag Cement Concrete

Concrete mix description	**Ready mix concrete**				**Precast concrete**				**Concrete block**	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Portland cement manufacturing, MBtu/cu yd concrete										
Coal	0.330	0.254	0.497	0.382	0.747	0.575	0.660	0.508	0.309	0.237
Gasoline	0.0002	0.0002	0.0004	0.0003	0.0005	0.0004	0.0005	0.0004	0.0002	0.0002
LPG	0.00004	0.00003	0.0001	0.00004	0.0001	0.0001	0.0001	0.0001	0.00003	0.00003
Middle distillates	0.005	0.004	0.007	0.006	0.011	0.009	0.010	0.008	0.005	0.004
Natural gas	0.036	0.028	0.055	0.042	0.082	0.063	0.073	0.056	0.034	0.026
Petroleum coke	0.083	0.064	0.125	0.096	0.187	0.144	0.166	0.127	0.077	0.059
Residual oil	0.0004	0.0003	0.001	0.000	0.001	0.001	0.001	0.001	0.000	0.000
Wastes	0.045	0.035	0.068	0.052	0.102	0.078	0.090	0.069	0.042	0.032
Electricity	0.057	0.044	0.086	0.066	0.130	0.100	0.114	0.088	0.053	0.041
Subtotal	**0.557**	**0.429**	**0.838**	**0.644**	**1.261**	**0.971**	**1.114**	**0.856**	**0.521**	**0.400**
Slag cement manufacturing, MBtu/cu yd concrete										
Diesel fuel	0.0003	0.0004	0.0004	0.0005	0.0006	0.0008	0.0005	0.0007	0.0002	0.0003
Natural gas	0.019	0.028	0.029	0.041	0.044	0.062	0.039	0.055	0.018	0.026
No. 2 fuel oil	0.003	0.004	0.004	0.006	0.006	0.009	0.005	0.008	0.002	0.004
Electricity	0.019	0.027	0.028	0.040	0.042	0.060	0.037	0.053	0.017	0.025
Subtotal	**0.041**	**0.058**	**0.061**	**0.088**	**0.093**	**0.132**	**0.081**	**0.116**	**0.038**	**0.054**
Aggregate production, MBtu/cu yd concrete										
Crushed stone										
Diesel fuel	0.035	0.035	0.034	0.034	0.029	0.029	0.031	0.031	0.018	0.018
Electricity	0.035	0.035	0.034	0.034	0.029	0.029	0.031	0.031	0.018	0.018

Table 4. Energy Inputs for Slag Cement Concrete (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Sand and gravel										
Diesel fuel	0.013	0.013	0.012	0.012	0.011	0.011	0.011	0.011	0.024	0.024
Electricity	0.013	0.013	0.012	0.012	0.011	0.011	0.011	0.011	0.024	0.024
Subtotal	**0.096**	**0.096**	**0.093**	**0.093**	**0.079**	**0.079**	**0.085**	**0.085**	**0.084**	**0.084**
Transporting materials to plant, MBtu/cu yd concrete										
Diesel fuel										
Cement	0.011	0.008	0.016	0.012	0.024	0.019	0.021	0.016	0.010	0.008
Slag cement	0.006	0.008	0.009	0.012	0.013	0.019	0.012	0.016	0.005	0.008
Silica fume	0	0	0	0	0	0	0.0042	0.0042	0	0
Coarse aggregate	0.042	0.042	0.044	0.044	0.039	0.039	0.041	0.041	0	0
Fine aggregate	0.031	0.031	0.026	0.026	0.021	0.021	0.023	0.023	0.075	0.075
Subtotal	**0.089**	**0.089**	**0.095**	**0.095**	**0.097**	**0.097**	**0.101**	**0.101**	**0.091**	**0.091**
Concrete plant operations, MBtu/cu yd concrete										
Diesel fuel	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139	0.139
Natural gas	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
Electricity	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Subtotal	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**	**0.179**
Concrete block curing, MBtu/cu yd concrete										
Middle distillates	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.024	0.024
Natural gas	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.024	0.024
Electricity	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0
Subtotal	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**0.049**	**0.049**
Total	**0.963**	**0.852**	**1.27**	**1.10**	**1.71**	**1.46**	**1.56**	**1.34**	**0.961**	**0.857**

