United States Environmental Protection Agency
in conjunction with the
U.S. Department of Transportation and the U.S. Department of Energy

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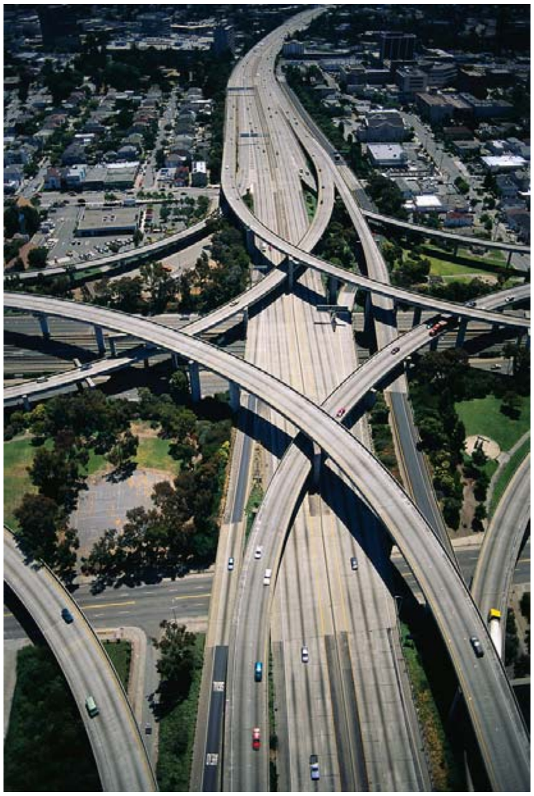
Study on Increasing the Usage of Recovered Mineral Components in Federally Funded Projects Involving Procurement of Cement or Concrete

to Address the

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users



Report to Congress

June 3, 2008

EPA530-R-08-007

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EXECUTIVE SUMMARY

Section 6017(a) of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59, Aug. 10, 2005 (SAFETEA-LU), directs the U.S. Environmental Protection Agency (EPA or the Agency) to, "…conduct a study to determine the extent to which procurement requirements, when fully implemented…may realize energy savings and environmental benefits attainable with substitution of recovered mineral components in cement used in cement or concrete projects."

SAFETEA-LU directs EPA to submit a report to Congress within 30 months of the enactment of SAFETEA-LU that addresses the following requirements:

> (A) Quantify (i) the extent to which recovered mineral components are being substituted for portland cement, particularly as a result of current procurement requirements; and (ii) the energy savings and environmental benefits associated with that substitution;
>
> (B) Identify all barriers in procurement requirements to greater realization of energy savings and environmental benefits, including barriers resulting from exceptions from current law; and
>
> (C) (i) Identify potential mechanisms to achieve greater substitution of recovered mineral components in types of cement and concrete projects for which recovered material components historically have not been used or have been used only minimally; (ii) evaluate the feasibility of establishing guidelines or standards for optimized substitution rates of recovered material component in those cement and concrete projects; and (iii) identify any potential environmental or economic effects that may result from greater substitution of recovered mineral components in these cement and concrete projects.

Energy savings and environmental benefits associated with substitution. Recovered mineral component (RMC) use yields positive environmental benefits through lower resource consumption. To overcome procurement data limitations, for ground granulated blast-furnace slag (GGBFS), coal combustion fly ash (coal fly ash) , and silica fume, the report derives estimates of their use in Federal projects by roughly apportioning total volumes to Federal and non-Federal projects (based upon the estimated proportion of total cement demand related to federally-funded projects). For the years 2004 and 2005, our life cycle analysis indicates that the use of GGBFS, coal fly ash, and silica fume in Federal concrete projects alone resulted in significant reductions in greenhouse gas (GHG) emissions, criteria air pollutants, and energy and water use. For these two years combined, the analysis indicates reduced energy use of 31.5 billion megajoules, avoided CO_2 equivalent air emissions of 3.8 million metric tons, and water savings of 2.1 billion liters. The report further illustrates how these benefits may accrue over a longer time period (through 2015) given alternative use scenarios. This aspect of the analysis also links to issue C noted above.

With respect to the issues identified under parts (B) and (C), research suggests that while a number of barriers impede the beneficial use of RMCs through procurement requirements, a variety of potential mechanisms exist for addressing these barriers. Specifically:

- **Procurement policies and material standards** initiatives, including ongoing assessment and refinement of EPA's Comprehensive Procurement Guidelines (CPGs), refinement of engineering standards governing substitution of RMCs, and development and application of green building standards.

- **Education, technical assistance, and recognition programs,** such as EPA's foundry sand outreach efforts and public/private partnerships, such as the Coal Combustion Products Partnership (C^2P^2) to encourage the beneficial use of coal combustion products (CCPs).

    - As part of education, technical assistance, and recognition, ongoing research and pilot projects are critical to advancing the use of RMCs.

- **Economic incentives,** such as using transportation funding mechanisms to increase RMC use and providing incentives related to various components of the RMC generation and use chain.[1]

The CPG program is part of EPA's continuing effort to promote the use of materials recovered from solid waste and by-products.[2] Under this program, EPA designates products that are made with recovered materials, and recommends practices for buying these products by procuring agencies.[3] Once a product is designated, procuring agencies are required to purchase it with the highest recovered material content level practicable (e.g., the highest material content level that can be economically obtained and can provide the needed product specifications). EPA has issued guidelines for procurement of cement and concrete containing coal fly ash, and has further designated cenospheres[4] and silica fume as RMCs for cement and concrete.

This report presents EPA's analysis and discussion of the requirements contained in SAFETEA - LU. Consistent with SAFETEA-LU, this Report reflects the input of multiple Federal partners in addition to EPA, including the U.S. Department of Transportation (DOT), the U.S. Department of Energy (DOE), the General Accountability Office (GAO), the United States Geological Survey (USGS) and the Office of the Federal Environmental Executive (OFFE). In addition, the Report also reflects comments and information from state entities and certain industry sources, such as the American Coal Ash Association (ACAA), the Slag Cement Association (SCA), the Silica Fume Association (SFA), the National Slag Association (NSA) - Edw. C. Levy Co., Headwaters, Inc., Venable LLP, and Holcim, Inc. We summarize the salient features of the report below.

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[1] These incentives are presented for Congressional consideration only. We recognize that the Department of Transportation does not currently have the legal authority to use transportation funding mechanisms to help increase RMC use.

[2] EPA also issues guidance on buying recycled-content products in Recovered Materials Advisory Notices (RMANs). The RMANs recommend recycled-content ranges for CPG products based on current information on commercially available recycled-content products.

[3] Procuring agencies include: (1) any federal agency, (2) any state or local agency using appropriated federal funds for procurement, or (3) any contractors to these agencies who are procuring these items for work they perform under the contract.

[4] Cenospheres are a very specialized product used in a number of different industries. Cenospheres are also sometimes called microspheres.

Industry Overview, Materials Evaluated, and Current Recovered Mineral Component Substitution Levels

Provisions of SAFETEA- LU identified certain RMCs for further study, and directed EPA to identify and consider other waste and byproduct materials diverted from solid waste that should be considered as "recovered mineral components."[5] The four congressionally-identified mineral components include: GGBFS; coal fly ash; blast furnace slag aggregate (BFSA)[6]; and silica fume. Congress specifically excluded lead slag from this Report. The other by-product materials identified by EPA for evaluation include: foundry sand, cenospheres, flue gas desulfurization (FGD) gypsum, flue gas desulfurization (FGD) dry scrubber material, power plant bottom ash, power plant boiler slag, steel furnace slag, and cement kiln dust (CKD). Table ES-1 provides a description of each of the RMCs and their general uses. Table ES-2 identifies the estimated annual quantities available for each RMC (including both domestic production and imports), and summarizes the positive environmental impacts and product enhancements associated with use of these materials.

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[5] Section 6017 (a) of SAFETEA-LU defines recovered mineral components as "(A) ground granulated blast furnace slag other than lead slag; (B) coal combustion fly ash; (C) blast furnace slag aggregate other than lead slag aggregate; (D) silica fume; and (E) any other waste material or byproduct recovered or diverted from solid waste that the Administrator, in consultation with an agency head, determines should be treated as recovered mineral component under this section."

