APPENDIX D:

RMC BENEFICIAL USE MODEL – TECHNICAL APPROACH

Recovered Mineral Components (RMC) Beneficial Use Model Technical Approach

As described in the main body of this report, beneficial use of RMCs in concrete can have environmental benefits associated with avoided portland cement production.[3] In addition to the general evaluation of these benefits, the report provides quantified estimates of a suite of environmental impacts for three of the RMCs identified by Congress: coal combustion fly ash; ground granulated blast furnace slag (GGBFS); and silica fume. In this appendix, we describe the model used to quantify these environmental benefits and provide the full model results.

The model estimates avoided resource use and avoided emissions when a specified quantity of coal fly ash, GGBFS, or silica fume is used in place of finished portland cement in federally-funded concrete projects.[4] To capture the full magnitude of benefits, the model follows a modified life-cycle approach in which the benefits of using RMC in concrete are evaluated across all stages of the product's life, from resource extraction through disposal.[5]

We illustrate the three primary steps in modeling the environmental benefits of using RMCs in Federal concrete applications in Figure D-1. As shown in this figure, the analytic process includes:

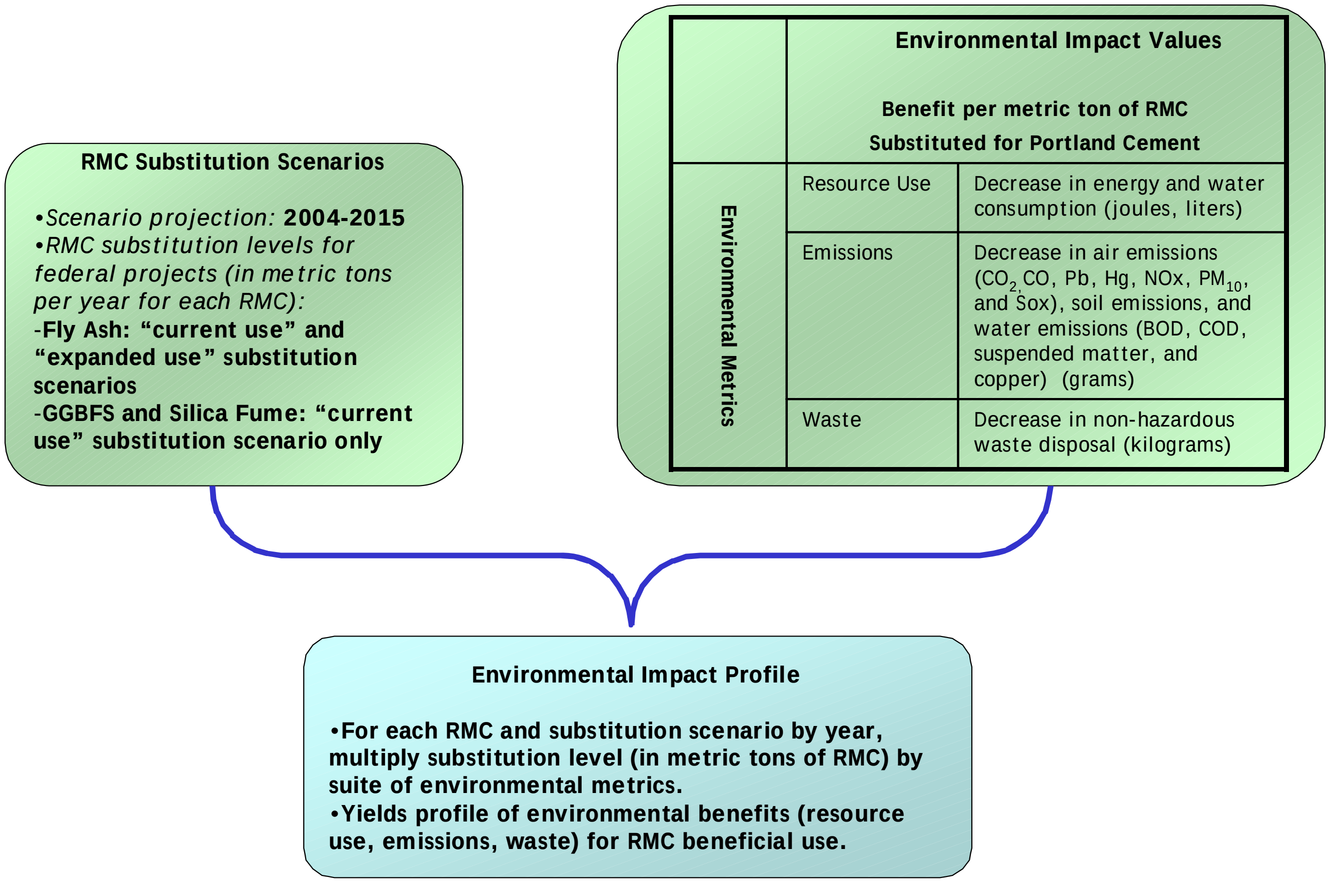
(1) Development of RMC substitution scenarios, representing the estimated annual quantity of each RMC (in metric tons) used in federally-funded concrete projects, including current and expanded substitution scenarios;
(2) Estimation of environmental impact values for the substitution of one unit (metric ton) of RMC as a partial substitute for finished portland cement in concrete; and
(3) Calculation of national-scale impacts under current use and expanded use scenarios by multiplying per-unit impacts by national-level RMC reuse quantities

We describe each of these steps in greater detail below.

[3] The Agency recognizes that these environmental benefits may represent the reduced need for new or expanded portland cement producing capacity in future years. With the use of RMCs, the same amount of portland cement/clinker will likely be produced, but will result in more concrete production than with 100% virgin material.
[4] As described in Section 2 of this report, RMCs can be used to offset virgin materials at more than one point in the cement production process. It is important to note that we are modeling the use of RMCs as a direct replacement for finished portland cement in concrete. This analysis does not evaluate use of RMCs in clinker production.
[5] We focus on coal fly ash, GGBFS, and silica fume because more comprehensive and robust life cycle data were available to analyze them. Relevant life cycle data for the substitution of other RMCs were not available for purposes of this report.

Figure D-1

Conceptual Schematic of RMC Beneficial Use Model



Step 1 - Estimation of RMC Usage in Federal Concrete Projects

In order to estimate the quantity of coal fly ash, GGBFS, and silica fume used in Federal concrete projects, we first estimate the quantity of each RMC used in the U.S. and multiply these estimates by the percentage assumed to be used in federally-funded projects. The Federal Highway Administration (FHWA) estimates that approximately 20% of all cement usage in the U.S. is incorporated in to federally-funded projects. Therefore, for this analysis, we assumed that 20% of the national RMC usage is incorporated into Federal projects. Table below 1 shows the derivation of the 20% FHWA estimate.

Table D-1: Derivation of FHWA Estimate for Concrete use in Federal Projects

Type	PCA Cement Use in Federal Construction Estimate[a]	Expert Estimate Cement Use in Federal Construction	
	thousand metric tons	*percent*	*thousand metric tons*[1]
Classroom buildings & Labs	2,270.5	1%[b]	22.7
Public Administrative/Services	498.8	10%[b]	49.9
Low rise hospitals	947	10%[b]	94.7
High-rise Hospitals	432.9	10%[b]	43.3
Passenger Terminals	84.7	20%[b]	16.9
State Highways (Urban and Rural)	15,415.4	74%[c]	11,418.4
Urban Streets & Roadways	6,240.1	74%[c]	4,622.0
Rural Roadways	424.7	4%[d]	17.0
Vehicle / Pedestrian Bridges	7,289.6	43%[e]	3,137.3
Maintenance & repair	4,055.7	1%[d]	40.6
Dams & Reservoirs	661.7	90%[b]	595.5
River & Harbor Development & Control	716.7	90%[b]	645.0
Water Supply Systems	3,597.1	50%[b]	1,798.6
Sanitary/Storm Sewers	2,265.6	30%[b]	679.7
Water & Sewer Tunnels	40.0	80%[b]	32.0
Airport Runways/Taxi ways/Lighting	1,269.2	99%[b]	1,256.5
Defense/Space facilities	122.1	100%[b]	122.1
Total Tons	**46,331.8**		**24,592.2**
National Total	**114,889**		**114,889**
Percent Used in Federal Construction	**40%**		**20%**

Notes:
1. Values may not add due to rounding.

Sources:
a. Portland Cement Association, "2004 Apparent Use of Portland Cement by Market," 2004. Skokie, IL.
b. Personal communication and follow-up email with Jon Mullarky, Federal Highway Administration, July 17, 2007 and July 18, 2007.
c. Federal Highway Administration, “Funding for Highways and Disposition of Highway-User Revenues, All Units of Government, 2004,” Modified March 21, 2006. http://www.fhwa.dot.gov/policy/ohim/hs04/htm/hf10.htm Accessed on August 14, 2007.
d. Federal Highway Administration, “Pubic Road Length-2004,” Modified March 14, 2006. http://www.fhwa.dot.gov/policy/ohim/hs04/htm/hm10.htm Accessed on August 14, 2007.
e. Federal Highway Administration, “National Bridge Inventory.” Modified July 10, 2007. http://www.fhwa.dot.gov/bridge/nbi.htm Accessed on August 14, 2007.

Section 3 of this report describes the assumptions used to develop historical and projected estimates of the quantity of each RMC used as a substitute for finished portland cement under both current and expanded use scenarios. These assumptions are described in greater detail below.

Current Use Estimates

Cement:

One of the primary assumptions used in the development of current use estimates for coal fly ash and GGBFS is that use of these RMCs will grow at the same rate as use of cement. For portland cement, USGS provides data for the years 2004 and 2005 on estimated U.S. cement production, imports and exports. Using these data, U.S. cement consumption for the years 2004 and 2005 was estimated as total imports plus total U.S. production minus U.S. exports. Using this approach, it was estimated that U.S. apparent cement consumption was 121,980 thousand metric tons in 2004, and 125,700 thousand metric tons in 2005.

The Portland Cement Association estimates that U.S. cement demand will be 195 million metric tons in 2030 (PCA, 2006a). Using the PCA estimate in 2030, demand for the years 2006 through 2015 was estimated by assuming a linear increase from 125,700 thousand metric tons in 2005 to 195,000 thousand metric tons in 2030. By applying the 20% Federal use estimate to the projections for total U.S. cement use, we derive the Federal substitution projections for cement. Cement consumption estimates for the years 2004 through 2015 are presented in Table D-2.

Table D-2: Projected Cement Usage

Year	Estimated U.S. Cement Consumption	Cement Consumption in Federal Projects	Cement Consumption in Non-Federal Projects
	thousand metric tons		
2004	121,980	24,396	97,584
2005	125,700	25,140	100,560
2006	128,472	25,694	102,778
2007	131,244	26,249	104,995
2008	134,016	26,803	107,213
2009	136,788	27,358	109,430
2010	139,560	27,912	111,648
2011	142,332	28,466	113,866
2012	145,104	29,020	116,083
2013	147,876	29,575	118,301
2014	150,648	30,130	120,518
2015	153,420	30,684	122,736

Coal Fly Ash:

The current use estimates for coal fly ash as an SCM are broken out into a "baseline" and "C^2P^2" scenario in order to account for the impact of EPA's C^2P^2 program on coal fly ash use. The baseline scenario estimates coal fly ash use in the absence of the C^2P^2 program. The C^2P^2 scenario estimates coal fly ash use assuming the C^2P^2 program achieves the targeted use of coal fly ash under the program.