Table 5. Emissions to Air from Transporting Finished Goods to Concrete Plant for Concrete Production

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Portland cement and silica fume transportation, lb/cu yd concrete										
Particulate matter	0.00231	0.00178	0.00348	0.00267	0.00523	0.00403	0.00552	0.00445	0.00216	0.00166
CO_2	1.77	1.36	2.66	2.04	4.00	3.08	4.23	3.41	1.65	1.27
SO_2	0.00281	0.00216	0.00422	0.00324	0.00635	0.00489	0.00671	0.00541	0.00262	0.00201
NO_x	0.0163	0.0125	0.0245	0.0188	0.0368	0.0284	0.0389	0.0314	0.0152	0.0117
VOC*	0.00292	0.00225	0.00440	0.00338	0.00661	0.00509	0.00699	0.00563	0.00273	0.00210
CO	0.0162	0.0125	0.0244	0.0187	0.0367	0.0282	0.0387	0.0312	0.0151	0.0116
CH_4	0.000483	0.000372	0.000726	0.000558	0.00109	0.000841	0.00115	0.000930	0.000451	0.000346
Slag cement transportation, lb/cu yd concrete										
Particulate matter	0.00125	0.00178	0.00187	0.00267	0.00282	0.00403	0.00248	0.00355	0.00116	0.00166
CO_2	0.957	1.36	1.43	2.04	2.16	3.08	1.90	2.72	0.884	1.27
SO_2	0.00152	0.00216	0.00227	0.00324	0.00343	0.00489	0.00301	0.00431	0.00140	0.00201
NO_x	0.00881	0.0125	0.0131	0.0188	0.0199	0.0284	0.0175	0.0250	0.00814	0.0117
VOC*	0.00158	0.00225	0.00236	0.00338	0.00357	0.00509	0.00314	0.00449	0.00146	0.00210
CO	0.00877	0.0125	0.0131	0.0187	0.0198	0.0282	0.0174	0.0249	0.00810	0.0116
CH_4	0.000261	0.000372	0.000390	0.000558	0.000589	0.000841	0.000518	0.000742	0.000241	0.000346

*These VOC values also include some non-VOC, such as CH_4.

Table 5. Emissions to Air from Transporting Finished Goods to Concrete Plant for Concrete Production (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Aggregate transportation, lb/cu yd concrete										
Particulate matter	0.0156	0.0156	0.0152	0.0152	0.0128	0.0128	0.0138	0.0138	0.0162	0.0162
CO_2	12.0	12.0	11.6	11.6	9.80	9.80	10.5	10.5	12.4	12.4
SO_2	0.0190	0.0190	0.0184	0.0184	0.0156	0.0156	0.0167	0.0167	0.0197	0.0197
NO_x	0.110	0.110	0.107	0.107	0.0903	0.0903	0.0970	0.0970	0.114	0.114
VOC*	0.0198	0.0198	0.0192	0.0192	0.0162	0.0162	0.0174	0.0174	0.0205	0.0205
CO	0.110	0.110	0.106	0.106	0.0899	0.0899	0.0965	0.0965	0.114	0.114
CH_4	0.00326	0.00326	0.00316	0.00316	0.00267	0.00267	0.00287	0.00287	0.00339	0.00339
Total material transportation, lb/cu yd concrete										
Particulate matter	0.0192	0.0192	0.0205	0.0205	0.0209	0.0209	0.0218	0.0218	0.0195	0.0195
CO_2	14.7	14.7	15.7	15.7	16.0	16.0	16.7	16.7	15.0	15.0
SO_2	0.0233	0.0233	0.0249	0.0249	0.0253	0.0253	0.0264	0.0264	0.0237	0.0237
NO_x	0.135	0.135	0.144	0.144	0.147	0.147	0.153	0.153	0.138	0.138
VOC*	0.0243	0.0243	0.0259	0.0259	0.0264	0.0264	0.0275	0.0275	0.0247	0.0247
CO	0.135	0.135	0.144	0.144	0.146	0.146	0.153	0.153	0.137	0.137
CH_4	0.00401	0.00401	0.00428	0.00428	0.00436	0.00436	0.00454	0.00454	0.00408	0.00408

*These VOC values also include some non-VOC, such as CH_4.