[6] Also known as Air Cooled Blast-Furnace Slag (ACBF Slag)

Table ES-1: Summary of RMCs

RMC	Description	Uses/Applications
RMCs Named by Congress		
Ground granulated blast-furnace slag (GGBFS)	A ferrous slag produced during the production of iron as a result of removing impurities from iron ore. Quick quenching (chilling) of molten slag yields glassy, granular product which can be ground to a fine, powdered hydraulic cement.	GGBFS can be used as partial replacement for portland cement, or, if not finely ground, as concrete aggregate.
Coal combustion fly ash	A finely-divided mineral residue from the combustion of ground or powdered coal in coal-fired power plants.	Partial replacement for portland cement in concrete applications. Can be used as a raw material in the production of portland cement clinker or as an inter-ground or blended supplementary cementitious material (SCM) in the production of blended cements.
Blast furnace slag aggregate (BFSA)	Produced by allowing molten slag to cool and solidify slowly. Also commonly referred to as: air cooled blast-furnace slag (ACBF slag).	After crushing and screening, used as aggregate in applications, such as concrete, asphalt, rail ballast, and roofing. It is also used in shingle coating, and glass making.
Silica fume	A very fine, dust-like material generated during alloyed metal production.	Concrete additive used to increase strength and durability.
Other RMCs Identified by EPA		
Foundry sand	Silica sand that is a byproduct of both ferrous and nonferrous metal castings.	Can be used in the manufacture of cement clinker and as an ingredient in concrete.
Cenospheres	Small, inert, lightweight, hollow, "glass" spheres composed of silica and alumina and filled with air or other gases. They occur naturally in coal fly ash.	Used in concrete production to increase concrete's strength and decreasing shrinkage and weight. [Cenospheres may also be used in a wide variety of materials, from paints and finishes to plastics and caulking.]
Flue gas desulfurization (FGD) gypsum	FGD by-products are generated by air pollution control devices used at some coal-fired electric power plants. Forced oxidation wet FGD systems create gypsum as a by-product.	Replacement for natural gypsum in wallboard production and grinding with clinker to produce finished cement.
Flue gas desulfurization (FGD) dry scrubber material	Dry FGD systems remove sulfur dioxide (SO_2) from coal-fired power plant flue gas. Main constituents of resulting byproduct include calcium sulfite, fly ash, portlandite, calcite, calcium sulfate.	Dry FGD material is used in concrete mixes and products as a substitute aggregate material. Dry FGD material may also be used for embankments and roadbase compositions.
Power plant bottom ash	A coarse, solid mineral residue that results from the burning of coal in utility boilers.	Used as aggregate in concrete, or for other aggregate uses such as compacted base course. Also used as raw material in cement clinker manufacture as alternative source of silica, alumina, iron, and calcium.
Power Plant Boiler slag	A coarse, hard, black, angular, glassy material, produced from slag in wet-bottom boilers.	Owing to its abrasive properties, boiler slag is used almost exclusively in the manufacture of blasting grit; can also be used as raw feed component to make cement clinker.
Steel furnace slag	A by-product from the conversion of iron to steel in a basic oxygen furnace or the melting of scrap to make steel in an electric arc furnace.	Used as raw material substitute in cement clinker manufacturing. Also used in aggregate base, fill and asphalt.
Cement kiln dust (CKD)	The fine-grained, solid, highly alkaline material removed from cement kiln exhaust gas by air pollution control devices.	Material is primarily recycled through closed loop processes in the cement kiln. Small amounts used as supplementary cementitious material (SCM) for blended and/or masonry cements. Material can be used as a soil liming agent.
<u>Note:</u> Congress specifically excluded lead slag from this Report.		

Table ES-2: RMC Generation and Benefits of Use

RMC	**Annual Quantity Generated, 2004.** *(excludes stockpiles)* (million metric tons)	Benefits of Use
RMCs Named by Congress		
Ground Granulated Blast Furnace Slag (GGBFS)	3.6[a]	Use of GGBFS in concrete results in environmental benefits from avoided virgin materials extraction and manufacturing of portland cement. These benefits include reduced energy use and associated greenhouse gas (GHG) emissions, reduced water use and reduced air pollution. In addition, the beneficial properties of concrete mixes containing GGBFS include increased strength, improved workability, lower heat of hydration, lower permeability, improved resistance to alkali-silica reactivity, and resistance to sulfate attack. Use of GGBFS creates more concrete from the same amount of portland cement.
Coal Combustion Fly Ash	64.2 [b]	Use of coal combustion fly ash in concrete results in environmental benefits from avoided virgin materials extraction and manufacturing of portland cement. These benefits include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution. In addition, certain performance benefits can be attained through the use of fly ash in cement, including greater workability in the mixed concrete and higher strength and increased longevity in the finished product. Also, creates more concrete from the same amount of portland cement. Can also be used as a raw material in the production of portland cement clinker or as an inter-ground or blended supplementary cementitious material (SCM) in the production of blended cements.
Blast Furnace Slag Aggregate (BFSA) (ACBF slag)	8.1[a]	As an aggregate in concrete mixes, BFSA reduces the need to quarry, crush, sort, and transport virgin aggregate materials, resulting in reduced energy use and associated GHG emissions, reduced water use and reduced air pollution.
Silica Fume	0.10 – 0.12[c]	The beneficial properties of concrete mixes containing silica fume include decreased water bleeding, increased strength, and reduced permeability to corrosive chemicals. Use of silica fume in concrete also reduces the required amount of portland cement for a specific quantity of concrete. Silica fume concrete is used in high-performance applications where special durability and strength performance is required.
Other RMCs Identified by EPA		
Foundry Sand	8.5[d]	Use of foundry sand in concrete results in environmental benefits from avoided virgin sand extraction. These benefits include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution.
Cenospheres	0.0052[e] (sold only) (Total not available)	When incorporated into special light weight concrete or other cementitious materials mixes as fillers or extenders, cenospheres and can decrease shrinkage and weight. Use of cenospheres can also offset the production of other filler materials, such as manufactured glass, calcium carbonate, clays, talc, and other silicas.
Flue Gas Desulfurization (FGD) Gypsum	10.8[c]	Use of FGD gypsum in wallboard production and as an additive in cement production results in environmental benefits from avoided extraction of virgin gypsum. These benefits are likely to include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution.
Flue Gas Desulfurization (FGD) Dry Scrubber Material	1.7[b]	Use of dry FGD material as a substitute for virgin aggregate results in environmental benefits from avoided virgin material extraction and aggregate production. These benefits include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution. Use of dry FGD as a substitute (partial or total) for natural gypsum used as an additive in the finish mill (to control the setting time of the portland cement).
Power Plant Bottom Ash	15.6[b]	Use of bottom ash in concrete results in environmental benefits from avoided aggregate production. These benefits include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution. The porous surface structure

RMC	**Annual Quantity Generated, 2004.** *(excludes stockpiles)* (million metric tons)	**Benefits of Use**
		of bottom ash also makes it useful in lightweight concrete and concrete block applications. As a raw material in cement manufacture, the bottom ash can supply some of the necessary oxides (thus saving on virgin raw materials), and can do so at a lower energy cost and with reduced emissions than for some virgin materials.
Boiler Slag	2.0[b]	Boiler slag can reduce the need for virgin materials used as a raw feed for clinker production. Boiler slag is also used in the manufacture of blasting grit.
Steel Furnace Slag	9.0[a]	Use of steel slag in clinker manufacturing helps to reduce energy use, decrease CO_2 and NO_X ,emissions, increase production capacity, and reduce virgin limestone extraction. As an aggregate, steel slag reduces virgin aggregate extraction. The benefits of avoided limestone or other types of aggregate extraction include reduced energy use and associated GHG emissions, reduced water use and reduced air pollution.
Cement Kiln Dust (CKD)	12.0 – 15.0[f]	Use of CKD as a filler or cementitious extender for finished cement can offset virgin materials extraction and reduce waste sent to landfills. Other beneficial uses of off-site CKD include stabilization of sludges, wastes, and contaminated soils. CKD may also be used for land reclamation, livestock feed ingredient, and as daily landfill cover.