For both scenarios, 2004 and 2005 estimates of coal fly ash usage in cement are taken from the American Coal Ash Association's (ACAA) annual survey of electric utilities (see Section 2). ACAA estimates that 12,811 thousand metric tons of coal fly ash were used as a finished portland cement substitute in 2004, and that 13,599 thousand metric tons were used in 2005.

Under the current use baseline scenario, it is assumed that in the absence of the C^2P^2 program, coal fly ash usage as a finished portland cement substitute would increase linearly after 2005 at the same rate as U.S. cement demand over 2004 levels, which is approximately 2.2%, or approximately 300,000 metric tons per year. Projected coal fly ash usage under the current use baseline scenario is shown in the top-half of Table D-3.

Under the current use C^2P^2 scenario, it is assumed that coal fly ash as a finished portland cement substitute will increase to 18.6 million short tons (approximately 16.9 million metric tons) by 2011. This is the goal of the C^2P^2 program.[6] A second order polynomial fit was used to estimate usage for the years 2006 through 2010. The equation used is $y = -8{,}765.346x^2 + 35{,}420{,}372.024x - 35{,}775{,}515{,}275.736$ where y = fly ash use as an SCM, and x = years projected past 2005. For the years 2011 through 2015, coal fly ash usage under the C^2P^2 scenario was estimated to increase at the same rate as U.S. cement demand over 2004 levels. As with cement,

[6] For an overview of the C^2P^2 program, see section 5 of this report. Additional program information can be found at: http://www.epa.gov/epaoswer/osw/conserve/c2p2/pubs/facts508.pdf.

it was assumed that 20% of coal fly ash is used in Federal projects and 80% is used in non-Federal projects. Table D-3 shows current use estimates for coal fly ash under the current use baseline and current use C^2P^2 scenarios. It is assumed that the difference between coal fly ash usage in these scenarios, also shown in Table D-3, represents the increment of coal fly ash usage attributable to the C^2P^2 program.

Table D-3: Coal Fly Ash Usage Under Current Use Scenarios

Year	Estimated U.S. Coal Fly Ash Consumption	Coal fly ash Consumption in Federal Projects	Coal fly ash Consumption in Non-Federal Projects
	--------------------------------*thousand metric tons*--------------------------------		
Baseline			
2004	12,811	2,562	10,249
2005	13,599	2,720	10,879
2006	13,900	2,780	11,120
2007	14,200	2,840	11,360
2008	14,498	2,900	11,598
2009	14,798	2,960	11,838
2010	15,098	3,020	12,078
2011	15,398	3,080	12,318
2012	15,698	3,140	12,558
2013	15,998	3,200	12,798
2014	16,298	3,260	13,038
2015	16,598	3,320	13,278
C^2P^2			
2004	12,811	2,562	10,249
2005	13,599	2,720	10,879
2006	14,208	2,842	11,366
2007	14,820	2,964	11,856
2008	15,390	3,078	12,312
2009	15,915	3,183	12,732
2010	16,395	3,279	13,116
2011	16,875	3,375	13,500
2012	17,203	3,441	13,762
2013	17,530	3,506	14,024
2014	17,860	3,572	14,288
2015	18,188	3,638	14,550
Quantity Attributable to C^2P^2 (C^2P^2 – Baseline)			
2004	0	0	0
2005	0	0	0
2006	308	62	246
2007	620	124	496
2008	892	178	714
2009	1,117	223	894
2010	1,297	259	1,038
2011	1,477	295	1,182
2012	1,505	301	1,204
2013	1,532	306	1,226
2014	1,562	312	1,250
2015	1,590	318	1,272

GGBFS:

Under current use, it was assumed that demand for GGBFS would increase linearly from 2004 use rates at the same rate as U.S. cement demand (which is approximately 2.2% per year). For GGBFS, this equals an annual increase of 76,000 metric tons. It was also assumed that 20% of GGBFS is used in Federal concrete projects with the remainder being used in non-Federal projects. Values for GGBFS usage under the current use scenario are shown in Table D-4.

Table D-4: GGBFS Usage Under Current Use Scenario

Year	**Estimated U.S. GGBFS Consumption**	**GGBFS Consumption in Federal Projects**	**GGBFS Consumption in Non-Federal Projects**
	----------------------------*thousand metric tons*	------------------------	
2004	3,460	692	2,768
2005	3,536	707	2,829
2006	3,612	722	2,890
2007	3,688	738	2,950
2008	3,764	753	3,011
2009	3,840	768	3,072
2010	3,916	783	3,133
2011	3,992	798	3,194
2012	4,068	814	3,254
2013	4,144	829	3,315
2014	4,220	844	3,376
2015	4,296	859	3,437

Silica Fume:

For current use, we assume that domestic silica fume supply is inelastic, as a result of relatively inelastic global supply of silicon metal and ferrosilicon and related ferroalloys production. Therefore, we assume that current (i.e., base year) rates of silica fume use in U.S. concrete projects will remain constant into the future (i.e., roughly 60,000 metric tons).[7] Values for silica fume under the current use scenario are shown in Table D-5. It was also assumed that 20% of GGBFS and 40% of silica fume were used in Federal projects with the remainder being used in non-Federal projects.

[7] Personal communication with Hendrick van Oss, USGS, July 12, 2007, and analysis of data from USGS *2005 Minerals Yearbook – Ferroalloys*, accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/ferroalloys/feallmyb05.pdf.

Table D-5: Silica Fume Usage Under Current Use Scenario

Year	Estimated U.S. Silica Fume Consumption	Silica Fume Consumption in Federal Projects	Silica Fume Consumption in Non-Federal Projects
	----------------------------*thousand metric tons*------------------------		
2004	60	12	48
2005	60	12	48
2006	60	12	48
2007	60	12	48
2008	60	12	48
2009	60	12	48
2010	60	12	48
2011	60	12	48
2012	60	12	48
2013	60	12	48
2014	60	12	48
2015	60	12	48

Expanded Use Estimates

In order to estimate potential impacts associated with Federal initiatives to increase beneficial use rates, two expanded usage scenarios were developed for coal fly ash. Expanded use scenarios were not developed for GGBFS and silica fume since utilization of these materials is already very high, and it is unlikely that new initiatives could significantly impact reuse rates.

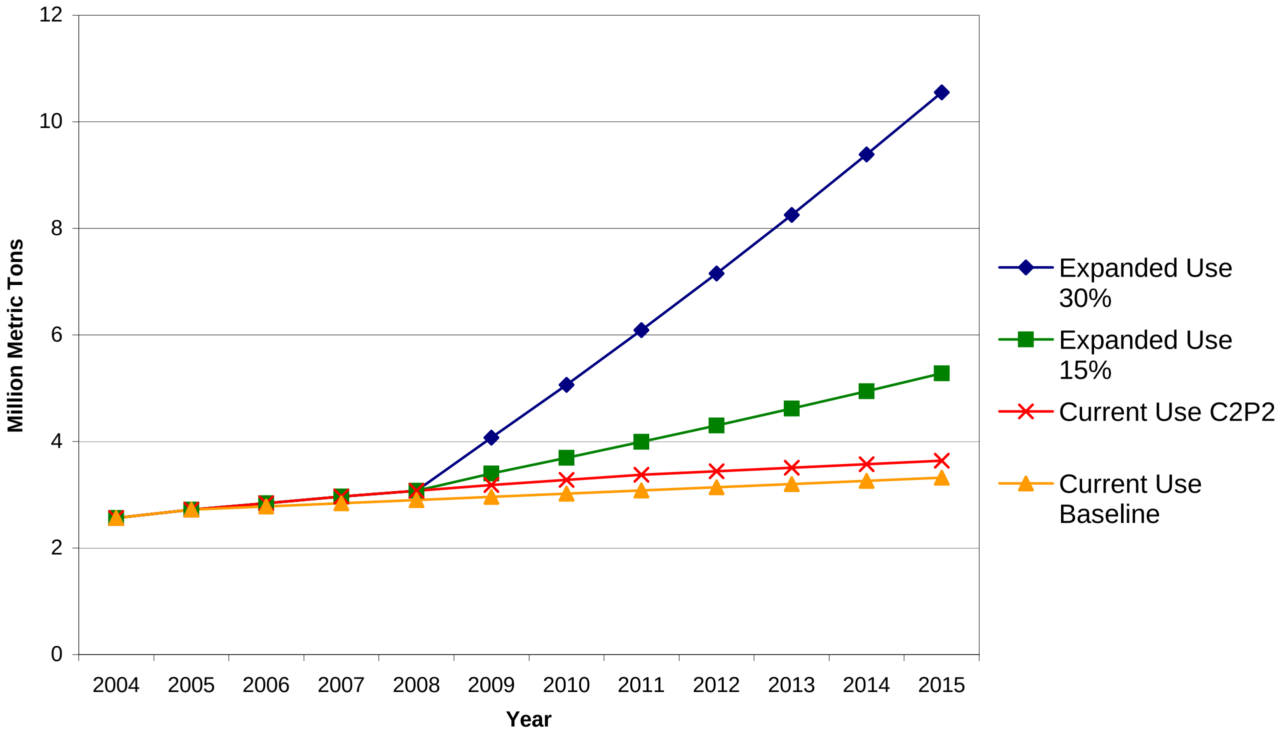
Under the first expanded usage scenario for coal fly ash (15% scenario), it was assumed that coal fly ash substitution in Federal projects would increase from current reuse rates of approximately 10% to the levels recommended under the comprehensive procurement guidelines (CPG), which is 15% substitution by 2015. Under the second expanded usage scenario (30% scenario), it was assumed that coal fly ash substitution in Federal projects would increase from current reuse rates of approximately 10% to the maximum levels recommended under the CPG program, which is 30%, by 2015. For both scenarios, it was assumed that the increase from current reuse to the expanded reuse rates would occur incrementally and linearly starting in the year 2009 and continuing through the year 2015.[8] Using this methodology, expanded usage for coal fly ash was calculated as shown in Table D-6. Figure D-2 illustrates coal fly ash consumption estimates under both expanded and current use scenarios.