Table 6. Emissions to Air by Process Step for Slag Cement Concrete Production

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Portland cement manufacture, lb/cu yd concrete										
Particulate matter	0.610	0.470	0.918	0.706	1.38	1.06	1.22	0.938	0.570	0.438
CO_2	220	169	330	254	497	383	439	338	205	158
SO_2	0.481	0.370	0.723	0.556	1.09	0.838	0.962	0.739	0.449	0.345
NO_x	0.629	0.484	0.946	0.727	1.422	1.10	1.26	0.966	0.587	0.451
VOC*	0.0101	0.00778	0.0152	0.0117	0.0228	0.0176	0.0202	0.0155	0.00944	0.00724
CO	0.214	0.165	0.322	0.247	0.484	0.372	0.428	0.329	0.200	0.153
CH_4	0.00863	0.00665	0.0130	0.0100	0.0195	0.0150	0.0173	0.0133	0.00807	0.00619
Slag cement manufacture, lb/cu yd concrete										
Particulate matter	0.020	0.029	0.030	0.043	0.046	0.065	0.040	0.058	0.019	0.027
CO_2	2.77	3.95	4.13	5.92	6.25	8.92	5.50	7.87	2.56	3.67
SO_2	0.0306	0.0436	0.0457	0.0654	0.0692	0.0986	0.0608	0.0870	0.0283	0.0406
NO_x	0.00415	0.00591	0.00620	0.00887	0.00937	0.01337	0.00824	0.01179	0.00384	0.00550
VOC*	0.000298	0.000425	0.000445	0.000638	0.000674	0.000961	0.000592	0.000848	0.000276	0.000396
CO	0.00910	0.0130	0.0136	0.0194	0.0205	0.0293	0.0181	0.0259	0.00841	0.0121
CH_4	0.000196	0.000279	0.000292	0.000418	0.000442	0.000631	0.000389	0.000556	0.000181	0.000260

*These VOC values also include some non-VOC, such as CH_4.

Table 6. Emissions to Air by Process Step for Slag Cement Concrete Production (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Aggregate production, lb/cu yd concrete										
Particulate matter	0.701	0.701	0.680	0.680	0.575	0.575	0.617	0.617	0.644	0.644
CO_2	7.93	7.93	7.69	7.69	6.50	6.50	6.98	6.98	6.94	6.94
SO_2	0.0126	0.0126	0.0122	0.0122	0.0103	0.0103	0.0111	0.0111	0.0110	0.0110
NO_x	0.0731	0.0731	0.0708	0.0708	0.0599	0.0599	0.0643	0.0643	0.0639	0.0639
VOC*	0.0131	0.0131	0.0127	0.0127	0.0107	0.0107	0.0115	0.0115	0.0115	0.0115
CO	0.07270	0.0727	0.0705	0.0705	0.0596	0.0596	0.0640	0.0640	0.0636	0.0636
CH_4	0.00216	0.00216	0.00210	0.00210	0.00177	0.00177	0.00191	0.00191	0.00189	0.00189
Transportation to ready mix plant, lb/cu yd concrete										
Particulate matter	0.0192	0.0192	0.0205	0.0205	0.0209	0.0209	0.0218	0.0218	0.0195	0.0195
CO_2	14.7	14.7	15.7	15.7	16.0	16.0	16.7	16.7	15.0	15.0
SO_2	0.0233	0.0233	0.0249	0.0249	0.0253	0.0253	0.0264	0.0264	0.0237	0.0237
NO_x	0.135	0.135	0.144	0.144	0.147	0.147	0.153	0.153	0.138	0.138
VOC*	0.0243	0.0243	0.0259	0.0259	0.0264	0.0264	0.0275	0.0275	0.0247	0.0247
CO	0.135	0.135	0.144	0.144	0.146	0.146	0.153	0.153	0.137	0.137
CH_4	0.00401	0.00401	0.00428	0.00428	0.00436	0.00436	0.00454	0.00454	0.00408	0.00408

*These VOC values also include some non-VOC, such as CH_4.