Notes:

[a] Hendrik G. van Oss, 2004b, values given are amount sold, as the industry does not report on actual production. Sales include imports of ground blast furnace slag (GBFS) that are ground domestically into GGBFS. Van Oss (2006) estimates total blast furnace slag production in 2004 to be 12-14 million metric tons (vs. total reported sales of 12.2 million metric tons), but this figure does not distinguish between GBFS, GGBFS, and BFSA.

[b] American Coal Ash Association (ACAA). 2004 Coal Combustion Product (CCP) Production and Use Survey.

[c] Kojundic, 8/30/2006

[d] Oman, Alicia, American Foundry Society (AFS), September 18, 2007. Personal Communication. Foundry Sand data are annual average for 2005/06.

[e] American Coal Ash Association (ACAA). 2004 Coal Combustion Product (CCP) Production and Use Survey. Reported as sold only.

[f] van Oss, 2005. The industry does not report total CKD production. A majority of this material is known to be recycled back into the kiln. According to PCA, in 2006 approximately 1.2 million metric tons was beneficially reused (other than in kilns) and 1.4 million metric tons was landfilled (PCA, 2006. Summary of 2006 Cement Kiln Dust and Clinker Production)

Congress specifically excluded lead slag from this Report.

Energy and Environmental Benefits of RMC Use in Federal Cement and Concrete Projects

As indicated in Table ES-2, the use of RMCs can decrease the demand for certain virgin materials and decrease the demand for the use of portland cement. This leads to decreased resource consumption, namely energy and water. Lower resource consumption can yield, in turn, reductions in various pollutants and other positive environmental impacts, such as a reduction in GHG emissions. To assess these potential benefits further, this analysis provides quantified estimates of the environmental impacts and benefits for three RMCs: coal fly ash, GGBFS, and silica fume.[7] Consistent with the Congressional mandate to examine "recovered mineral components in cement used in cement or concrete projects," these estimates focus specifically on the impacts resulting from the use of these three mineral components as a partial replacement for, or supplement to, portland cement in Federal construction projects involving concrete. The assessed metrics include resource savings (e.g., reduced energy and water consumption), various avoided priority air pollutants (e.g., NO_2, PM_{10}, SOx, Hg, Pb), and various measures of avoided GHG emissions (e.g., CO_2, CF_4, CH_4, N_2O), which we further translate into equivalent metrics of avoided gasoline and oil consumption, and vehicles removed from the road.[8]

The analysis employs three primary steps in modeling the environmental benefits of using RMCs in Federal concrete applications: (1) development of RMC substitution scenarios; (2) use of life-cycle analysis to estimate quantified environmental impacts associated with the substitution of one unit (metric ton) of RMC; and, (3) calculation of the environmental impact profile for the total quantities of substituted RMC.

Concerning RMC substitution scenarios, the report first focuses on past years for which actual use data can be estimated (2004 and 2005). The report then develops multiple projected use scenarios for the years 2006 through 2015 based upon existing trends (i.e., baseline) and expanded use based upon attainment of certain program goals (e.g., attainment of the C^2P^2 goal of 16.9 million metric tons of coal fly ash use in concrete by 2011). Because data concerning the volume of these RMCs procured by the Federal government are unavailable, the report derives an estimate based on a rough measure of the proportion of the total volume of cement demand attributable to Federal concrete projects (equal to approximately 20% of the annual totals). Chapter 3 and Appendix D provide detailed background on the derivation of RMC use scenarios for Federal concrete projects.

For purposes of illustrating the general magnitude of potential impacts, Table ES-3 shows projected quantities of coal fly ash, GGBFS and silica fume used in Federal concrete projects for one scenario -- "baseline" usage. Chapter 3 and Appendix D provide detailed results for all

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[7] The report focuses on these three RMCs due to the fact that more robust data sources and modeling resources exist with respect to material volumes and their use in federally-funded concrete projects. While it is likely that other materials used to supplement or substitute for portland cement would have similar benefits, it is difficult to extrapolate results from the RMCs addressed here because quantities in use are uncertain and different processing requirements for different materials can have a significant impact on the magnitude of environmental benefits.

[8] Additionally, unquantified benefits may be associated with improved performance of concrete and resulting decreases in the materials and energy needed to repair, replace, and upgrade road beds. Evaluation of these benefits, however, would require more robust estimates of average changes in management required for different concrete uses. To date, this type of information has been too limited to support a national estimate.

scenarios. The shaded area, covering years 2004 and 2005, represents the historical period. As the table shows, under this scenario, the forecast estimates that coal fly ash use in Federal concrete projects will grow from approximately 2.6 million metric tons in 2004, to 3.3 million metric tons in 2015. The GGBFS forecast contemplates lower growth, from approximately 0.7 million metric tons in 2004 to 0.9 million metric tons in 2015. Coal fly ash shows higher utilization growth potential as this RMC is currently used at lower rates compared to the highly-utilized GGBFS. Overall volumes of silica fume use are lower relative to coal fly ash and GGBFS.

Table ES-3: Use Projections for Fly Ash, GGBFS, and Silica Fume in Federal Concrete Projects (baseline scenario)

Year	Federal Demand for Portland Cement	Coal Fly Ash used in Federal Projects - Baseline Scenario	GGBFS used in Federal Projects - Baseline Scenario	Silica Fume used in Federal Projects - Baseline Scenario
	--------------------------------------*million metric tons*--			
2004	24.4	2.6	0.7	0.01
2005	25.1	2.7	0.7	0.01
2006	25.7	2.8	0.7	0.01
2007	26.2	2.8	0.7	0.01
2008	26.8	2.9	0.8	0.01
2009	27.4	3.0	0.8	0.01
2010	27.9	3.0	0.8	0.01
2011	28.5	3.1	0.8	0.01
2012	29.0	3.1	0.8	0.01
2013	29.6	3.2	0.8	0.01
2014	30.1	3.3	0.8	0.01
2015	30.7	3.3	0.9	0.01

Notes:

(1) These figures reflect use of materials as a supplement to or partial replacement for portland cement in Federal projects only.

(2) Shaded area represents "historical" period for which actual use data are estimated. Unshaded area represents the "forecast" period.

Table ES-4 presents the results of a life cycle inventory analysis of the use coal of fly ash, GGBFS and silica fume in Federal concrete projects under the baseline usage scenarios described above. These results are aggregated estimated benefits covering the historical period (2004 and 2005) and projected over the full time frame, 2004 through 2015. For a detailed description of the modeling approach, please refer to Appendix D.

Table ES-4: Estimated Environmental Benefits of Using Coal Fly Ash, GGBFS, and Silica Fume as a Substitute for, or Supplement to Portland Cement in Federal Concrete Projects, Baseline Scenario[9]

Metric (units)	Historical Environmental Benefits: 2004-2005	Projected Environmental Benefits: Baseline Scenario 2004-2015[a]
Energy Savings *(billion megajoules)*	31.5	212.1
Water Savings *(billion liters)*	2.1	14.1
Avoided C0$_2$ equivalent (GHG) *(million metric tons)*	3.8[b]	25.7[b]
Passenger cars not driven for one year[c] *(million)*	0.8[b]	5.7[b]
Passenger cars and light trucks not driven for one year[c] *(million)*	0.7[b]	4.7[b]
Avoided criteria pollutants (air) *(thousand metric tons)*	31.3	209.7
Avoided Hg (air) *(metric tons)*	0.3	1.9
Avoided soil emissions *(metric tons)*	0.0*	0.0*
Avoided end of life waste *(metric tons)*	0.0	0.0

Notes:
a. Calculated as the sum of impacts for coal fly ash current use baseline, and GGBFS and silica fume current use scenarios.
b. Results reflect only coal fly ash impacts.
c. These metrics are equivalent expressions of the avoided greenhouse gas metrics and do not represent additional benefits.
* Negligible.

We also developed representative benefits estimates for use of BFSA as an aggregate. See Appendix D.

As shown in Table ES-4, the use of coal fly ash, GGBFS and silica fume as a partial substitute for, or supplement to, portland cement in Federal concrete projects yield energy and water savings, as well as avoided criteria pollutant emissions. In addition, use of coal fly ash alone may result in 3.8 million metric tons of avoided carbon dioxide equivalent in the years 2004 to 2005. This savings is equivalent to removing 0.8 million passenger cars from the road for one year. Through the year 2015 under this scenario, we estimate that the use of such RMCs in Federal concrete projects may result in reduced CO$_2$ emissions of over 25.7 million metric tons, which is equivalent to removing 5.7 million passenger cars from the road for one year. Impacts on the reuse on soil and end of life waste are not significant because the use and disposal of portland cement and concrete are not affected by RMC use.