[8] The Bill language instructs all agency heads to implement recommendations of the 30 month study with regard to procurement guidelines no later than one year after the release of the study, or approximately early to mid 2009

Table D-6: Coal Fly Ash Usage Under Expanded Use Scenarios

Year	Estimated U.S. Coal Fly Ash Consumption	Coal Fly Ash Consumption in Federal Projects	Coal Fly Ash Consumption in Non-Federal Projects
	--------------------------*thousand metric tons*--------------------------		
15% Scenario			
2004	12,811	2,562	10,249
2005	13,599	2,720	10,879
2006	14,208	2,842	11,366
2007	14,820	2,964	11,856
2008	15,390	3,078	12,312
2009	16,347	3,269	13,078
2010	17,221	3,444	13,777
2011	18,114	3,623	14,491
2012	18,925	3,785	15,140
2013	19,754	3,951	15,804
2014	20,603	4,121	16,482
2015	21,467	4,293	17,173
30% Scenario			
2004	12,811	2,562	10,249
2005	13,599	2,720	10,879
2006	14,208	2,842	11,366
2007	14,820	2,964	11,856
2008	15,390	3,078	12,312
2009	17,689	3,538	14,151
2010	19,962	3,992	15,970
2011	22,311	4,462	17,848
2012	24,630	4,926	19,704
2013	27,021	5,404	21,617
2014	29,486	5,897	23,589
2015	32,021	6,404	25,616

Figure D-2: U.S. Coal Fly Ash Consumption Under Current and Expanded Usage Scenarios



Step 2: Estimation of RMC Unit Impact Values

The second modeling step involves developing environmental benefit metrics for each RMC, on a per metric ton basis. Each metric provides a basis for converting RMC substitution quantities into a measure of environmental impact. For example, substituting one metric ton of coal fly ash for finished portland cement in concrete has consequent effects on energy usage, water consumption, and air emissions related to the portland cement manufacturing process.

Life cycle analysis (LCA) is a tool that illustrates the full spectrum of these benefits by providing quantified estimates of the environmental impacts of a product across all stages in the product's life, from resource extraction through disposal (i.e., "cradle to grave"). The first stage of LCA involves developing a life cycle inventory (LCI). The LCI identifies and quantifies the environmental flows associated with a product, including energy and raw materials consumed, and emissions and wastes released, as a result of its manufacture and use. Life cycle data for concrete products that incorporate RMCs are a useful basis for calculating the unit metrics described above. Specifically, the model compares the LCIs for a representative concrete product using 100% portland cement versus one using a blended cement containing an RMC. The difference between these LCIs represents incremental environmental benefit.

The remainder of this section summarizes the life cycle data sources that provide the basis for the unit metrics, outlines the method of deriving unit metrics from these sources, and presents the unit metric values.

Life Cycle Data Sources

To generate life cycle impacts from RMC substitution, we rely primarily on data derived from the Building for Environmental and Economic Sustainability (BEES) model. With support from EPA, the National Institute of Standards and Technology (NIST) developed BEES to compare the life cycle environmental impacts of alternative building products.[9] The BEES methodology measures environmental performance using an LCA approach, following guidance in the International Standards Organization 14040 series of standards for LCA. Thus, all stages in the life of the product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management.[10]

BEES includes LCI data from concrete industry sources for both generic and brand name concrete products. The brand name product data are specific to operations at Lafarge and Headwaters Resources (formerly ISG Resources) concrete plants, whereas the generic product data reflect concrete industry averages. BEES contains several LCI data sets for concrete products that incorporate RMCs at various substitution levels, as well as data for concrete products made with 100% portland cement (i.e., without blended cement). The exception concerns data for products that incorporate silica fume. BEES includes Lafarge data for products with silica fume cement but does not include Lafarge data for products made with 100% portland cement. The closest approximation to a 100% portland cement mix-design for Lafarge products in BEES is a Portland Type I Cement mix-design, which includes 95% portland cement and 5% coal fly ash in the mix. For concrete products made with blended cement, BEES assumes a 1:1 replacement ratio for portland cement on the basis of mass.[11]

In this analysis, we use BEES LCI data to estimate the beneficial environmental impacts of coal fly ash, GGBFs and silica fume as a partial substitute for portland cement in concrete. The beneficial impacts of using RMCs in concrete are measured as the difference in life cycle impacts for a concrete product made with 100% portland cement (or the closest approximation thereof) and one made with blended cement containing an RMC. Of all the concrete products for which LCI data are provided in BEES, we arbitrarily selected a concrete beam with a compressive strength of 4 KSI (4,000 psi) and a lifespan of 75 years as the basis of this analysis. Selection of a different concrete product in BEES with a different compressive strength (e.g., a

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[9] The BEES model and supporting documentation can be downloaded at: www.bfrl.nist.gov/oae/software/bees.html.

[10] BEES is a Life Cycle Assessment (LCA) model designed to quantify physical flows of energy, resources, and environmental effects at a process-level resolution for specific use applications. An alternative approach would be to use an input-output (IO) model. An IO model provides the capacity to evaluate economic and environmental effects across the entire supply chain for hundreds of industry sectors. While this approach avoids some of the system boundary limitations of process-flow LCAs, our focus for this study was on energy and environmental benefits for targeted use applications, for which an LCA process-flow model is more appropriate.

[11] Silica fume does not actually replace portland cement in a 1:1 ratio (as is the case with fly ash and GGBFS). The addition of silica fume to concrete has a synergistic effect on compressive strength, making the replacement ratio complex. For simplicity, however, our model assumes a 1:1 replacement ratio for silica fume and portland cement in concrete when modeling life cycle impacts. This is likely to overstate the benefits of the use of this material as an SCM.

concrete column with a compressive strength of 5 KSI) does not effect the calculation of unit impact values. Table D-7 presents the specific BEES data files for a 4 KSI concrete beam that were used to calculate unit impact values for coal fly ash, GGBFS and silica fume. It is important to note that data files representing higher RMC substitution levels in a concrete beam (e.g., 20% fly ash instead of 15% fly ash) could have been selected without effect on the calculation of the unit impact value.

Table D-7: BEES LCI Data files Used to Calculate Unit Impact Values

RMC Category	4 KSI Concrete Beam			
	Without Blended Cement		With Blended Cement	
Coal Fly Ash	100% portland cement	Data file B1011A	15% fly ash, 85% portland cement	Data file B1011B
GGBFS	100% portland cement	Data file B1011A	20% GGBFS, 80% portland cement	Data file B1011D
Silica Fume	95% portland cement, 5% fly ash (Portland Type I)	Data file B1011CC	10% silica fume, 85% portland cement, 5% fly ash	Data file B1011S

For each data file listed in Table D-7, BEES provides complete environmental life cycle inventory data. The life cycle inventory data are quantified estimates of the energy and resource flows going into the product and the releases to the environment coming from the product, summed across all stages of the product life cycle for one cubic yard of concrete product. Differences in these flows across products with different RMC substitution levels provide the basis for deriving unit values for a suite of environmental metrics. BEES quantifies these flows for hundreds of environmental metrics but, to capture the general spectrum of impacts, this analysis focused on the following:

(1) Total primary energy (quantity and dollars);
(2) Water use (quantity and dollars);
(3) Greenhouse gas emissions (CO_2 from fossil fuels, CF_4, CH_4, and N_20)
(4) CO emissions;
(5) Pb emissions to air;
(6) Hg emissions to air;
(7) NOx emissions to air;
(8) PM_{10} emissions to air;
(9) SOx emissions to air; and
(10) Biochemical oxygen demand in water
(11) Chemical oxygen demand in water
(12) Copper emissions to water
(13) Suspended matter in water
(14) Emissions to soil (sum of all emissions reported by BEES)
(15) End of life (non-hazardous) waste.

Table D-8 presents the complete BEES lifecycle inventory data for the metrics listed above. The data fields in Table D-8 are defined as follows:

a. XPORT DIST: Transport distance of concrete beam to construction site.
b. FLOW: The environmental impact being reported.
c. UNIT: The unit in which the environmental flow is reported.
d. TOTAL: The total impact across all life cycle stages for all three components (i.e., the sum of fields COMP1, COMP2 and COMP3).
e. COMP1: The total impact across all life cycle stages for Component 1. Component 1 is the main component, which is a 1 cubic yard concrete beam.
f. COMP2: The total impact across all life cycle stages for Component 2. Component 2 refers to the first installation component associated with the concrete beam, but BEES does not provide a specific definition.
g. COMP3: The total impact across all life cycle stages for Component 3. Component 3 refers to the second installation component associated with the concrete beam, but BEES does not provide a specific definition.
h. RAW1: Impacts associated with raw materials extraction for Component 1.
i. RAW2: Impacts associated with raw materials extraction for Component 2.
j. RAW3: Impacts associated with raw materials extraction for Component 3.
k. MFG1: Impacts associated with manufacturing of Component 1.
l. MFG2: Impacts associated with manufacturing of Component 2.
m. MFG3: Impacts associated with manufacturing of Component 3.
n. XPORT1: Impacts associated with transport of Component 1.
o. XPORT2: Impacts associated with transport of Component 2.
p. XPORT3: Impacts associated with transport of Component 3.
q. USE1: Impacts associated with use of the total product (all three components).
r. WASTE1: Impacts associated with disposal of the total product (all three components).

Table D-8: BEES Life Cycle Inventory Data

BEES Data file B1011A: Generic Concrete Beam, 100% Portland Cement (4KSI)

FLOW	UNIT	TOTAL	COMP1	COMP2	COMP3	RAW1	RAW2	RAW3	MFG1	MFG2	MFG3	XPORT1	XPORT2	XPORT3	USE1	WASTE1
Water Used (total)	liter	1,702.10	1,055.10	570.94	4.39	1,011.14	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Carbon Dioxide (CO2, fos	g	266,110.00	213,972.00	50,991.90	1,146.09	207,804.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Lead (Pb)	g	0.43	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Methane (CH4)	g	297.63	206.68	88.66	2.29	202.58	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
(a) Nitrogen Oxides (NOx as	g	1,299.12	1,171.98	118.58	8.56	1,096.00	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
(a) Nitrous Oxide (N2O)	g	7.10	6.71	0.28	0.12	5.95	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Sulfur Oxides (SOx as SO	g	608.93	479.47	125.58	3.88	471.71	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) BOD5 (Biochemical Oxygen	g	15.80	7.04	7.47	1.28	6.25	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
(w) COD (Chemical Oxygen Dem	g	82.36	59.57	20.40	2.39	52.89	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) Suspended Matter (unspec)	g	43.64	31.97	9.85	1.81	28.39	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
E Total Primary Energy	MJ	2,779.14	1,994.61	658.19	126.35	1,904.34	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

BEES Data file B1011B: Generic Concrete Beam, 85% Portland Cement and 15% Fly Ash (4KSI)																
FLOW	**UNIT**	**TOTAL**	**COMP1**	**COMP2**	**COMP3**	**RAW1**	**RAW2**	**RAW3**	**MFG1**	**MFG2**	**MFG3**	**XPORT1**	**XPORT2**	**XPORT3**	**USE1**	**WASTE1**
Water Used (total)	liter	1,690.06	1,043.05	570.94	4.39	999.10	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Carbon Dioxide (CO2, fos	g	243,685.00	191,547.00	50,991.90	1,146.09	185,379.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Lead (Pb)	g	0.43	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Methane (CH4)	g	278.61	187.66	88.66	2.29	183.56	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
(a) Nitrogen Oxides (NOx as	g	1,231.00	1,103.86	118.58	8.56	1,027.87	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
(a) Nitrous Oxide (N2O)	g	6.68	6.28	0.28	0.12	5.53	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Sulfur Oxides (SOx as SO	g	555.41	425.95	125.58	3.88	418.19	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) BOD5 (Biochemical Oxygen	g	15.69	6.93	7.47	1.28	6.14	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
(w) COD (Chemical Oxygen Dem	g	81.45	58.66	20.40	2.39	51.98	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) Suspended Matter (unspec	g	43.14	31.48	9.85	1.81	27.90	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
E Total Primary Energy	MJ	2,629.00	1,844.47	658.19	126.35	1,754.19	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