Table 6. Emissions to Air by Process Step for Slag Cement Concrete Production (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Concrete plant operations, lb/cu yd concrete										
Particulate matter	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171
CO_2	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9	23.9
SO_2	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141	0.141
NO_x	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241	0.0241
VOC*	0.000447	0.000447	0.000447	0.000447	0.000447	0.000447	0.000447	0.000447	0.000447	0.000447
CO	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591
CH_4	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Concrete block curing, lb/cu yd concrete										
Particulate matter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	no data	no data
CO_2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.48	6.48
SO_2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0247	0.0247
NO_x	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00689	0.00689
VOC**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.49×10^{-5}	9.49×10^{-5}
CO	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.00172	0.00172
CH_4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	9.49×10^{-5}	9.49×10^{-5}

*These VOC values also include some non-VOC, such as CH_4.

Table 7. Total Emissions from Slag Cement Concrete Production

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Total emissions, lb/cu yd concrete										
Particulate matter	1.52	1.39	1.82	1.62	2.19	1.89	2.07	1.81	1.42	1.30
CO_2	269	220	382	307	550	438	492	393	260	213
SO_2	0.688	0.591	0.947	0.799	1.33	1.11	1.20	1.00	0.678	0.585
NO_x	0.865	0.723	1.19	0.975	1.66	1.34	1.51	1.22	0.823	0.688
VOC*	0.0482	0.0460	0.0547	0.0514	0.0611	0.0561	0.0603	0.0558	0.0462	0.0442
CO	0.436	0.391	0.555	0.487	0.716	0.614	0.668	0.577	0.415	0.373
CH_4	0.0150	0.0131	0.0197	0.0168	0.0265	0.0222	0.0244	0.0205	0.0143	0.0125
Other emissions from slag cement manufacture										
Emissions to air, lb/cu yd concrete										
H_2S**	0.0356	0.0507	0.0531	0.0760	0.0803	0.1145	0.0706	0.1011	0.0329	0.0472
Metals**	8.65×10^{-6}	1.23×10^{-5}	1.29×10^{-5}	1.85×10^{-5}	1.95×10^{-5}	2.78×10^{-5}	1.72×10^{-5}	2.46×10^{-5}	7.99×10^{-6}	1.15×10^{-5}
Emissions to land, lb/cu yd concrete										
Slag reject	0.224	0.173	0.338	0.259	0.508	0.391	0.449	0.345	0.210	0.161
Other solid waste	0.0490	0.0378	0.0738	0.0567	0.1110	0.0854	0.0981	0.0754	0.0458	0.0352

*These VOC values also include some non-VOC, such as CH_4.

**H_2S and metals emissions were not included in the scope of the portland cement concrete LCI (Ref 2).

Table 7. Total Emissions from Slag Cement Concrete Production (Continued)

Concrete mix description	Ready mix concrete				Precast concrete				Concrete block	
28 day compressive strength, psi	3,000		5,000		7,500		10,000		Unspecified	
Slag cement, %	35	50	35	50	35	50	31	44	35	50
Emissions to water, unit/cu yd concrete										
Water that leaves site, gal	5.57	7.93	8.31	11.9	12.6	17.9	11.1	15.8	5.15	7.39
Suspended solids, lb	0.000805	0.00115	0.00120	0.00172	0.00182	0.00259	0.00160	0.00229	0.000744	0.00107
Chemical oxygen demand (COD)	3.83×10^{-6}	5.46×10^{-6}	5.72×10^{-6}	8.19×10^{-6}	8.66×10^{-6}	1.23×10^{-5}	7.61×10^{-6}	1.09×10^{-5}	3.54×10^{-6}	5.08×10^{-6}
Waste at cement plant, lb/cu yd concrete										
Cement kiln dust	12.7	9.78	19.1	14.7	28.7	22.1	25.4	19.5	11.9	9.10

*These VOC values also include some non-VOC, such as CH_4.