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August 11, 2003

Mr. Jan Prusinski
Executive Director
Slag Cement Association
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Life Cycle Inventory of Slag Cement Manufacturing Process
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 the manufacture of slag cement. This report contains the basis, methodology, and summary of survey results.

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 provisions of a service.

Background

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. Slag is waste material from a blast furnace during the production of pig iron. This life cycle inventory for slag cement assumes slag comes into to the system boundary with no environmental burdens since it is a waste product. To process slag so it can be used as a supplementary cementitious material in concrete, it is quenched with water and ground. The manufacture of slag cement includes the following processes: (i) quenching/granulation, (ii) dewatering and/or drying, (iii) crushing, (iv) grinding, (v) storage, and (vi) shipping.

The functional unit, the basis for comparison, is one ton of slag cement. The system boundary for the slag cement manufacturing LCI was selected to start at the point where slag is quenched with water and end with slag cement ready for shipment. The system boundary does not include upstream profiles of energy sources. For example, the energy and emissions associated with

producing coal or generating electricity are not included. However, the quantities of all fuels are included, and some of the emissions to air from combustion of natural gas are included.*

METHODOLOGY

Data Collection

Construction Technology laboratories, Inc. (CTL) collected data from members of the Slag Cement Association. A questionnaire and instructions (attached as Appendix A) were submitted to Mr. Jan Prusinski of the Slag Cement Association who then forwarded the questionnaires to association members. Completed questionnaires were returned to CTL and are confidential. The questionnaire consists of three parts:

- Part I is general facility information,
- Part II is detailed production information for the facility, and
- Part III is detailed transportation information.

For each site producing either slag granules or slag cement, one questionnaire was completed. The responder reported the materials, energy, and emissions to air, water, and land for each stage in the manufacture of slag cement; although not all responders reported all data. All fuels, energy, and emissions associated with transportation were reported separately.

Where available, data were reported for 12 consecutive months of operation. If data for a 12-month period were not available, the time period for which data were available was reported. If a quantity is not available or unknown, a "?" was reported; if a quantity is not applicable, "N/A" was reported; and if a quantity is in fact zero, "0" was reported.

Three data-quality indicators were required and reported for each data point: source, type, and year. Refer to the data-quality guidelines in Appendix A for an explanation of the data-quality indicators. The source of all the data reported was facility specific. The type of data was a combination of measured, calculated, and estimated. The data were collected in 2001 and 2002.

Data Compilation

Construction Technology Laboratories, Inc. evaluated the data for order-of-magnitude accuracy and completeness and worked with responders to clarify reported data. Thirteen questionnaires were returned to CTL and twelve are included in this LCI. One questionnaire did not contain sufficient operating data. CTL summarized the data by calculating a production weighted-

* The following emissions to air from combustion of natural gas are included in this LCI: carbon monoxide, hydrogen sulfide, metals, methane, nitrogen oxides, non-methane hydrocarbons, particulate matter, and sulfur oxides.

average for the U.S. Consequently, the data are not traceable to a particular plant and confidentiality is ensured.

SUMMARY OF DATA

Annual data for the life cycle inventory of the manufacture of slag cement are summarized in the following tables. Table 1 lists the summary results of the materials, energy, and emissions for the manufacture of slag cement. Table 2 lists the ancillary materials used in the various stages of manufacturing slag cement. Table 3 summarizes the emission to air, water, and land. Table 4 summarizes fuel and electricity use. Table 5 summarizes shipping data. The material shipped includes slag to granulators, slag granules from granulating to grinding facilities, ancillary materials, and slag cement to distribution centers.

We appreciate the opportunity to be of service to the Slag Cement Association and look forward to assisting you with the next phase of this project. Please contact one of us if you have any questions.

Sincerely,
CONSTRUCTION TECHNOLOGY LABORATORIES, INC.