It is difficult to quantify the incremental contribution to RMC use that may be attributable to any particular relevant procurement requirements. A number of economic, operational, and regulatory factors combine to influence procurement behavior, and data limitations prevent the

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[9] Blast furnace slag aggregate (BFSA) is primarily used as a source of aggregate in concrete and does not act as a supplementary cementitious material, or substitute for portland cement. Our assessment focuses on the benefits of substitution for portland cement. However, an illustration of the types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete mixtures, in asphalt mixtures, or as roadbase, can be found in Appendix D.

type of detailed analysis that would support attribution of specific behavior changes to specific programs. In general terms, however, the analysis identifies the combined impact of the CPG, state, Federal government, industry, and market-driven influences on the use of RMCs in Federal concrete projects.

Barriers to Increased RMC Substitution

Consistent with Part (B) of the Congressional mandate, this report describes barriers to increased RMC use, focusing specifically on the RMCs identified in the report for which current supply significantly exceeds current use. (i.e., coal fly ash, foundry sand, FGD gypsum, FGD dry scrubber material, power plant bottom ash, and CKD). Barriers to the increased use of RMCs in cement and concrete projects fall into four main categories:

- Technical barriers;
- Legal, regulatory, and contractual barriers;
- Economic barriers; and
- Perceived safety and health risk barriers.

These categories can include a range of specific issues that have the potential to limit the use of an RMC. For example, regulatory barriers may include certain state and local-level regulations and procedures governing the use of RMCs in various applications. Technical issues that limit the use of RMCs include the variability of standards for use of RMCs in portland cement and concrete and operational constraints with materials not typically used as RMCs; variation in RMC properties; and the availability of consistent, high-quality materials. Potential economic factors limiting RMC substitution include the RMC value to the supplier, transportation costs, the market price of RMCs, and disposal costs. Safety and health risk perception barriers include a lack of understanding of the potential and proper use, features, and risks associated with RMCs.

In addition to external barriers, the CPG provides that a procuring agency need not procure RMCs if certain criteria are met. If these criteria are over-interpreted by project managers, it could result in lower usage rates of RMCs than are technically and economically feasible. That is, while the CPG requires Federal agencies to procure products containing certain RMCs, the guidelines allow that such RMCs do not have to be procured if they: (1) are not available within a reasonable period of time; (2) fail to meet the performance standards set forth in the applicable specifications or fail to meet the reasonable performance standards of the procuring agencies; or (3) are only available at an unreasonable price. Additional limitations of the CPG include a lack of awareness of CPG requirements and products, the perception that CPG is not mandatory, and the cost and availability of CPG materials.

Mechanisms to Increase RMC Substitution

EPA, in collaboration with a variety of stakeholders, has identified a number of mechanisms that may serve to address the barriers noted above. These mechanisms are particularly focused on

RMCs with high reuse potential, but which appear to be under-utilized. For example, coal fly ash exists in large quantities, but is currently (2006) used in portland cement and concrete at a rate of roughly 13.6 million metric tons per year out of a generation of roughly 65.7 million metric tons. The report focuses on current and potential mechanisms to increase substitution rates relevant to these materials, specifically in Federal cement and concrete projects.[10]

Central to this report, and RMC use in Federal concrete projects, is the role of the CPG. As noted, the extent to which major Federal procuring agencies have purchased products containing RMCs is difficult to measure because few data systems identify purchases of specific recycled-content designated products. However, the multi-faceted approach to green purchasing implemented under the CPG has led to many successes, including influencing the amount of RMCs procured for use in concrete products. As one example, for FY 2003, more than 80% of the concrete purchases made by NASA, DOE, and GSA contained coal fly ash or slag. The CPG program, therefore, represents a critical mechanism to achieve higher RMC reuse levels.

To continue and expand upon this progress, the procurement guidelines and their implementation are the focus of ongoing improvement efforts (e.g, updating of CPG Supplier database). Further, a number of other potential mechanisms exist for addressing barriers. Chapter 5 provides a detailed listing of these potential mechanisms. In summary, the current and potential mechanisms for increasing RMC use include:

- **Procurement policy initiatives**, including improved procurement data systems, allowing for the identification and tracking of cement and concrete purchases using RMCs; enhanced CPG compliance and implementation procedures; and, delivery of effective information resources, training, and outreach to Federal agency contracting, purchase card, and program personnel.

- **Material standards optimization**, including refinement of engineering standards governing substitution of RMCs, development and application of green building standards, and incorporation of these considerations into contract bidding specifications and procedures.

- **Education and recognition programs,** such as EPA's CCPs outreach efforts and public/private partnerships, such as the FHWA, ACAA, DOE, the Electric Power Research Institute (EPRI), the United States Department of Agriculture (USDA), and the Utility Solid Waste Activities Group (USWAG) collaboration on C^2P^2 to promote the beneficial use of CCPs.

- **Technical assistance and research**, such as FHWA's ongoing research on the beneficial use of RMCs in highway construction projects, which includes primary research concerning material specifications and guidance on their use.

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[10] We also note that the amount of certain RMCs produced annually in the U.S. surpasses the amount that can be incorporated into Federal cement and concrete projects alone. Although Federal projects currently comprise a moderate percentage of U.S. cement and concrete projects, increasing reuse rates to higher levels will require greater reuse among both Federal and non-Federal cement and concrete projects. To that end, many of the mechanisms contemplated here can apply to non-federal, as well as Federal projects.

- **Economic incentives,** such as using transportation funding mechanisms to increase RMC use and enhancing the economic viability of various components of the RMC generation and use chain.

The linkages between these mechanisms and barriers are complex and varied. For example, some barriers related to inaccurate perceptions concerning RMC use may be overcome relatively easily through education or outreach efforts. These mechanisms, however, would be less effective in instances where strong economic disincentives to RMC use are present. In addition, implementation of many of these mechanisms is subject to resource availability and active participation by a broad range of entities. These factors all indicate that increasing RMC use in concrete products requires an ongoing, multi-faceted approach.

1.0 INTRODUCTION

1.1 Background and Organization

Section 6017(a) of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, P.L. 109-59, Aug. 10, 2005 (SAFETEA-LU)[11], directs the U.S. Environmental Protection Agency (EPA or the Agency) to, "…conduct a study to determine the extent to which procurement requirements, when fully implemented…may realize energy savings and environmental benefits attainable with substitution of recovered mineral components in cement used in cement or concrete projects."

SAFETEA-LU directs EPA to submit a report to Congress within 30 months of the enactment of SAFETEA-LU that addresses the following requirements:

(A) Quantify (i) the extent to which recovered mineral components are being substituted for portland cement, particularly as a result of current procurement requirements, and (ii) the energy savings and environmental benefits associated with that substitution;

(B) Identify all barriers in procurement requirements to greater realization of energy savings and environmental benefits, including barriers resulting from exceptions from current law; and

(C) (i) Identify potential mechanisms to achieve greater substitution of recovered mineral component in types of cement or concrete projects for which recovered mineral components historically have not been used or have been used only minimally; (ii) evaluate the feasibility of establishing guidelines or standards for optimized substitution rates of recovered mineral component in those cement or concrete projects; and (iii) identify any potential environmental or economic effects that may result from greater substitution of recovered mineral component in those cement or concrete projects.

This report contains EPA's analysis of the information addressed in SAFETEA-LU. The report is organized into six sections:

- The ***Introduction*** discusses EPA's existing comprehensive procurement guidelines (CPGs), presents an overview of the screening process that EPA used to identify and prioritize the analysis of specific recovered mineral components (RMCs), and outlines the current state of different types of specifications for various RMCs.

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[11] SAFETEA-LU and the Energy Policy Act of 2005, P.L. 109-58, August 8, 2005 (EPACT), include similar provisions amending Subtitle F of the Solid Waste Disposal Act that direct EPA to conduct this study and submit a Report to Congress. SAFETEA-LU was enacted later in time and, therefore, impliedly repealed EPACT.