BEES Data file B1011D: Generic Concrete Beam, 20% Slag Cement (4KSI)																
FLOW	**UNIT**	**TOTAL**	**COMP1**	**COMP2**	**COMP3**	**RAW1**	**RAW2**	**RAW3**	**MFG1**	**MFG2**	**MFG3**	**XPORT1**	**XPORT2**	**XPORT3**	**USE1**	**WASTE1**
Water Used (total)	liter	1,695.90	1,048.90	570.94	4.39	1,004.95	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Carbon Dioxide (CO2, fos	g	237,595.00	185,457.00	50,991.90	1,146.09	179,289.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
(a) Carbon Monoxide (CO)	g	578.28	374.49	202.06	1.74	355.98	201.70	1.16	3.82	0.00	0.55	14.69	0.35	0.03	0.00	0.00
(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Lead (Pb)	g	0.42	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Methane (CH4)	g	273.15	182.20	88.66	2.29	178.10	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
(a) Nitrogen Oxides (NOx as	g	1,213.22	1,086.08	118.58	8.56	1,010.10	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
(a) Nitrous Oxide (N2O)	g	6.60	6.20	0.28	0.12	5.45	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Sulfur Oxides (SOx as SO	g	540.47	411.01	125.58	3.88	403.25	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) BOD5 (Biochemical Oxygen	g	15.83	7.07	7.47	1.28	6.28	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
(w) COD (Chemical Oxygen Dem	g	82.64	59.85	20.40	2.39	53.17	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) Suspended Matter (unspec	g	43.78	32.12	9.85	1.81	28.54	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
E Total Primary Energy	MJ	2,599.20	1,814.67	658.19	126.35	1,724.40	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

BEES Data file B1011CC: Lafarge Concrete Beam, Portland Type I Cement (4KSI)																
FLOW	**UNIT**	**TOTAL**	**COMP1**	**COMP2**	**COMP3**	**RAW1**	**RAW2**	**RAW3**	**MFG1**	**MFG2**	**MFG3**	**XPORT1**	**XPORT2**	**XPORT3**	**USE1**	**WASTE1**
Water Used (total)	liter	1,667.98	1,020.98	570.94	4.39	977.03	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Carbon Dioxide (CO2, fos	g	316,116.00	263,978.00	50,991.90	1,146.09	257,810.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
(a) Carbon Monoxide (CO)	g	528.02	324.22	202.06	1.74	305.71	201.70	1.16	3.82	0.00	0.55	14.69	0.35	0.03	0.00	0.00
(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Lead (Pb)	g	0.44	0.02	0.42	0.00	0.02	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Methane (CH4)	g	361.22	270.27	88.66	2.29	266.18	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
(a) Nitrogen Oxides (NOx as	g	1,647.13	1,519.99	118.58	8.56	1,444.01	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
(a) Nitrous Oxide (N2O)	g	5.81	5.41	0.28	0.12	4.65	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Sulfur Oxides (SOx as SO	g	1,734.02	1,604.56	125.58	3.88	1,596.80	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) BOD5 (Biochemical Oxygen	g	15.67	6.92	7.47	1.28	6.13	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
(w) COD (Chemical Oxygen Dem	g	80.79	58.00	20.40	2.39	51.32	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) Suspended Matter (unspec	g	45.91	34.25	9.85	1.81	30.66	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
E Total Primary Energy	MJ	3,011.48	2,226.95	658.19	126.35	2,136.68	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

BEES Data file B1011S: Lafarge Concrete Beam, 10% Silica Fume Cement (4KSI)																
FLOW	**UNIT**	**TOTAL**	**COMP1**	**COMP2**	**COMP3**	**RAW1**	**RAW2**	**RAW3**	**MFG1**	**MFG2**	**MFG3**	**XPORT1**	**XPORT2**	**XPORT3**	**USE1**	**WASTE1**
Water Used (total)	liter	1,776.93	1,129.92	570.94	4.39	1,085.97	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Carbon Dioxide (CO2, fos	g	301,197.00	249,059.00	50,991.90	1,146.09	242,891.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
(a) Carbon Monoxide (CO)	g	479.46	275.66	202.06	1.74	257.15	201.70	1.16	3.82	0.00	0.55	14.69	0.35	0.03	0.00	0.00
(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Lead (Pb)	g	0.43	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Methane (CH4)	g	212.79	121.85	88.66	2.29	117.75	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
(a) Nitrogen Oxides (NOx as	g	1,040.88	913.74	118.58	8.56	837.75	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
(a) Nitrous Oxide (N2O)	g	6.81	6.41	0.28	0.12	5.65	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(a) Sulfur Oxides (SOx as SO	g	826.84	697.38	125.58	3.88	689.62	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) BOD5 (Biochemical Oxygen	g	16.12	7.36	7.47	1.28	6.57	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
(w) COD (Chemical Oxygen Dem	g	85.09	62.30	20.40	2.39	55.62	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(w) Suspended Matter (unspec	g	47.09	35.42	9.85	1.81	31.84	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
E Total Primary Energy	MJ	2,309.89	1,525.36	658.19	126.35	1,435.09	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

Figure D-3 shows the assumed life cycle system boundaries for a 4 KSI concrete beam in BEES made without blended cement. The LCI data presented in Table D-8 reflect these system boundaries.

Figure D-3: System boundaries for 4 KSI concrete beam without blended cement

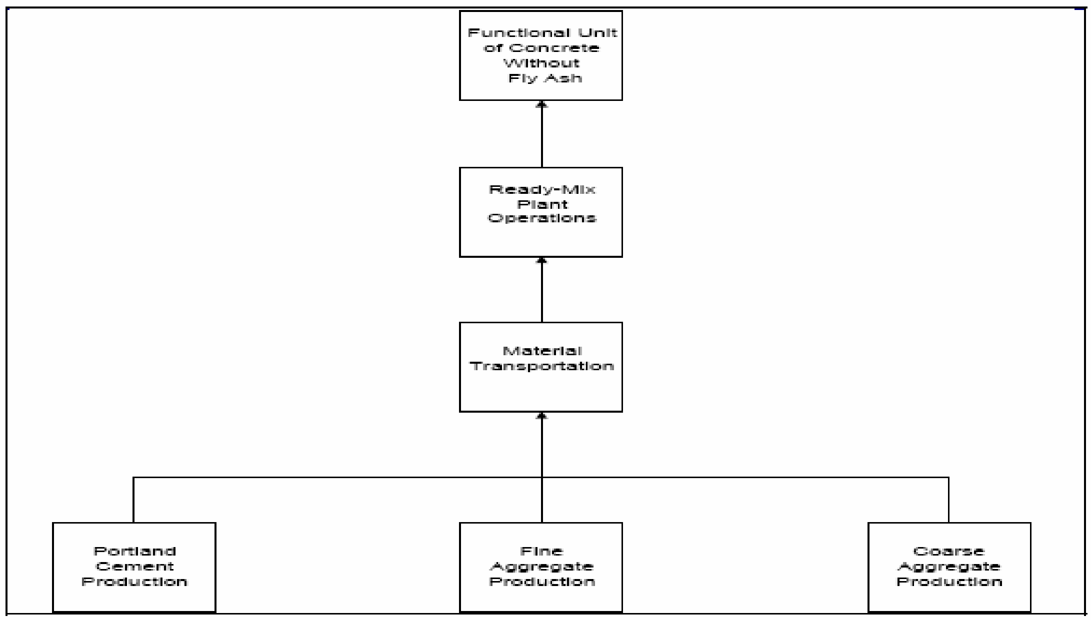
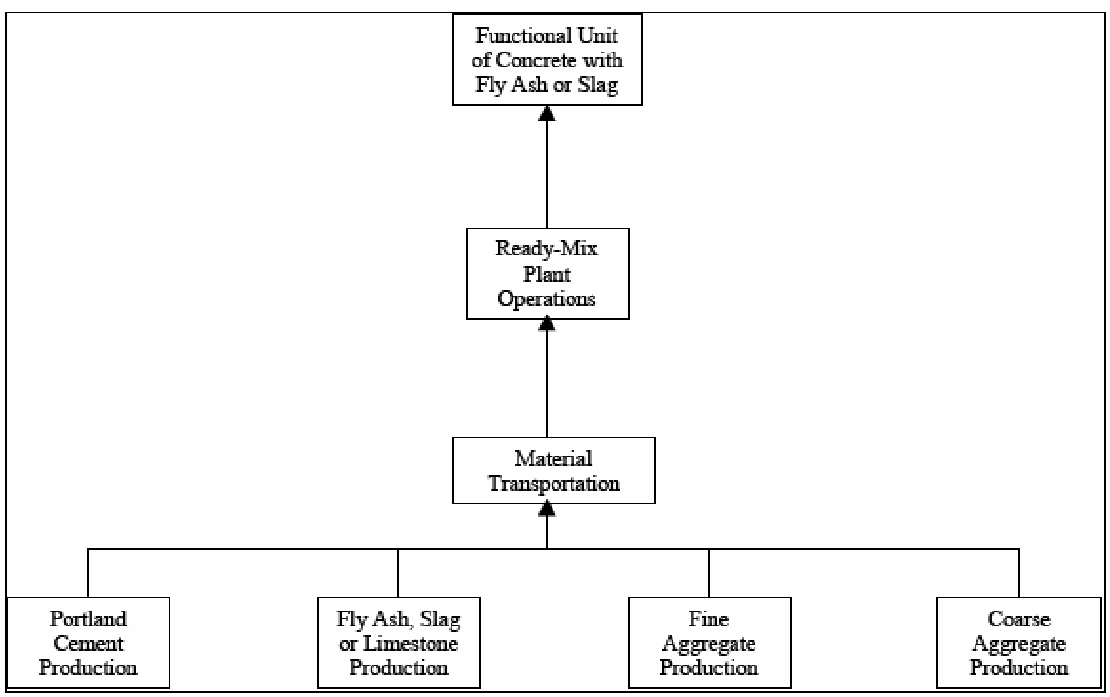


Figure D-4 shows the assumed life cycle system boundaries for a 4 KSI concrete beam in BEES made with blended cement (i.e., incorporating an RMC).