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Table 1. Summary Results – Materials (M), Energy (En), and Emissions (Em) for the Manufacture of Slag Cement

Process materials, energy, and emissions, unit	Production weighted average		
	Granulating, unit/ton slag cement	Grinding, unit/ton granules	Total, unit/ton slag cement
Granulation			
Make-up water (M), gallon	184		184
Electricity for water pumps, etc. (En), kWh	10.5		10.5
Purge water leaving site (M), gallon	59.5		59.5
Particulate matter in air (Em), lb	0.0148		0.0148
Suspended solids (Em), lb	0.00248		0.00248
Dewatering and/or drying			
Natural gas (En), standard ft^3		264	264
No. 2 fuel oil, gallons (En)		0.273	0.273
Electricity (En), kWh	2.15	3.60	5.75
CO (Em), lb		0.0201	0.0201
NO_x (Em), lb		0.0388	0.0388
SO_2 (Em)	0.00152	0.000203	0.00173
Particulate matter in purge air (Em), lb	0.00370	0.0149	0.0186
Crushing			
Electricity (En), kWh		0.0506	0.0506
Grinding			
Water (M), gallons		13.9	13.9
Liquid fuel for mobile equipment (En), gallon		0.0289	0.0289
Natural gas (En), standard ft^3		23.2	23.2
Electricity (En), kWh		66.4	66.4
Grinding media incorporated in product (M), lb		0.194	0.194
Grinding media discarded off-site (M), lb		0.0618	0.0618
Particulate matter (Em), lb		0.215	0.215
Storage piles			
Particulate matter (Em), lb		0.00892	0.00892
Storage silos			
Water (M), gallon		22.4	22.4
Electricity (En), kWh		3.17	3.17
Particulate matter (Em), lb		0.0479	0.0479

Table 2. Ancillary Materials

Materials, unit	Production weighted average		
	Granulating, unit/ton slag cement	Grinding, unit/ton granules	Total, unit/ton slag cement
Total ancillary materials, all stages			
Filter bags, lb		0.00843	0.00843
Grease, gallon		0.00549	0.00549
Grinding aids, lb		0.00252	0.00252
Grinding media, lb		0.706	0.706
Oil, gallon		0.00254	0.00254
Solvents, gallon		0.000220	0.000220

Table 3. Emissions to Air, Land, and Water

Environmental flow, unit	Production weighted average		
	Granulating, unit/ton slag cement	Grinding, unit/ton granules	Total, unit/ton slag cement
1. Total solid waste, all stages			
Solid waste, ton - slag reject		0.000920	0.000920
Solid waste, ton – other		0.000201	0.000201
2. Total emissions to air, all stages			
Carbon monoxide (CO), lb	0.0786	0.0303	0.109
Hydrogen sulfide, H_2S, lb	0.539		0.539
Metals (total), lb		0.000131	0.000131
Methane (CH_4), lb		0.00274	0.00274
Nitrogen oxides (NO_x as NO_2), lb		0.0484	0.0484
Non-methane hydrocarbons (total), lb		0.00159	0.00159
Particulate matter, lb	0.0185	0.287	0.305
Sulfur oxides (SO_x as SO_2), lb	0.460	0.00152	0.462
3. Total water effluent, all stages			
Water that leaves the site, gallon	59.5	24.8	84.4
Suspended solids, lb	0.00248	0.00968	0.0122
Chemical oxygen demand (COD)		0.0000581	0.0000581

Table 4. Fuel and Electricity Use

Process energy, unit	Production weighted average		
	Granulating, unit/ton slag cement	Grinding, unit/ton granules	Total, unit/ton slag cement
Electricity (En), kWh	12.6	70.0	82.7
Natural gas (En), standard ft^3		287	287
No. 2 fuel oil, gallons (En)		0.273	0.273
Liquid fuel for mobile equipment (En), gallon		0.0289	0.0289

Table 5. Transportation* (Shipping)

Material and mode of transported	Material transported, percent	Average distance, mile
Iron blast furnace slag to granulators		
Rail	36.4%	3
Mode not specified	63.6%	Not reported
Granulated slag to grinding facility		
Truck	54.2%	5.3
Ship	21.0%	5,000
Mode not specified	24.8%	Not reported
Slag cement to distribution terminal		
Truck	6.9%	70
Rail	29.4%	170
Barge	40.2%	180
Mode not specified	23.5%	Not reported
Ancillary materials		
Truck (solids)	9.2%	30
Mode not specified (solids)	90.8%	10
Truck (liquids), gallon	25.4%	Not reported
Mode not specified (liquids), gallon	74.6%	Not reported
Purchased fuels		
Truck (liquid fuels), gallon	21.7%	Not reported
Mode not specified (liquid fuels), gallon	78.3%	Not reported
Pipeline (natural gas), standard ft^3	22.8%	Not reported
Mode not specified (natural gas), standard ft^3	77.2%	Not reported

*Material transportation is measured in tons unless otherwise noted. Most vessels transporting material over water return full, and most vessels transporting material over land return empty.