- ***Chapter 2*** responds to Part (A) of the Congressional charge by describing the current industry, uses, and substitution levels of the specific RMCs identified in the Introduction (Section 1).

- ***Chapter 3*** responds to Part (A) of the Congressional charge by analyzing the energy and environmental impacts associated with the beneficial use of three specific RMCs identified by Congress.

- ***Chapter 4*** addresses Part (B) of the Congressional charge by identifying and describing various barriers to increased RMC substitution.

- ***Chapter 5*** addresses Part (C) of the Congressional charge by identifying and describing various mechanisms to increase RMC substitution.

- ***Chapter 6*** presents the report's conclusions.

Consistent with SAFETEA-LU, this Report reflects the input of multiple Federal partners in addition to EPA, including the U.S. Department of Transportation (DOT); the Department of Energy (DOE); the General Accountability Office (GAO); the United States Geological Survey (USGS); and the Office of the Federal Environmental Executive (OFEE). In addition, the Report also reflects comments and information from various states and certain industry sources. Such sources include, but are not limited to: the American Coal Ash Association (ACAA); the Slag Cement Association (SCA); the Silica Fume Association (SFA); the National Slag Association (NSA) - Edw. C. Levy Co.; Headwaters, Inc.; Venable LLP; and Holcim, Inc.

1.2 The Comprehensive Procurement Guidelines and Federal Requirements Governing the Use of Recovered Mineral Components (RMCs) in Federal Cement and Concrete Projects

The CPG program is part of EPA's continuing effort to promote the use of materials recovered from solid waste and by-products. Buying recycled-content products enhances the likelihood that recyclable materials will be used again in the manufacture of new products.

The CPG program is mandated by Congress under Section 6002 of the Resource Conservation and Recovery Act (RCRA). Over the years, CPG implementation has been bolstered by presidential Executive Orders, the most recent being Executive Order 13423.[12] Under this program, EPA designates products that are made with recovered materials, and recommends practices for procuring agencies[13] to procure these products. Once a product is designated, procuring agencies are required to purchase it with the highest recovered material content level

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[12] On January 24, 2007, the President signed Executive Order (E.O) 13423 "Strengthening Federal Environmental, Energy, and Transportation Management." E.O. 13423 consolidates and strengthens five previously enacted executive orders. For more details on E.O. 13423, see (http://www.epa.gov/oaintrnt/practices/eo13423.htm).

[13] Procuring agencies include: (1) any federal agency, (2) any state or local agency using appropriated federal funds for procurement, or (3) any contractors to these agencies who are procuring these items for work they perform under the contract.

practicable (e.g., the highest material content level that can be economically obtained and can meet the needed specifications).

In 1983, EPA issued guidelines for the procurement of cement and concrete containing fly ash (40 CFR Part 249, 48FR 4230, January 28, 1983). The Agency later amended the rule in CPG IV to add cenospheres, ground granulated blast-furnace slag (GGBFS), and silica fume as RMCs for cement and concrete. Thus designated by EPA, cement and concrete containing RMCs are to be preferentially procured by procuring agencies, as required by statute and Executive Order.

To aid procuring agencies, EPA also has issued guidance on buying recycled-content products in Recovered Materials Advisory Notices (RMANs). The RMANs recommend recycled-content ranges for CPG products based on current information on commercially available recycled-content products. RMAN levels are updated as marketplace conditions change.

1.2.1 Recovered Materials Content[14]

In the CPGs for cement and concrete, EPA advises procuring agencies to prepare or revise their procurement programs for cement and concrete, or for construction projects involving cement and concrete, to allow for the use of coal fly ash, GGBFS, cenospheres, or silica fume, as appropriate.[15,16] Recovered materials are frequently used as substitutes for or supplements to portland cement when mixing concrete. Some recovered materials can also be used in the manufacture of portland cement itself, by replacing other raw materials used in making clinker (the intermediate product in portland cement manufacturing) and also in the later blending stages of the cement manufacturing process. The blended cement produced by this process is then used in concrete in place of straight portland cement. Finally, many recovered materials can be used as a direct substitute for the aggregate (i.e., non-cement) portion of concrete.

The CPGs require that procuring agencies consider the use of all of these recovered materials and choose the one (or mixture) that meets their performance requirements, consistent with availability and price considerations. EPA recommends that procuring agencies specifically include provisions in all construction contracts to allow for the use, as optional or alternate materials, of cement or concrete which contains coal fly ash, GGBFS, cenospheres, or silica fume, where appropriate. Due to variations in cement, strength requirements, costs, and construction practices, EPA does not recommend specific RMC content levels for cement or concrete containing coal fly ash, GGBFS, cenospheres, or silica fume. However, EPA provides the following information about recovered materials content:[17]

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[14] Information on recovered materials content reproduced from: http://www.epa.gov/cpg/products/cement.htm, accessed June 4, 2007.

[15] While the EPA language cited here (accessible at: http://www.epa.gov/cpg/products/cemspecs.htm) uses the general term “cement,” the discussion targets materials and practices that generally refer to portland cement. In subsequent, related documents, including Federal Register documents, the Agency specifies portland cement.

[16] EPA's published information sometimes refers to ground granulated blast-furnace slag as "GGBF slag." For consistency, we have changed this terminology to GGBFS, even when quoting Agency material. A commonly used industry term for this material is “slag cement.”

[17] The following bullets are reproduced from: http://www.epa.gov/cpg/products/cement.htm, accessed July 3, 2007, with modifications to the first bullet to include portland cement and reflect the distinction between blended cements and concrete. Two additional bullets are added to show how slag aggregate can be used in concrete.

- Replacement rates for portland cement in concrete generally do not exceed 20% to 30%. Blended cements are produced at a cement kiln where fly ash is added at the kiln ranging from zero to 40% coal fly ash by weight, according to the American Society for Testing and Materials (ASTM). These levels are identified under ASTM C 595 for cement Types IP and IS(PM).[18] Fifteen percent is a more accepted rate when coal fly ash is used as a partial cement replacement as an admixture in concrete. (See also: ASTM C 1157 Standard Performance Specification for Hydraulic Cement.)

- According to ASTM C 595, GGBFS may replace up to 70% of the portland cement in some concrete mixtures.[19, 20] Most GGBFS concrete mixtures contain between 25% and 50% GGBFS by weight. EPA recommends that procuring agencies refer, at a minimum, to ASTM C 989 for the GGBFS content appropriate for the intended use of the cement and concrete.

- According to industry sources, there are some cases where slag aggregate can replace 100% of the virgin aggregate in concrete. [21]

- According to industry sources, cement and concrete containing cenospheres typically contains a minimum of 10% cenospheres by volume.[22]

- According to industry sources, cement and concrete containing silica fume typically contains silica fume that constitutes five to 10% of cementitious material on a dry weight basis.[23]

- According to ASTM C33, Standard Specifications for Concrete Aggregate. BFSA may be used as aggregate for concrete, as can recycled crushed concrete, sand, gravel, crushed gravel, or crushed stone in concrete mixes.

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[18] Note that ASTM standards may be updated or revised over time.

[19] According to Hendrik van Oss of the USGS, GGBFS may also replace up to 70 % of the portland cement in some cement blends.

[20] Recent changes to ASTM C595 have removed the limit of GGBFS in Type I(S) cement. GGBFS is now governed by ASTM C989. Now there are industry guidelines for “normally accepted” substitution rates. The SCA publishes such guidance in its information sheet *SCIC #2: Concrete Proportioning* available at: http://www.slagcement.org/image/123800_c_sU128801_s_i185530/No2_Proportioning.pdf.

[21] June 27, 2007 statement from Rich Lehman of the Edw. C. Levy Company..

[22] Refer to 69 FR 24041, published on April 30, 2004 for more information. Note that this information is consistent with the generation rates for cenospheres and silica fume published in *Background Document for the Final Comprehensive Procurement Guideline (CPG) IV and Final Recovered Materials Advisory Notice (RMAN) IV,* U.S. Environmental Protection Agency, April 2004 (EPA 2004).