Figure D-4: System boundaries for 4 KSI concrete beam with blended cement



Estimating the Unit Impact of Using RMCs

The BEES data presented in Table D-8 above were used to calculate the benefits of using a specified unit (in this case, one metric ton) of each RMC in concrete by taking the difference in environmental impacts between a concrete product made with 100% portland cement and one made with an RMC at a given substitution level (holding compressive strength and assumed transport distance constant for both products). To illustrate the methodology, a sample calculation of an environmental impact metric concerning CO_2 emissions reductions resulting from the substitution of coal fly ash for portland cement is presented (see Table D-9). As illustrated in this table, the process proceeds through two steps:

- **Step 1 - derive impact per cubic yard of concrete.** This step relies on the BEES data, which is derived on a cubic yard basis, using the LCIs described above. Specifically, it derives a CO_2 emissions profile for a concrete product using two mix designs: one using 100% portland cement and one using 15% coal fly ash and 85% portland cement. The difference between the CO_2 emissions profiles for the two mix designs represents the initial measure of environmental impact. For example, the manufacture of one cubic yard of concrete using 15% coal fly ash results in 22,425 fewer grams of CO_2 emissions compared to a cubic yard of concrete made with 100% portland cement.
- **Step 2 - derive impact per metric ton of coal fly ash.** This step translates the CO_2 emissions per cubic yard of concrete into a measure per metric ton of coal fly ash. This translation is required to match the RMC substitution scenarios, which are presented in metric tons. The process requires first estimating the proportion of one metric ton of coal fly ash present in a cubic yard of concrete, given a 15% substitution rate. This proportion is dependent upon the pounds of cementitious material present in a cubic yard of concrete, which varies depending upon concrete mix design. As shown in the table, the calculations yield an estimate of avoided CO_2 emissions per metric ton of coal fly ash substituted equal to 701,378 grams.

A similar process is repeated for each of the environmental metrics listed above, for each RMC.

Table D-9: Example Calculation of Impact Metric for Avoided CO_2 Related to 15% Coal Fly Ash Substitution

Impacts per cubic Yard Concrete			*Note/Sources*
	Code		
100% portland cement	[a]	266,110 grams per cubic yard of concrete	Values represent impacts related to building products and pavement as characterized in BEES data file B1011A. BEES Version 3.0 Performance Data.
15% coal fly ash	[b]	243,685 grams per cubic yard of concrete	Values represent impacts related to building products and pavement as characterized in BEES data file B1011B. BEES Version 3.0 Performance Data.
Incremental benefit	[c]=[a]-[b]	22,425 grams per cubic yard of concrete	Represents CO_2 reduced per cubic yard of concrete produced with 15% fly ash substitution for portland cement.
Impacts per Metric Ton Coal Fly Ash			
lbs cement/yd^3 concrete	[d]	470 lbs cement/cubic yard of concrete	Represents proportion of cubic yard of concrete made up of cementitious material, given a mix-design or constituent density (Lipiatt, 2002, p. 40).
% coal fly ash substitution	[e]	15%	Fifteen percent of cementitious material is replaced with coal fly ash.
lbs/metric ton	[f]	2,205 lbs/metric ton	Conversion for pounds to metric tons.
MT coal fly ash/yd^3 concrete	[g]=[d]*[e]/[f]	0.032 MT coal fly ash/cubic yard of concrete	Conversion of quantity of coal fly ash in one cubic yard of concrete from pounds to metric tons.
unit impact	[h]=[c]/[g]	701,378 grams per metric ton of coal fly ash substituted for cement	Represent unit impact values for CO_2 (in grams), based on substitution of one metric ton of coal fly ash in a concrete building product or pavement.

The greenhouse gas metrics taken from BEES (i.e., CO_2, CH_4, N_20 and CF_4 emissions) were converted to equivalent impacts such as Carbon Dioxide equivalent, passenger cars removed from the road for one year, passenger cars and light trucks removed from the road for one year, avoided gasoline consumption, and avoided oil consumption, using the Greenhouse Gas Equivalencies Calculator developed by the U.S. Climate Technology Cooperation (U.S.-CTC).[12] It is important to note that these metrics are equivalent expressions of the avoided greenhouse gas metrics reported by BEES; they do not represent additional benefits.

Unit Impact Values

Table D-10 presents estimates of the environmental impacts avoided per metric ton of RMC used as a substitute for finished portland cement. As shown in the table, separate estimates were developed for coal fly ash, GGBFS, and silica fume. [13]

[12] The Greenhouse Gas Equivalencies Calculator can be accessed at: http://www.usctcgateway.net/tool/. Avoided Carbon Dioxide equivalent is an expression of the cumulative global warming potential of all four greenhouse gasses for which BEES data were available (CO_2, CF_4, CH_4, and N_20). It is calculated from the global warming potentials of individual greenhouse gasses, using the global warming potential of $C0_2$ as the reference point.
[13] Analysis of life cycle impacts is, in its simplest form, the calculation of all impacts associated with a single production system. However, when one production system (or a set of linked production systems) makes two or more products with market value (i.e., co-products) it is accepted practice in life cycle analysis to *allocate* the total life cycle production impacts across products. It is important to consider whether co-products of electricity generation (e.g., fly ash) that are beneficially used should have some portion of the production impacts associated with coal combustion (e.g., energy use, greenhouse gas equivalents) attributed to them. The allocated impacts from coal-fired generation would likely associate only very small flows to the RMCs modeled in this Report. For this reason, we do not include either an economic or mass-based allocation in our analysis.

Table D-10: Environmental Impacts Avoided per Metric Ton of RMC Used as a Substitute for Finished Portland Cement in Concrete

Metric	----------------------Material ---------------------		
	Coal Fly Ash[a]	GGBFS	Silica Fume[b]
Energy Savings (megajoules)	4,695.9	4,220.9	32,915.0
Energy Savings (US $)	129.1	116.1	905.2
Water Savings (Liters)	376.3	145.2	-5,111.4
Water Savings (US $)	0.2	0.1	-3.2
Avoided CO_2 Equivalent (GHG) (grams)[c]	718,000.0	Not calculated	Not calculated
Avoided CO_2 Emissions (grams)	701,377.7	668,889.1	699,923.3
Avoided CF_4 Emissions (grams)	0.0	Not calculated	Not calculated
Avoided CH_4 Emissions (grams)	594.8	Not calculated	Not calculated
Avoided N_2O Emissions (grams)	13.2	Not calculated	Not calculated
Passenger cars not driven for one year[d]	0.2	Not calculated	Not calculated
Passenger cars and light trucks not driven for one year[d]	0.1	Not calculated	Not calculated
Avoided gasoline consumption (liters)[d]	310.0	Not calculated	Not calculated
Avoided oil consumption (barrels) [b]	1.7	Not calculated	Not calculated
Avoided NO_2 Emissions (grams)	2,130.2	2,014.8	28,442.2
Avoided PM_{10} Emissions (grams)	0.0	0.0	-0.1
Avoided SOx Emission (grams)	1,673.9	1,605.8	42,560.1
Avoided CO Emissions (grams)	654.3	621.5	2,278.2
Avoided Hg Emissions (grams)	0.0	0.0	-0.3
Avoided Pb Emissions (grams)	0.0	0.0	0.6
Avoided biochemical oxygen demand in water (grams)	3.4	-0.8	-21.0
Avoided chemical oxygen demand in water (grams)	28.7	-6.5	-201.4
Avoided copper water emissions (grams)	0.0	0.0	0.0
Avoided suspended matter in water (grams)	15.4	-3.5	-55.1
Avoided emissions to soil (grams)	0.0	0.0	0.0
Avoided end of life waste (kilograms)	0.0	0.0	0.0

Notes:

a. Impact metrics based upon representative concrete products for building and pavement applications.

b. Negative values represent an incremental increase in impacts relative to the use of portland cement.

Metric	----------------------Material ---------------------		
	Coal Fly Ash[a]	GGBFS	Silica Fume[b]
c. Avoided CO2 equivalent is an expression of the cumulative global warming potential of all four greenhouse gasses for which BEES data were available (CO2, CF4, CH4, and N20). It can be calculated from the global warming potentials of individual greenhouse gasses, using the global warming potential of C02 as the reference point. Avoided CO2 equivalent was calculated using the Greenhouse Gas Equivalencies Calculator developed by the U.S. Climate Technology Cooperation (accessed at: http://www.usctcgateway.net/tool/). d. The greenhouse gas metrics taken from BEES were converted to equivalent impacts such as passenger cars removed from the road for one year, passenger cars and light trucks removed from the road for one year, avoided gasoline consumption, and avoided oil consumption, using the Greenhouse Gas Equivalencies Calculator. It is important to note that these metrics are equivalent expressions of the avoided greenhouse gas metrics reported by BEES; they do not represent additional benefits. GHG equivalency metrics were not calculated for GGBFS and silica fume, due primarily to the fact that use of these materials is unlikely to change significantly across scenarios.			

Step 3: Environmental Impact Profile Calculations

The final step in estimating an environmental impact profile for each RMC is to multiply the appropriate RMC substitution figures by the set of relevant impact metrics. Table D-11 below illustrates a profile for coal fly ash, based on estimated substitution levels for 2004. Column "c" captures the environmental benefit measures.

Table D-11: Example Environmental Impact Profile for Coal fly ash Substituted for Portland Cement, 2004

Metric	Incremental Impact Avoided per 1 MT Fly Ash	MT of Fly Ash Substituted (2004)	Environmental Impact Profile
	[a]	[b]	c =[a]*[b]
Energy Savings (megajoules)	4,695.9	2,562,000	12,030,806,021
Energy Savings (US $)	129.1	2,562,000	330,847,166
Water Savings (Liters)	376.3	2,562,000	963,971,579
Water Savings (US $)	0.2	2,562,000	595,887
Avoided CO2 Equivalent (GHG) (grams)	718,000.0	2,562,000	1,839,516,000,000
Avoided CO2 Emissions (grams)	701,377.7	2,562,000	1,796,929,563,830
Avoided CF4 Emissions (grams)	0.0	2,562,000	0
Avoided CH4 Emissions (grams)	594.8	2,562,000	1,523,844,349
Avoided N2O Emissions (grams)	13.2	2,562,000	33,787,885
Passenger cars not driven for one yeard	0.2	2,562,000	409,920
Passenger cars and light trucks not driven for one yeard	0.1	2,562,000	333,060
Avoided gasoline consumption (liters)	310.0	2,562,000	794,220,000
Avoided oil consumption (barrels)	1.7	2,562,000	4,278,540
Avoided NO2 Emissions (grams)	2,130.2	2,562,000	5,457,697,774
Avoided PM10 Emissions (grams)	0.0	2,562,000	29,248
Avoided SOx Emission (grams)	1,673.9	2,562,000	4,288,431,500
Avoided CO Emissions (grams)	654.3	2,562,000	1,676,332,953
Avoided Hg Emissions (grams)	0.0	2,562,000	108,898
Avoided Pb Emissions (grams)	0.0	2,562,000	80,852
Avoided biochemical oxygen demand in water (grams)	3.4	2,562,000	8,678,148
Avoided chemical oxygen demand in water (grams)	28.7	2,562,000	73,439,730
Avoided copper water emissions (grams)	0.0	2,562,000	0
Avoided suspended matter in water (grams)	15.4	2,562,000	39,424,274
Avoided emissions to soil (grams)	0.0	2,562,000	0
Avoided end of life waste (kilograms)	0.0	2,562,000	0

The environmental impact profile is calculated in this way for the quantity of each RMC used in Federal concrete projects under current and expanded substitution scenarios for years 2004 to 2015.[14] Table D-12 presents the detailed results of these calculations.