APPENDIX A – INSTRUCTIONS AND BLANK QUESTIONNAIRE

MATERIALS, ENERGY, AND EMISSIONS FOR SLAG CEMENT

The purpose of this questionnaire is to collect life-cycle data on the production of slag cement. CTL will evaluate the data for accuracy and completeness, and then summarize it for the U.S. average production of slag cement in a manner that will ensure confidentiality. The results will be presented to the Slag Cement Association in a life cycle inventory report (LCI). An LCI is a compilation of the inputs of materials and energy, and the emissions to air, water, and land to make slag cement.

We have assumed that slag cement is produced in the following stages: (i) granulation, (ii) dewatering and/or drying, (iii) crushing, (iv) grinding, (v) storage, and (vi) transportation. We are asking you to report the materials, energy, and emissions to air, water, and land for each stage in the production of slag cement. If a production stage does not exist at your facility, indicate so on the relevant portion of the questionnaire. Similarly, if a process in not covered in the questionnaire, provide the information so that the process can be included.

Instructions for completing the questionnaire

1. Complete one questionnaire per facility.
2. The term facility can designate either a granulation facility, or a grinding facility, or combination of both. For example, if slag is granulated at a site in Indiana and ground at a site in Illinois, complete one questionnaire for each facility.
3. The questionnaire consists of three parts:
    - Part I is general facility information,
    - Part II is detailed production information for the facility, and
    - Part III is detailed transportation information.
4. Report data for 12 consecutive months of operation. If data for a 12-month period are not available, report the time period for which data are available.
5. If a quantity is not available or unknown, report "?"; if a quantity is not applicable, report "N/A"; and if a quantity is in fact zero, report "0".
6. Three data-quality indicators are required for each data point: source, type, and year. Refer to the data quality guidelines on the next page for examples.
    - Source is either "F" for facility specific, "L" for literature, or "O" for other.
    - Type is either "M" for measured, "C" for calculated, "A" for average value, "E" for estimated, or "U" for unknown.
    - Year is the year the data was collected or the year the data is based on.
7. All fuels, energy, and emissions associated with transportation should be reported separately.
8. Return complete questionnaire to:

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DATA QUALITY GUIDELINES*

Data Source

Report either "L" for literature, "F" for facility, or "O" for other.

Data Type

Five types are defined. Report either "M" for measured, "C" for calculated, "A" for averaged, "E" for estimated, or "U" for unknown.

Measured: the flow quantity is based on continuous measurement. For instance, electricity consumption is readily available from electric meters. Coal consumption is continuously measured with scales or other forms of stock accountability.

Calculated: the flow quantity has been calculated using emission factors, mass balance, or other indirect methods. For instance, SOx emissions may have been measured for several years, and an emission factor determined and used for subsequent years. Another example is CO_2 air emissions calculated from the carbon balance.

Averaged Value: the flow quantity has been extrapolated from spot measurements. For instance, volatile organic compounds (VOCs) may be measured three times per year, one day each time; from these values the annual quantity may be calculated.

Estimated: the flow quantity has been established based on approximations. For instance, the transportation distance for a given raw material may be estimated due to lack of better information.

Unknown: This data type is only appropriate for data from the literature when the information provided is insufficient to classify the data as one of the previous types.