[23] Silica fume use in cement is different than other RMCs because it can be added as a supplement to a final cement product to help reduce permeability and increase durability, without replacing virgin portland cement. In addition, silica fume can be used as a substitute for portland cement.

1.2.2 Specifications

1.2.2.1 Coal Fly Ash and GGBFS

Under the CPG, EPA recommends that procuring agencies revise their specifications to require that contracts for individual construction projects or products allow for the use of coal fly ash or GGBFS, unless the use of these materials is technically inappropriate for a particular construction application. According to the CPG, procuring agencies should use the existing voluntary consensus specifications referenced below for cement and concrete containing coal fly ash and/or GGBFS[24].

- **Federal and State Specifications:** EPA advises procuring agencies to consult Federal and state sources to identify established specifications for coal fly ash or GGBFS in cement and concrete. For example, the Federal Highway Administration (FHWA) maintains a database of state highway agency material specifications.[25] AASHTO specifications are another source. Furthermore, the states of Alabama, Connecticut, Florida, Georgia, Illinois, Indiana, Maryland, Michigan, North Carolina, North Dakota, Ohio, Pennsylvania, South Carolina, Virginia, West Virginia, and the District of Columbia all have adopted specifications that allow the use of GGBFS in one or more applications.[26] Procuring agencies may obtain these specifications from the respective state transportation departments and adapt them for use in their programs for cement and concrete, as appropriate.

- **Contract Specifications:** EPA advises procuring agencies that prepare or review "contract" specifications for individual construction projects to revise those specifications, as appropriate, to allow for the use of cement and concrete containing coal fly ash or GGBFS as optional or alternate materials for the targeted project. These revisions should be consistent with the agencies' performance and price objectives. [27]

- **Performance Standards:** EPA advises procuring agencies to review and, if necessary, revise performance standards relating to cement or concrete construction projects. This should be done to ensure that existing standards do not arbitrarily restrict the use of coal fly ash or GGBFS, either intentionally or inadvertently, unless the restriction is justified on a job-by-job basis: (1) to meet

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[24] Although not referenced in the current CPG, BFSA is recognized by AASHTO, ASTM, and many procuring agencies as an appropriate coarse aggregate for use in concrete mixes, and for other aggregate uses.

[25] www.specs.fhwa.dot.gov

[26] For a detailed table of state DOT specifications, refer to "Engineering and Environmental Specifications of State Agencies for Utilization and Disposal of Coal Combustion Products: Volume 1 – DOT Specifications," 2005. Dockter, B. and Diana M. Jagiella, Table 3, Page 32.

[27] Chapter 5 provides further detail concerning RCRA §6002 requirements related to material and contract specifications.

reasonable performance requirements for the cement or concrete, or, (2) because the use of coal fly ash or GGBFS would be inappropriate for technical reasons. This justification should be documented based on specific technical performance information.

- **Mix Design:** Existing cement ratios could potentially unfairly discriminate against the use of coal fly ash or GGBFS if design specifications specify minimum portland cement or maximum water content; such specifications should be reevaluated in order to allow the partial substitution of coal fly ash or GGBFS for portland cement in the concrete mixture, unless technically inappropriate. Cement ratios can be retained, as long as they reflect the cementitious characteristics that coal fly ash or GGBFS can impart to a concrete mixture (e.g., by considering portland cement plus coal fly ash or portland cement plus GGBFS as the total cementitious component).

- **Quality Control:** The RMAN does not relieve the contractor of responsibility for providing a satisfactory product. Cement and concrete suppliers are already responsible both for the quality of the ingredients of their product, and for meeting appropriate performance requirements. This will continue to be the case under the RMAN, with no shift in normal industry procedures for assigning responsibility and liability for product quality. Procuring agencies should continue to expect suppliers of blended cement, coal fly ash or GGBFS, and concrete to demonstrate (through reasonable testing programs or previous experience) the performance and reliability of their product and the adequacy of their quality control programs.

1.2.2.2 Cenospheres and Silica Fume

For cement and concrete containing cenospheres, EPA advises that procuring agencies contact cenosphere suppliers to obtain specifications, such as material safety data sheets for assisting with use of cenospheres in cement and concrete.

For cement and concrete containing silica fume, procuring agencies can refer to the following national specifications and guidelines, which enable procuring agencies to buy high-performance concrete containing silica fume of a standard quality: ASTM C1240, AASHTO M307, and ACI 234R-06.[28] In addition, ACI 234R-06 also describes the properties of silica fume; how silica fume interacts with cement; the effects of silica fume on the properties of fresh and cured concrete; typical applications of silica fume concrete; and recommendations on proportions, specifications, and handling of silica fume in the field.

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[28] For more information, see: U.S. Department of Transportation, Federal Highway Administration (FHWA), April 2005. “Silica Fume Users Manual.” (Publication No. FHWA-IF-05-016)

1.3 RMCs Analyzed

The language in SAFETEA-LU defines RMCs as follows:

A. Ground granulated blast-furnace slag (GGBFS) (other than lead slag);[29]

B. Coal combustion fly ash;

C. Blast-furnace slag aggregate (BFSA or air-cooled blast-furnace slag) (other than lead slag aggregate);[30]

D. Silica fume; and,

E. Any other waste material or byproduct recovered or diverted from solid waste that the Administrator, in consultation with an agency head, determines should be treated as recovered mineral component under this section.

Based on a review of construction materials standards and other information collected from a range of industry sources, the Agency created and applied selected criteria to determine which other waste materials or byproducts recovered or diverted from solid waste, as identified under point "E" above, should be included in the study for evaluation. We have further determined that it is most beneficial to focus on materials that embody greater potential for beneficial use, and for which data currently exists. Therefore, to be included in this study, we concluded that a material should be evaluated against the following four screening criteria.

- Be a potential waste material or byproduct recovered or diverted from solid waste;
- Have a total annual generation greater than 0.9 million metric tons (1 million short tons);
- Be addressed in a national cement or concrete standard, (e.g., ASTM[31], ACI[32], or AASHTO[33]); and,

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[29] GGBFS is a product of the iron smelting process and is addressed in this evaluation, along with boiler slag from power plants and steel furnace slag. Lead slag is from an entirely different metallurgical source.

[30] EPA interprets the term "blast-furnace slag aggregate" to mean nongranulated blast-furnace slag that is used as aggregate in concrete as a replacement for other mineral aggregates. Steel furnace slag, made during the conversion of iron to steel and used primarily as an aggregate in base and asphalt, among other uses, and boiler slag, produced during the combustion of coal in power plants and used primarily in the manufacture of blasting grit, are addressed separately from blast-furnace slag. Pelletized slag works well as a lightweight aggregate (for lightweight concrete) and in mineral wool used in thermal and heat insulation.

[31] ASTM standards can be found in the "Annual Book of ASTM Standards," Available from ASTM International at www.astm.org. Construction materials standards are contained in *Section 4 – Construction*.

[32] American Concrete Institute, www.concrete.org.

[33] American Association of State Highway and Transportation Officials, www.transportation.org.

- Have data available which may be capable of supporting a more detailed analysis, including annual data on the quantity of material sent to cement or concrete manufacturers for five years up to 2004, and life cycle inventory data to support analysis of the substitution of the material using existing modeling platforms.

Based on our review of the available information, EPA identified the following additional materials for screening and possible evaluation as “other potential RMCs”:

- Foundry sand;
- Cenospheres;
- Flue gas desulfurization (FGD) gypsum;
- Flue gas desulfurization (FGD) dry scrubber material;
- Bottom ash from power plants;
- Boiler slag from power plants;
- Steel furnace slag; and
- Cement kiln dust (CKD).

EPA applied the screening criteria to the four materials identified by Congress, as well as the eight materials identified as “other potential RMCs.” Table 1-1 presents all of the mineral components considered for possible evaluation in this report, including those that did not meet all the screening criteria. Table 1-1 indicates that the four materials identified by the Congress generally satisfy the criteria. To make projections, it is important for the base year to be consistent across the RMCs. The 2004 quantity data represent the most recent year for which estimates for all four identified RMCs are available. A more detailed discussion of each material, including information on production, properties, and beneficial uses in cement and concrete production, is presented in Chapter 2.