[14] The detailed results utilize certain additional refinements for consistent reporting purposes. For example, emission impacts may be converted from grams to metric tons. In addition, certain of the metrics, including water and energy consumption, are monetized. Appropriate discounting protocols are applied to these monetized figures.

Table D-12: Detailed Environmental Impact Calculations

Fly Ash Current Use Baseline Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	12.0	12.8	13.1	13.3	13.6	13.9	14.2	14.5	14.7	15.0	15.3	15.6	168.0
Energy Savings	billion ($ 2006)	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.6
Energy Savings	billion ($ discounted @ 7%)	0.3	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.2	0.2	0.2	3.6
Water Savings	billion liters	1.0	1.0	1.0	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	13.5
Water Savings	million ($ 2006)	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.8	0.8	8.3
Water Savings	million ($ discounted @ 7%)	0.6	0.6	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.4	0.4	0.4	6.4
Avoided $C0_2$ Equivalent (air)	million metric tons	1.8	2.0	2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.3	2.4	25.7
Avoided CO_2	*million metric tons*	*1.8*	*1.9*	*1.9*	*2.0*	*2.0*	*2.1*	*2.1*	*2.2*	*2.2*	*2.2*	*2.3*	*2.3*	*25.1*
Avoided CF_4	*metric tons*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Avoided CH_4	*thousand metric tons*	*1.5*	*1.6*	*1.7*	*1.7*	*1.7*	*1.8*	*1.8*	*1.8*	*1.9*	*1.9*	*1.9*	*2.0*	*21.3*
Avoided N_20	*metric tons*	*33.8*	*35.9*	*36.7*	*37.5*	*38.2*	*39.0*	*39.8*	*40.6*	*41.4*	*42.2*	*43.0*	*43.8*	*471.9*
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.7
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.7
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.0	11.1
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	5.9	6.0	6.2	6.3	6.4	6.6	6.7	6.8	6.9	7.1	76.2
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Avoided SOx (air)	thousand metric tons	4.3	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.5	5.6	59.9
Avoided CO (air)	thousand metric tons	1.7	1.8	1.8	1.9	1.9	1.9	2.0	2.0	2.1	2.1	2.1	2.2	23.4
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.5
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
Avoided biochemical oxygen demand (water)	metric tons	8.7	9.2	9.4	9.6	9.8	10.0	10.2	10.4	10.6	10.8	11.0	11.2	121.2
Avoided chemical oxygen demand (water)	metric tons	73.4	78.0	79.7	81.4	83.1	84.8	86.6	88.3	90.0	91.7	93.4	95.2	1,025.7
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	39.4	41.9	42.8	43.7	44.6	45.5	46.5	47.4	48.3	49.2	50.2	51.1	550.6
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Fly Ash Current Use C^2P^2 Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	12.0	12.8	13.3	13.9	14.5	14.9	15.4	15.8	16.2	16.5	16.8	17.1	179.2
Energy Savings	billion ($ 2006)	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	4.9
Energy Savings	billion ($ discounted @ 7%)	0.3	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2	3.8
Water Savings	billion liters	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	14.4
Water Savings	million ($ 2006)	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.8	0.8	8.9
Water Savings	million ($ discounted @ 7%)	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.4	6.8
Avoided $C0_2$ Equivalent (air)	million metric tons	1.8	2.0	2.0	2.1	2.2	2.3	2.4	2.4	2.5	2.5	2.6	2.6	27.4
Avoided CO_2	*million metric tons*	*1.8*	*1.9*	*2.0*	*2.1*	*2.2*	*2.2*	*2.3*	*2.4*	*2.4*	*2.5*	*2.5*	*2.6*	26.8
Avoided CF_4	*metric tons*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	0.0
Avoided CH_4	*thousand metric tons*	*1.5*	*1.6*	*1.7*	*1.8*	*1.8*	*1.9*	*2.0*	*2.0*	*2.0*	*2.1*	*2.1*	*2.2*	22.7
Avoided N_20	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*42.0*	*43.2*	*44.5*	*45.4*	*46.2*	*47.1*	*48.0*	503.3
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	6.1
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	5.0
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	11.8
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	6.8	7.0	7.2	7.3	7.5	7.6	7.7	81.3
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Avoided SOx (air)	thousand metric tons	4.3	4.6	4.8	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.0	6.1	63.9
Avoided CO (air)	thousand metric tons	1.7	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.3	2.4	25.0
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	1.6
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.2
Avoided biochemical oxygen demand (water)	metric tons	8.7	9.2	9.6	10.0	10.4	10.8	11.1	11.4	11.7	11.9	12.1	12.3	129.3
Avoided chemical oxygen demand (water)	metric tons	73.4	78.0	81.5	85.0	88.2	91.2	94.0	96.7	98.6	100.5	102.4	104.3	1,093.9
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	39.4	41.9	43.7	45.6	47.4	49.0	50.5	51.9	53.0	54.0	55.0	56.0	587.2
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Impacts Attributable to C^2P^{2a}		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	0.0	0.0	0.3	0.6	0.8	1.0	1.2	1.4	1.4	1.4	1.5	1.5	11.2
Energy Savings	billion ($ 2006)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Energy Savings	billion ($ discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Water Savings	billion liters	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.9
Water Savings	million ($ 2006)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.6
Water Savings	million ($ discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Avoided $C0_2$ Equivalent (air)	million metric tons	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	1.7
Avoided CO_2	*million metric tons*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	1.7
Avoided CF_4	*metric tons*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	0.0
Avoided CH_4	*thousand metric tons*	*0.0*	*0.0*	*0.0*	*0.1*	*0.1*	*0.1*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	*0.2*	1.4
Avoided N_20	*metric tons*	*0.0*	*0.0*	*0.8*	*1.6*	*2.3*	*2.9*	*3.4*	*3.9*	*4.0*	*4.0*	*4.1*	*4.2*	31.4
Passenger cars not driven for one year	million passenger cars	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Avoided gasoline consumption	billion liters	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided NOx (air)	thousand metric tons	0.0	0.0	0.1	0.3	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.7	5.1
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided SOx (air)	thousand metric tons	0.0	0.0	0.1	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	4.0
Avoided CO (air)	thousand metric tons	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	1.6
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided Biochemical oxygen demand (water)	metric tons	0.0	0.0	0.2	0.4	0.6	0.8	0.9	1.0	1.0	1.0	1.1	1.1	8.1
Avoided chemical oxygen demand (water)	metric tons	0.0	0.0	1.8	3.6	5.1	6.4	7.4	8.5	8.6	8.8	8.9	9.1	68.2
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	0.0	0.0	1.0	1.9	2.7	3.4	4.0	4.5	4.6	4.7	4.8	4.9	36.6
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the Fly Ash Current Use C^2P^2 Scenario minus the Fly Ash Current Use Baseline Scenario.

GGBFS Current Use Scenario		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Energy Savings	billion megajoules	2.9	3.0	3.1	3.1	3.2	3.2	3.3	3.4	3.4	3.5	3.6	3.6	39.3
Energy Savings	billion ($ 2006)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.1
Energy Savings	billion ($ discounted @ 7%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.8
Water Savings	billion liters	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.4
Water Savings	million ($ 2006)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.8
Water Savings	million ($ discounted @ 7%)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.6
Avoided CO_2	million metric tons	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	6.2
Avoided NOx (air)	thousand metric tons	1.4	1.4	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.7	1.7	1.7	18.8
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided SOx (air)	thousand metric tons	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4	14.9
Avoided CO (air)	thousand metric tons	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	5.8
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Avoided Biochemical oxygen demand (water)	metric tons	-0.5	-0.5	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.7	-7.1
Avoided chemical oxygen demand (water)	metric tons	-4.5	-4.6	-4.7	-4.8	-4.9	-5.0	-5.1	-5.2	-5.3	-5.4	-5.5	-5.6	-60.5
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	-2.4	-2.5	-2.5	-2.6	-2.6	-2.7	-2.7	-2.8	-2.8	-2.9	-2.9	-3.0	-32.4
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Silica Fume Current Use Scenario		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Total**
Energy Savings	billion megajoules	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.7
Energy Savings	billion ($ 2006)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Energy Savings	billion ($ discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Water Savings	billion liters	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.7
Water Savings	million ($ 2006)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.5
Water Savings	million ($ discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-0.4
Avoided CO_2	million metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	4.1
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided SOx (air)	thousand metric tons	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6.1
Avoided CO (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided Biochemical oxygen demand (water)	metric tons	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-3.0
Avoided chemical oxygen demand (water)	metric tons	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-2.4	-29.0
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-7.9
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total Current Use C^2P^2 Scenario[a]		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
Energy Savings	billion megajoules	15.3	16.2	16.8	17.4	18.0	18.6	19.1	19.6	20.0	20.4	20.7	21.1	223.2
Energy Savings	billion ($ 2006)	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	6.1
Energy Savings	billion ($ discounted @ 7%)	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	4.7
Water Savings	billion liters	1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.4	1.4	1.4	1.4	15.0
Water Savings	million ($ 2006)	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	9.3
Water Savings	million ($discounted @ 7%)	0.6	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	7.1
Avoided CO_2	million metric tons	2.3	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.1	33.1
Avoided NOx (air)	thousand metric tons	7.2	7.6	7.9	8.1	8.4	8.7	8.9	9.1	9.3	9.5	9.7	9.8	104.1
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Avoided SOx (air)	thousand metric tons	5.9	6.2	6.4	6.7	6.9	7.1	7.3	7.4	7.6	7.7	7.8	8.0	85.0
Avoided CO (air)	thousand metric tons	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.7	2.8	2.8	2.9	2.9	31.1
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	2.0
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.6
Avoided Biochemical oxygen demand (water)	metric tons	7.9	8.4	8.8	9.2	9.6	9.9	10.3	10.6	10.8	11.0	11.2	11.4	119.1
Avoided chemical oxygen demand (water)	metric tons	66.5	71.0	74.4	77.8	80.9	83.8	86.5	89.1	90.9	92.7	94.5	96.3	1,004.4
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	36.4	38.7	40.6	42.4	44.1	45.6	47.1	48.5	49.5	50.4	51.4	52.3	546.9
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the sum of the fly ash current use C^2P^2, current use GGBFS and current use silica fume scenarios. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