*We are using the data quality guidelines from the BEES Please Questionnaire Users Guide, http://www.bfrl.nist.gov/oae/software/bees/please/main.html

PART I – Facility Information

Company Contact Information		
Person in Charge of Completing Questionnaire:		
Address:		
Tel:		
Fax:		
Email:		
Site Information		
Site Name:		
Function (granulation and/or grinding):		
Site Location:		
Products Produced at the Site:	**Name**	**Quantity Produced per Year**
	Slag cement	
Date Questionnaire Completed:		

PART II - Production Stage Data

Plant name: _____

Reporting period (12 months or other): _____

Production Stage	Quantity	Data quality		
		Source*	Type**	Year
1. Granulation				
a. Electricity for water pumps, etc., kWh				
b. Make-up water, million gallons				
c. Purge water leaving site, gallons				
d. Suspended solids in purge water leaving site, lb				
e. Particulate matter in air, lb				
f. Other water effluents (list and specify units)				
2. Dewatering and/or drying				
a. Electricity, kWh				
b. Natural gas, million standard ft^3				
c. Particulate matter in purge air, lb				
d. Other emissions (list and specify units)				
3. Crushing				
a. Electricity, kWh				
b. Liquid fuel (list and specify units)				
c. Particulate matter, lb				
d. Water, gallons				
4. Grinding				
a. Electricity, kWh				
b. Liquid fuel (list and specify units)				
c. Particulate matter, lb				
d. Grinding media incorporated in product (list and specify units)				
e. Grinding media reused elsewhere (list and specify units)				
f. Grinding media discarded off-site (list and specify units)				
g. Water, gallons				
5. Storage piles				
a. Liquid fuel (list and specify units)				
b. Particulate matter, lb				
c. Water, gallons				

**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.

PART II – Production Stage Data (Continued)

Production Stage	Quantity	Data quality		
		Source*	Type**	Year
6. Storage silos				
a. Electricity, kWh				
b. Liquid fuel (list and specify units)				
c. Particulate matter, lb				
d. Water, gallons				
7. Total solid waste, all stages (specify units)				
a. Solid waste, ton (please describe)				
8. Total emissions to air, all stages				
a. Carbon dioxide (CO_2), lb				
b. Methane (CH_4), lb				
c. Nitrous oxide (N_2O), lb				
d. Sulfur oxides (SO_X as SO_2), lb				
e. Nitrogen oxides (NO_X as NO_2), lb				
f. Carbon monoxide (CO), lb				
g. Non-methane hydrocarbons (total), lb				
h. Metals (total) (please describe), lb				
i. Others (list and specify units), lb				
9. Total water effluent, all stages (specify units)				
a. Wastewater that leaves the site, gallons				
b. Suspended solids, lb				
c. Metals (total), lb				
d. Hydrocarbons (total) (please describe), lb				
e. Biologic oxygen demand (BOD)				
f. Ammonia (NH_4+)				
g. Nitrogen (N, total)				
h. Phosphates (PO_4, $_3$-)				
i. Phosphorus (P)				
j. Chemical oxygen demand (COD)				
k. Nitrogenous matter (Kjeldhal, as N)				
l. Nitrates (NO_3-)				
m. Nitrogenous matter (unspecified, as N)				
n. Phosphorous matter (unspecified, as P)				
o. Nitrogen dioxide (NO_2)				
p. Nitrogen oxide (NO)				
q. Nitrites (NO_2-)				
r. Phosphorus pentoxide (P_2O_5)				
s. Others (list and specify units)				

*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.

PART III - Transportation Stage Data

Plant name: _____

Reporting period (12 months or other): _____

Transportation	Quantity	Data quality			Distance	Mode	Empty return*** (yes/no)	Data quality		
		Source*	Type**	Year	(mile)			Source*	Type**	Year
Raw materials, all stages										
a. Iron blast furnace slag, ton										
Products, all stages										
a. Granulated slag to grinding facility, ton										
b. Slag cement to distribution terminal, ton										
c. Others (list and specify units)										
Total ancillary materials, all stages										
a. Grinding media (specify type), lb										
b. Filter bags, lb										
c. Oil, gallon										
d. Grease, gallon										
e. Solvents (describe), gallon										
f. Others (list and specify units)										
Total purchased fuels, all stages										
a. Natural gas, standard ft^3										
b. Fuel oil, gallon										
c. Diesel oil, gallon										
d. Gasoline, gallon										
e. Others (list and specify units)										

*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.

***For example, if trucks or barge usually make the return trip empty, indicate "yes".