While none of the “other potential RMCs” identified by EPA meets all four of the specified screening criteria, this report provides an initial summary of all materials screened. The summary describes the volumes generated and beneficially used, as well as the characteristics of the beneficial reuse markets for each of these materials. However, the quantitative assessment of energy and environmental benefits in this report is limited to three materials for which there are sufficient data and existing modeling frameworks: coal fly ash, GGBFS, and silica fume. Although data exist for BFSA, power plant bottom ash, and boiler slag, available modeling frameworks do not support analysis of their energy and environmental impacts. The three materials examined in detail (coal fly ash, GGBFS, and silica fume) are all among those specified as RMCs by the language in SAFETEA-LU.

Table 1-1: Mineral Components Screened for Inclusion in Report

Material	Estimated Annual Quantity Generated, 2004[a] *(million metric tons)*	Estimated Quantity Beneficially Used, 2004 *(million metric tons)*	Screening Criteria			
			Exists as By-product	**Produce > 0.9 million metric tons/year**	**Subject of National Standard[1]**	**Data Sufficient for Analysis**
RMCs NAMED BY CONGRESS						
Ground Granulated Blast-furnace Slag[b]	3.60	3.60	X	X	X	X
Coal Combustion Fly Ash [c]	64.20	25.50	X	X	X	X
Blast-furnace Slag Aggregate[b, d] (ACBF Slag)	8.10	8.10	X	X	X	[h]
Silica Fume [e]	0.10 – 0.12	0.08	X		X	X
OTHER RMCs IDENTIFIED BY EPA						
Foundry Sand [f]	8.50	2.40	X	X	X	
Cenospheres [c]	N.A.	0.0052 (sold only)	X	X		
Flue Gas Desulfurization (FGD) Gypsum [c]	10.80	8.20	X	X	X	
Flue Gas Desulfurization (FGD) Dry Scrubber Material [c]	1.70	0.16	X	X	X[g]	
Power Plant Bottom Ash [c]	15.60	7.40	X	X	X	[h]
Power Plant Boiler Slag [c]	2.00	1.80	X	X	X	[h]
Steel Furnace Slag [b]	9.00	9.00	X	X		X
Cement Kiln Dust (CKD) [i]	12.00 – 15.00	1.20 (excludes reuse back into kiln)	X	X		

Notes:

[a] The estimated annual quantity available does not reflect stockpiled quantities.

[b] van Oss, 2004b, values given are amount sold, as the industry does not report on actual production. These sales figures include imported materials. For example, an estimated one million tons of ferrous slag (i.e., granulated blast-furnace slag) were imported into the U.S. in 2004; of this, approximately 75% was then ground to produce GGBFS domestically prior to sale.

[c] ACAA, 2004. 2004 Coal Combustion Product (CCP) Production and Use Survey.

[d] BFSA, while categorized as an evaluated material, was not fully modeled due to data and modeling limitations. A modified assessment of BFSA benefits is presented in Appendix D.

[e] Kojundic, 8/30/2006

[f] Oman, Alicia. American Foundry Society (AFS). Personal communication September 18, 2007. Foundry Sand data are annual average for 2005/06.

[g] ASTM C1157 sets a performance-based standard for blended hydraulic cement. There are no restrictions on the composition of the cement. These materials may be used in a concrete project that allows use of ASTM C1157.

[h] While this information has recently become available, these materials have not been incorporated into current modeling platforms (e.g., BEES), and therefore are not included in the materials subject to a more detailed evaluation. However, as indicated above, a modified assessment of BFSA benefits is presented in Appendix D.

[i] van Oss, 2005 (total estimate). The industry does not report CKD production. A majority of this material is known to be recycled back into the kiln. According to PCA, in 2006 approximately 1.2 million metric tons was beneficially reused (other than in kilns) and 1.4 million metric tons was landfilled (PCA, 2006. Summary of 2006 Cement Kiln Dust and Clinker Production).

[1] The Agency recognizes that, in general, most raw materials (e.g., limestone, sand, clay) used in portland cement manufacture are not subject to a national standard. However, the characteristics and specifications of raw materials are generally understood and commonly accepted.

N.A.– Data not available.

Congress specifically excluded lead slag from this Report

2.0 INDUSTRY OVERVIEW, MATERIALS EVALUATED, AND CURRENT RMC SUBSTITUTION LEVELS

This section provides a summary of the production and beneficial uses associated with the RMCs identified in the Introduction (Section 1). This includes RMCs specifically identified by Congress for further study, as well as the "other potential RMCs" identified by EPA. These topics are consistent with Part (A) of the Congressional mandate, which instructs EPA to analyze "…the extent to which recovered mineral components are being substituted for portland cement, particularly as a result of current procurement requirements…."

The four mineral components identified by Congress include GGBFS, coal fly ash, BFSA, and silica fume. The other materials identified by EPA for consideration as RMCs include foundry sand, cenospheres, flue gas desulfurization (FGD) gypsum, flue gas desulfurization (FGD) dry scrubber material, power plant bottom ash, power plant boiler slag, steel furnace slag, and cement kiln dust (CKD). Descriptions and definitions of the materials and terms discussed in this section, and throughout the report, are provided in a glossary at the end of this report.

All of the materials examined in this section are currently being reused as material substitutes in the cement manufacturing process or the concrete mixing process (or both).[34] The degree to which these materials are being used in cement and concrete production ranges from relatively low (i.e., approximately 10% to 15%) to 100%. When used appropriately, these materials enhance the performance, handling, and durability of finished concrete products; this section qualitatively describes these benefits. In addition, the use of these materials in cement and concrete production yields a number of environmental and economic benefits, which we analyze and quantify in Section 3. Furthermore, using RMCs helps limit the amount of virgin material that must be mined or imported to meet U.S. demand for cement.

In its simplest form, concrete is a mixture of cementitious material, water, and aggregates. The principal cementitious material in concrete is portland cement. When portland cement is combined with water, a chemical reaction called hydration occurs that causes the cement and hence the concrete to harden and strengthen over time into a rock-like mass.

The concrete manufacturing process involves the production of portland cement and the mixing of cement with water and aggregates. This process can be summarized in the following steps:

- **Clinker Production**: Cement making raw materials are proportioned, crushed, and ground into a raw material mix or meal that is used to make portland cement (e.g., limestone, shale, clay, sand, iron, etc.) and then fed into a large rotary kiln. As the raw mix moves through the kiln, the temperature of the mix is gradually raised to 1400-1450 degrees Celsius, which cause

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[34] RMCs often have other applications as substitutes for aggregate in various applications (including concrete and unencapsulated uses, such as flowable fill and granular or stabilized road base) and other applications, such as blasting grit and soil amendments. However, consistent with the focus of the Congressional mandate, this report focuses on uses associated with cement and concrete.

volatiles (especially CO_2) to be given off, while the remaining chemical oxides in the mix recombine into new compounds that exhibit hydraulically cementitious properties. These new compounds ("cement or clinker minerals") exist together as semifused nodules of clinker that are up to about 4 inches in diameter.

- **Grinding**: The clinker is combined with other materials, such as gypsum, or another RMC, and fed into a cement mill where it is very finely ground into a powder-like consistency to form portland cement or blended cement.

- **Concrete Mixing**: Portland cement (plus any RMC incorporated as a partial substitute), fine and course aggregate, and water are mixed together in large drums to produce concrete. Soon after the aggregates, water, and the cement are combined, the mixture starts to harden. The concrete must be mixed thoroughly to coat all of the aggregate particles with cement paste.

The principal cementitious material in concrete is portland cement, but other supplementary cementitious materials (SCMs) can be used to partially offset portland cement in concrete. Some SCMs are called pozzolans, which by themselves do not have any cementitious properties, but when used with portland cement, react to form cementitious material. Other materials, such as slag, do exhibit cementitious properties. When SCMs are combined with portland cement in dry form prior to mixing in concrete, the result is a blended cement. Appendix A provides further technical detail on cement and concrete manufacturing.

2.1 RMCs Identified by Congress

2.1.1 Blast-furnace Slag

Blast-furnace slag is a byproduct of the process for smelting iron from iron ore. Various types of slags are produced when slagging agents (primarily limestone or dolomite) or fluxing materials are added to iron ores in blast furnaces to remove impurities. The fluxing process lowers the boiling point and increases the ore's fluidity. In the process of reducing iron ore to iron, a molten slag forms as a non-metallic liquid (consisting primarily of silicates and aluminosilicates of calcium and other bases) that floats on top of the molten iron. The molten slag is then separated from the liquid metal and cooled. Depending on the cooling process used, either granulated blast-furnace slag (GBFS) or BFSA is produced.