Fly Ash Expanded Use 15% Scenario		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Energy Savings	billion megajoules	12.0	12.8	13.3	13.9	14.5	16.0	17.3	18.8	20.2	21.7	23.2	24.8	208.5
Energy Savings	billion ($2006)	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	5.7
Energy Savings	billion ($discounted @ 7%)	0.3	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	4.2
Water Savings	billion liters	1.0	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2.0	16.7
Water Savings	million ($2006)	0.6	0.6	0.7	0.7	0.7	0.8	0.9	0.9	1.0	1.1	1.1	1.2	10.3
Water Savings	million ($discounted @ 7%)	0.6	0.6	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	7.7
Avoided $C0_2$ Equivalent (air)	million metric tons	1.8	2.0	2.0	2.1	2.2	2.4	2.7	2.9	3.1	3.3	3.5	3.8	31.9
Avoided CO_2	*million metric tons*	*1.8*	*1.9*	*2.0*	*2.1*	*2.2*	*2.4*	*2.6*	*2.8*	*3.0*	*3.2*	*3.5*	*3.7*	*31.1*
Avoided CF_4	*metric tons*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Avoided CH_4	*thousand metric tons*	*1.5*	*1.6*	*1.7*	*1.8*	*1.8*	*2.0*	*2.2*	*2.4*	*2.6*	*2.7*	*2.9*	*3.1*	*26.4*
Avoided N_20	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*44.8*	*48.7*	*52.7*	*56.7*	*60.9*	*65.2*	*69.6*	*585.4*
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	7.1
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	5.8
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6	13.8
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	7.2	7.9	8.5	9.2	9.8	10.5	11.2	94.6
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.5
Avoided SOx (air)	thousand metric tons	4.3	4.6	4.8	5.0	5.2	5.7	6.2	6.7	7.2	7.7	8.3	8.8	74.3
Avoided CO (air)	thousand metric tons	1.7	1.8	1.9	1.9	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.5	29.0
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	1.9
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	1.4
Avoided biochemical oxygen demand (water)	metric tons	8.7	9.2	9.6	10.0	10.4	11.5	12.5	13.5	14.6	15.6	16.7	17.9	150.4
Avoided chemical oxygen demand (water)	metric tons	73.4	78.0	81.5	85.0	88.2	97.4	105.8	114.5	123.3	132.4	141.7	151.3	1,272.5
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	39.4	41.9	43.7	45.6	47.4	52.3	56.8	61.5	66.2	71.1	76.1	81.2	683.1
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Fly Ash Expanded Use 30% Scenario		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Energy Savings	billion megajoules	12.0	12.8	13.3	13.9	14.5	19.1	23.8	28.6	33.6	38.7	44.1	49.6	304.0
Energy Savings	billion ($2006)	0.3	0.4	0.4	0.4	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.4	8.4
Energy Savings	billion ($discounted @ 7%)	0.3	0.4	0.4	0.4	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	5.8
Water Savings	billion liters	1.0	1.0	1.1	1.1	1.2	1.5	1.9	2.3	2.7	3.1	3.5	4.0	24.4
Water Savings	million ($2006)	0.6	0.6	0.7	0.7	0.7	0.9	1.2	1.4	1.7	1.9	2.2	2.5	15.1
Water Savings	million ($discounted @ 7%)	0.6	0.6	0.7	0.6	0.6	0.8	0.9	1.0	1.1	1.2	1.2	1.3	10.5
Avoided $C0_2$ Equivalent (air)	million metric tons	1.8	2.0	2.0	2.1	2.2	2.9	3.6	4.4	5.1	5.9	6.7	7.6	46.5
Avoided CO_2	*million metric tons*	*1.8*	*1.9*	*2.0*	*2.1*	*2.2*	*2.9*	*3.6*	*4.3*	*5.0*	*5.8*	*6.6*	*7.4*	*45.4*
Avoided CF_4	*metric tons*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*
Avoided CH_4	*thousand metric tons*	*1.5*	*1.6*	*1.7*	*1.8*	*1.8*	*2.4*	*3.0*	*3.6*	*4.3*	*4.9*	*5.6*	*6.3*	*38.5*
Avoided N_20	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*53.7*	*66.8*	*80.4*	*94.3*	*108.8*	*123.8*	*139.2*	*853.7*
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.7	10.4
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.4	8.4
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.3	20.1
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	8.7	10.8	13.0	15.2	17.6	20.0	22.5	137.9
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.7
Avoided SOx (air)	thousand metric tons	4.3	4.6	4.8	5.0	5.2	6.8	8.5	10.2	12.0	13.8	15.7	17.7	108.4
Avoided CO (air)	thousand metric tons	1.7	1.8	1.9	1.9	2.0	2.7	3.3	4.0	4.7	5.4	6.1	6.9	42.4
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	2.8
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	2.0
Avoided biochemical oxygen demand (water)	metric tons	8.7	9.2	9.6	10.0	10.4	13.8	17.1	20.6	24.2	27.9	31.8	35.7	219.3
Avoided chemical oxygen demand (water)	metric tons	73.4	78.0	81.5	85.0	88.2	116.7	145.1	174.7	205.1	236.5	269.0	302.5	1,855.7
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	39.4	41.9	43.7	45.6	47.4	62.6	77.9	93.8	110.1	127.0	144.4	162.4	996.2
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Total 15% Scenario[a]		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	15.3	16.2	16.8	17.4	18.0	19.6	21.0	22.5	24.0	25.6	27.2	28.8	252.5
Energy Savings	billion ($2006)	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.7	0.8	6.9
Energy Savings	billion ($discounted @ 7%)	0.4	0.4	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	5.2
Water Savings	billion liters	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2.0	17.3
Water Savings	million ($2006)	0.6	0.7	0.7	0.7	0.7	0.8	0.9	1.0	1.0	1.1	1.2	1.3	10.7
Water Savings	million ($discounted @ 7%)	0.6	0.7	0.7	0.7	0.6	0.7	0.7	0.7	0.7	0.7	0.7	0.7	7.9
Avoided CO_2	million metric tons	2.3	2.4	2.5	2.6	2.7	2.9	3.1	3.3	3.6	3.8	4.0	4.3	37.5
Avoided NO_2 (air)	thousand metric tons	7.2	7.6	7.9	8.1	8.4	9.1	9.8	10.5	11.1	11.8	12.6	13.3	117.4
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.5
Avoided SOx (air)	thousand metric tons	5.9	6.2	6.4	6.7	6.9	7.4	7.9	8.5	9.0	9.6	10.1	10.7	95.4
Avoided CO (air)	thousand metric tons	2.1	2.2	2.3	2.4	2.5	2.7	2.9	3.1	3.3	3.6	3.8	4.0	35.2
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	2.2
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	1.8
Avoided biochemical oxygen demand (water)	metric tons	7.9	8.4	8.8	9.2	9.6	10.7	11.7	12.7	13.7	14.8	15.8	17.0	140.2
Avoided chemical oxygen demand (water)	metric tons	66.5	71.0	74.4	77.8	80.9	90.0	98.3	106.9	115.6	124.6	133.8	143.3	1,183.0
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	36.4	38.7	40.6	42.4	44.1	49.0	53.4	58.0	62.7	67.5	72.5	77.6	642.8
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the sum of the fly ash expanded use 15% scenario, the current use GGBFS scenario and the current use silica fume scenario. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

Total 30% Scenario[a]		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	15.3	16.2	16.8	17.4	18.0	22.7	27.5	32.4	37.4	42.6	48.0	53.6	348.0
Energy Savings	billion ($2006)	0.4	0.4	0.5	0.5	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.5	9.6
Energy Savings	billion ($discounted @ 7%)	0.4	0.4	0.5	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.7	0.8	6.8
Water Savings	billion liters	1.0	1.1	1.1	1.2	1.2	1.6	2.0	2.3	2.7	3.2	3.6	4.0	25.0
Water Savings	million ($2006)	0.6	0.7	0.7	0.7	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5	15.4
Water Savings	million ($discounted @ 7%)	0.6	0.7	0.7	0.7	0.6	0.8	0.9	1.0	1.1	1.2	1.2	1.3	10.8
Avoided CO_2	million metric tons	2.3	2.4	2.5	2.6	2.7	3.4	4.1	4.8	5.6	6.3	7.2	8.0	51.7
Avoided NO_2 (air)	thousand metric tons	7.2	7.6	7.9	8.1	8.4	10.6	12.7	14.9	17.2	19.6	22.0	24.6	160.8
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.8
Avoided SOx (air)	thousand metric tons	5.9	6.2	6.4	6.7	6.9	8.6	10.2	12.0	13.8	15.7	17.6	19.6	129.4
Avoided CO (air)	thousand metric tons	2.1	2.2	2.3	2.4	2.5	3.2	3.8	4.5	5.2	5.9	6.7	7.5	48.5
Avoided Hg (air)	metric tons	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.5	3.1
Avoided Pb (air)	metric tons	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	2.4
Avoided biochemical oxygen demand (water)	metric tons	7.9	8.4	8.8	9.2	9.6	12.9	16.3	19.8	23.4	27.1	30.9	34.8	209.1
Avoided chemical oxygen demand (water)	metric tons	66.5	71.0	74.4	77.8	80.9	109.3	137.6	167.0	197.4	228.7	261.1	294.5	1,766.2
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	36.4	38.7	40.6	42.4	44.1	59.3	74.5	90.3	106.6	123.4	140.8	158.8	955.8
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the sum of the fly ash expanded use 30% scenario, the current use GGBFS scenario and the current use silica fume scenario. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

Total 15% Scenario Incremental to Total C^2P^2 Scenario[a]		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	TOTAL
Energy Savings	billion megajoules	0.0	0.0	0.0	0.0	0.0	1.0	1.9	2.9	4.0	5.2	6.4	7.7	29.3
Energy Savings	billion ($2006)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.8
Energy Savings	billion ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.5
Water Savings	billion liters	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	2.3
Water Savings	million ($2006)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.4	1.4
Water Savings	million ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.9
Avoided CO_2	million metric tons	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.6	0.8	1.0	1.1	4.4
Avoided NO_2 (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.5	0.9	1.3	1.8	2.4	2.9	3.5	13.3
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided SOx (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.4	0.7	1.0	1.4	1.9	2.3	2.7	10.4
Avoided CO (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.4	0.6	0.7	0.9	1.1	4.1
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2
Avoided biochemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.7	1.4	2.1	2.9	3.8	4.6	5.6	21.1
Avoided chemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	6.2	11.8	17.7	24.7	31.9	39.3	47.0	178.6
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	0.0	0.0	0.0	0.0	0.0	3.3	6.4	9.5	13.2	17.1	21.1	25.2	95.9
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the 15% Scenario Total minus Total C^2P^2. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

Total 30% Scenario Incremental to Total C^2P^2 Scenario[a]		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Energy Savings	billion megajoules	0.0	0.0	0.0	0.0	0.0	4.2	8.4	12.8	17.4	22.3	27.3	32.5	124.8
Energy Savings	billion ($2006)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.5	0.6	0.8	0.9	3.4
Energy Savings	billion ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	2.1
Water Savings	billion liters	0.0	0.0	0.0	0.0	0.0	0.3	0.7	1.0	1.4	1.8	2.2	2.6	10.0
Water Savings	million ($2006)	0.0	0.0	0.0	0.0	0.0	0.2	0.4	0.6	0.9	1.1	1.4	1.6	6.2
Water Savings	million ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.4	0.6	0.7	0.8	0.8	3.7
Avoided CO_2	million metric tons	0.0	0.0	0.0	0.0	0.0	0.6	1.3	1.9	2.6	3.3	4.1	4.9	18.6
Avoided NO_2 (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	1.9	3.8	5.8	7.9	10.1	12.4	14.7	56.6
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.3
Avoided SOx (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	1.5	3.0	4.5	6.2	7.9	9.7	11.6	44.5
Avoided CO (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.6	1.2	1.8	2.4	3.1	3.8	4.5	17.4
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.2	0.3	1.1
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.8
Avoided biochemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	3.0	6.0	9.2	12.6	16.1	19.7	23.4	90.0
Avoided chemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	25.4	51.1	77.9	106.4	136.0	166.6	198.2	761.8
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	0.0	0.0	0.0	0.0	0.0	13.6	27.5	41.8	57.1	73.0	89.5	106.4	409.0
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the 30% Scenario Total minus Total C^2P^2. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

Total 30% Scenario Incremental to Total 15% Scenario[a]		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**TOTAL**
Energy Savings	billion megajoules	0.0	0.0	0.0	0.0	0.0	3.2	6.4	9.9	13.4	17.1	20.9	24.8	95.5
Energy Savings	billion ($2006)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	2.6
Energy Savings	billion ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	1.6
Water Savings	billion liters	0.0	0.0	0.0	0.0	0.0	0.3	0.5	0.8	1.1	1.4	1.7	2.0	7.7
Water Savings	million ($2006)	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5	0.7	0.8	1.0	1.2	4.7
Water Savings	million ($discounted @ 7%)	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.6	2.9
Avoided CO_2	million metric tons	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.5	2.0	2.5	3.1	3.7	14.3
Avoided NO_2 (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	1.4	2.9	4.5	6.1	7.7	9.5	11.2	43.3
Avoided PM_{10} (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2
Avoided SOx (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	1.1	2.3	3.5	4.8	6.1	7.4	8.8	34.1
Avoided CO (air)	thousand metric tons	0.0	0.0	0.0	0.0	0.0	0.4	0.9	1.4	1.9	2.4	2.9	3.5	13.3
Avoided Hg (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.2	0.9
Avoided Pb (air)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.6
Avoided biochemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	2.3	4.6	7.1	9.7	12.3	15.0	17.9	68.9
Avoided chemical oxygen demand (water)	metric tons	0.0	0.0	0.0	0.0	0.0	19.2	39.3	60.2	81.8	104.1	127.3	151.3	583.2
Avoided copper (water)	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	0.0	0.0	0.0	0.0	0.0	10.3	21.1	32.3	43.9	55.9	68.4	81.2	313.1
Avoided soil emissions	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

a. Calculated as the Total 30% Scenario minus the Total 15% Scenario. The expanded GHG metrics are not included in these totals because these metrics were not evaluated for either GGBFS or silica fume.

General Limitations of Analysis

Beyond the specific assumptions and modeling constraints cited throughout this appendix, there are several broad limitations with respect to the analysis, including:

- **Uncertainty concerning applicable RMC substitution levels.** Two sources of uncertainty exist. First, it has been noted that there is difficulty in identifying both the quantity of concrete procured for federally-funded projects, and the quantities of each RMC used in these projects. Second, it is difficult to isolate, for quantification, the effect of current procurement regulations on RMC substitution. Thus, the results may over- or understate actual benefits depending upon the accuracy of the estimated quantities. In addition, the results likely overstate benefits attributable to current procurement regulations.

- **Static nature of unit impact values.** The BEES model presents an LCI based upon current manufacturing processes and related energy intensity and emissions levels, which may change over time. Thus, the accuracy of the impact values derived from these LCIs likely declines the further out they are applied to the 10-year projection of RMC substitution levels.

- **Social welfare impacts of RMC substitution.** The benefit results capture absolute differences in resource use and emissions between two concrete product types. These absolute differences likely overstate marginal welfare impacts resulting from RMC substitution. For example, a portion of energy savings from RMC substitution may be consumed elsewhere within the economy. Accordingly, the results are best viewed as a relative measure of benefits across RMCs and concrete product types.

WARM Analysis of Coal fly ash Substitution

EPA's Waste Reduction Model (WARM) is another lifecycle tool capable of evaluating the greenhouse gas and energy impacts of coal fly ash substitution in concrete. For comparison with BEES results for coal fly ash substitution, we calculate the avoided greenhouse gas and energy impacts per metric ton coal fly ash substitution using WARM. As with BEES, we do not run the WARM model for coal fly ash but instead use underlying energy and greenhouse gas emissions factors for the coal fly ash recycling scenario.[15] Table D-13 presents a comparison of the energy and greenhouse gas unit impacts derived from WARM and BEES.

Table D-13: Comparison of WARM and BEES Unit Impacts

	Impacts per One MT Coal Fly Ash as Cement Replacement	
	WARM[a]	**BEES**
Avoided energy (million Btu)	5.26	4.45
Avoided CO_2 (MT)	NA[b]	0.70
Avoided CH_4 (MT)	NA[b]	0.00
Metric tons carbon dioxide equivalent ($MTCO_2E$)	0.96	0.71[c]
Metric tons carbon equivalent (MTCE)	0.26	0.20[c]

Notes:
a. WARM impacts on a short ton coal fly ash basis were converted to a metric ton basis by multiplying each impact by 1.10231131 short tons/MT.
b. WARM does not report these metrics.
c. BEES impacts for avoided CO_2 and CH_4 were converted to $MTCO_2E$ and MTCE using the U.S. Climate Technology Cooperation Gateway's *Greenhouse Gas Equivalencies Calculator*, accessed at: http://www.usctcgateway.net/tool/.

As shown, the unit impacts calculated from BEES and WARM are very similar.

[15] The coal fly ash recycling scenario energy and emissions factors in WARM are calculated as the difference in energy use and greenhouse gas emissions between virgin production of one ton of cement and production of one ton of coal fly ash. The same general calculation is used to derive the coal fly ash unit impacts in BEES. We do not run WARM as a comparison between coal fly ash landfill disposal and coal fly ash recycling because such an analysis would be inconsistent with the impacts being measured in BEES.

Beneficial Use of Blast Furnace Slag Aggregate (BFSA)

As described in section two of this report, blast furnace slag aggregate can replace virgin aggregate in concrete mixes or in roadbase. When used in this capacity, blast furnace slag aggregate reduces the need to quarry, crush, sort, and transport virgin aggregate. Extraction and processing of virgin crushed rock is a resource and energy intensive process. To the extent that virgin aggregate production can be offset by use of blast furnace slag aggregate, these energy and resource requirements are reduced.

The life cycle analysis presented in section three of this report evaluates the substitution of ground, granulated blast furnace slag (GGBFS) for finished portland cement, but does not evaluate substitution of blast furnace slag aggregate for virgin aggregate in concrete or roadbase. Using a modified-LCA approach, we illustrate the magnitude of environmental and energy savings that can be realized through beneficial use of blast furnace slag aggregate. We modeled the environmental and energy savings from beneficial use of blast furnace slag aggregate as the avoided lifecycle impacts of extracting, processing and transporting an equivalent quantity of virgin aggregate. This approach provides a reasonable approximation of the magnitude of benefits since virgin aggregate extraction is the only significant process change when BFSA is used in place of virgin aggregate in concrete mixes, or as base material.

We rely on life cycle inventory data contained in the Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE) to quantify the environmental savings from one ton of avoided virgin aggregate extraction.[16] We then multiply the unit environmental impacts of avoided virgin aggregate extraction by the total 2004 baseline[17] quantity of BFSA under two alternative scenarios.

Based on available data and communications with experts in the field, we estimated that approximately 8.1 million metric tons of BFSA were sold in the U.S. in our baseline year of 2004 (see Chapter 2). Available data at the time of our analysis indicated that virtually 100% of BFSA generated annually in the U.S. was beneficially used. However, recent information received from the National Slag Association (Kiggins, 2007) indicates that as much as 1.4 million metric tons of BFSA may go unused annually, resulting in only 6.7 million metric tons being beneficially used (based on 2004 data). To determine the maximum level of potential BFSA beneficial use impacts we first estimated benefits based on the full quantity (8.1 million metric tons) of BFSA reported sales for 2004[18.] These results are presented under Scenario 1 in Table D-14. Assuming that approximately 1.4 million metric tons of BFSA goes unused annually, this would mean that society is currently enjoying the environmental benefits

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[16] PaLATE is an Excel-based tool developed by the Consortium for Green Design and Manufacturing at U.C. Berkeley for life cycle analysis of environmental and economic performance of pavements and roads.. The model was developed for pavement designers and engineers, transportation agency decision-makers, civil engineers, and researchers. PaLATE can evaluate the relative impacts of using different virgin and secondary materials in the construction and maintenance of roads. For additional information on PaLATE, or to obtain a copy of the model, see http://www.ce.berkeley.edu/~horvath/palate.html.

[17] We did not develop beneficial use trends and projected benefit estimates through the year 2015, as we did for GGBFS, fly ash and silica fume due to our inability to reliably link projected BFSA use as an aggregate to future cement use (see Section 3.3.1 of the Report).

[18] This quantity includes an estimated 1.8 percent of the total that was actually used as clinker raw material.

associated with the use of only 6.7 million metric tons. Scenario 2 in Table D-14 presents the incremental benefits associated with using the additional 1.4 million metric tons of potentially available BFSA. Consistent with our analysis in Chapter 3, and earlier in this Appendix, we estimate that BFSA use in Federal projects would represent approximately 20% of the total estimated benefits.

TABLE D-14: ESTIMATED ENVIRONMENTAL BENEFITS FROM USE OF BLAST FURNACE SLAG AGGREGATE AS A SUBSTITUTE FOR VIRGIN AGGREGATE

METRIC	UNITS	UNIT IMPACT (per metric ton virgin aggregate)	SCENARIO 1* Impacts for 8.1 million metric tons BFSA as substitute for virgin aggregate	SCENARIO 2** Impacts for use of an additional 1.4 million metric tons BFSA as substitute for virgin aggregate
CO_2	grams	12,039.83	97,522,590,241	16,855,756,338
CO	grams	15.85	128,402,187	22,192,971
NO_2	grams	24.26	196,507,899	33,964,328
SO_2	grams	11.82	95,734,247	16,542,878
PM_{10}	grams	172.52	1,397,444,725	241,478,448
Energy	MJ	170.00	1,377,028,355	237,950,500
	Btu	161,129	1,305,170,991,400	225,533,547,560
Electricity (kWh)	kWh	11.20	90,688,961	15,671,052
Hg	grams	0.00	4	0.7
Pb	grams	0.00	28,178	4,869
RCRA Hazardous Waste Generated	grams	197.57	1,600,281,470	276,528,638
Water Consumption	thousand gallons	23.68	191,797,367	33,142,585

* Scenario 1 assumes 100% BFSA usage (8.1 million metric tons) during our baseline year of 2004 (see Chapter 2).
** Scenario 2 presents the estimated incremental benefits of 1.4 million metric tons only, reflecting the NSA estimate that approximately 1.4 million metric tons of BFSA goes unused each year. Under this scenario, the baseline 2004 usage would be 6.7 million metric tons, leaving the additional 1.4 million metric tons available for beneficial use.

MJ = megajoule

Although not quantified in our analysis, the National Slag Association has indicated that the beneficial use of BFSA provides a further economic benefit by helping the U.S. Steel Industry remain competitive in the global steel market. (Kiggins, 2007).