GBFS is produced by quickly quenching (chilling) molten slag to produce a glassy, granular product. The most common process is quenching with water, but air or a combination of air and water can be used. This rapid cooling allows very little mineral crystallization to take place and produces sand-sized particles of glassy material. When the cooled material is ground very finely into GGBFS, also known as slag cement, the disordered structure of the material gives it moderate hydraulic cementitious properties, meaning it will hydrate and gain strength when mixed with water, though at a much slower rate than portland cement. When used in concrete mixes with portland cement, however, the GGBFS combines with the free lime generated by partial portland cement hydration processes and hardens at an accelerated rate. When used in this manner, GGBFS develops strong hydraulic cementitious properties and can be used with portland cement in concrete manufacture. GGBFS can represent 20% to 80% of the total cementitious material used in concrete mixes, depending upon the application and engineering requirements. GGBFS is discussed in more detail in section 2.1.1.1.

Unground or less finely ground slag (GBFS) can also be used as aggregate in concrete mixes. Due to the greater cost of the granulation process compared to air-cooling, however, it is unlikely that newly created or high quality GBFS would be used in low-value applications, such as aggregate. The growing price for GGBFS further limits the opportunities for its use as an aggregate. Previously stockpiled or low-quality GBFS is more likely to be used as an aggregate.

BFSA, also referred to as air-cooled blast-furnace slag (ACBFS), is produced by allowing the molten slag to cool and solidify slowly under ambient (atmospheric) conditions. This is typically done by pouring the molten blast-furnace slag into pits for slow cooling. Once cooled, it is crushed, screened, and used as aggregate in applications, such as road base, concrete, asphalt concrete, rail ballast, roofing, shingles, mineral wool, and glass making. ACBFS also can be used as a raw material in clinker manufacture. This material is discussed in greater detail in section 2.1.1.2.

The iron and steel industries do not collect data on the total quantity of blast-furnace slag produced in the United States. The USGS estimates, however, that the quantity of blast-furnace slag produced is equivalent to 25% to 30% of crude iron (i.e., pig iron) production (van Oss, 2004b). In addition, USGS collects data on sales of slag. In 2004, U.S. sales of blast-furnace slag were valued at approximately $289 million. Most of the slag produced is air-cooled slag (approximately 75% by tonnage), with a lesser amount of granulated slag (approximately 25%) and a small amount of pelletized slag. Some is also used as lightweight aggregate for concrete. A significant quantity of the GGBFS sold in the United States is produced by grinding imported material.

USGS estimates that approximately one million metric tons of blast-furnace slag were imported into the United States in 2005, including about 760,000 metric tons of granulated slag. Table 2-1 summarizes the estimated total blast-furnace slag production in the United States for 2000 through 2005 (van Oss, 2006, unless otherwise noted). Table 2-1 also includes U.S. sales of GBFS and BFSA. Sales of GGBFS in 2004 were approximately 3.6 million metric tons out of a total GBFS sales of 4.1 million metric tons.

Table 2-1: U.S. Iron Blast-furnace Slag Domestic Production and Sales (iron only)

Year	Estimated Slag Production	Sales of GBFS	Sales of GGBFS (subset of GBFS)	Sales of BFSA (ACBFS)
	million metric tons			
2000	12.0–14.5	2.3*	2.0***	8.9
2001	10.5–12.5	2.3*	2.4***	8.1
2002	10.0–12.0	3.7	3.3 ** 2.9 ***	7.4
2003	10.0–12.0	3.6	3.5 ** 3.1 ***	7.3
2004	12.0–14.0	4.1	3.6 ** 3.5 ***	8.1
2005	9.0–11.0**	4.4**	3.7**	8.4**

* 2000 and 2001 sales were believed to be underreported
** van Oss, 2002, 2003, 2004, 2005, 2006.
*** National Slag Association Data, as reported by van Oss, 2002, 2003 and 2004b and Slag Cement Association, 2006.
Note: Sales of GGBFS includes imported material that is ground in the U.S.

As of December 31, 2005, 16 integrated steel mills located in nine different states were in operation in the United States (Wagaman, 2006).[35] According to USGS, 44 facilities were processing blast-furnace slag in the United States in 2004.[36] Five of these facilities produced GBFS (Wierton, West Virginia; South Chicago, Illinois; Gary, Indiana; Sparrows Point, Maryland; and Birmingham, Alabama). In addition, some grinding facilities only grind imported GBFS or are exploiting old slag piles from past years' production (van Oss, 2004b). Figure B-1 in Appendix B shows the geographic distribution of cement plants that use slag as a raw material in clinker production and blend slag into finished cement products. Also, a table containing additional information on these locations can be found in Appendix C.

2.1.1.1 Granulated Blast-furnace Slag (GBFS)[37]

According to the USGS, approximately 4.1 million metric tons of GBFS were sold in the United States in 2004 (see Table 2-2). The total value of these sales was approximately $236 million, the majority of which was represented by sales of GGBFS. Average sales prices for GBFS were $61.50 per metric ton, with a reported range of $22.05 per metric ton for unground GBFS to $71.65 per metric ton for GGBFS. This range does not include old, weathered GBFS from existing stockpiles that is sold as fine aggregate for a few dollars per metric ton. The prices for GBFS are rising, are much higher than for other slag types and GGBFS tends to sell for 75%-80% of the price of cement (von Oss, 2007). In 2004, approximately 91% of GBFS (3.73 million metric tons) was sold for cementitious uses. This included approximately 104,000 metric tons of GBFS used in the manufacture of clinker, and

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[35] An integrated steel mill is one that smelts iron ore into liquid iron in blast furnaces and uses basic oxygen furnaces to refine this iron into steel.
[36] Since slag producers can have contracts with multiple processors at the same location, some of these facilities might be doubled counted.
[37] Data presented in this section address GBFS, which includes ground and unground blast-furnace slag. Separate data are not available for GGBFS, but GGBFS is known to account for the majority of GBFS.

approximately 345,000 metric tons used in the manufacture of blended cement. The remaining GBFS sold for cementitious uses (3.28 million metric tons) was used directly in concrete as a substitute for portland cement. The majority of materials not sold for cementitious uses (i.e., the 9% of the 4.1 million metric tons sold in 2004) were old and poor quality material mined from existing slag piles; this material was sold for use as a fine aggregate (van Oss, 2004b). Although no data exist on the disposal or landfilling of blast-furnace slag, it is likely that the utilization of GBFS is nearly 100% of U.S. production, which reflects the high value of these materials as SCMs, aggregates, or components of blended cements. In fact, granulated slag is currently being imported into the U.S. in order to meet the needs of the U.S. construction industry.

Table 2-2 summarizes GBFS (both ground and unground) sales and usage in clinker and cement manufacture for 2000 through 2005 based on data from the USGS (van Oss, 2004, 2004b, 2003, 2003b, 2002, 2002b, 2001). GBFS usage in concrete is estimated by subtracting total usage in clinker and cement manufacture from total sales.

Table 2-2: Granulated Blast-furnace Slag (GBFS) Usage

Year	**Estimated GBFS Sales**	**GBFS Usage in Clinker Manufacture**	**GBFS Usage in Cement Manufacture**	**GBFS Usage in Concrete**
	---------------------------------*million metric tons*			-----------------------------------
2000	2.3*	--	0.303 0.105***	1.997**
2001	2.3*	--	0.300 0.154***	2.0**
2002	3.7	0.060	0.369 0.157***	3.271**
2003	3.6	0.017	0.333 0.157***	3.25**
2004	4.1	0.104	0.345 0.159***	3.651**
2005	4.4	0.144	0.521	3.735**

Source: USGS data
* 2000 and 2001 sales were believed to be underreported.
**Estimated by subtraction.
*** Slag Cement Association, 2006.

The primary benefit of using GGBFS as a SCM is that it allows the same amount of portland cement to yield more yards of concrete, increasing productivity and reducing the total quantity of portland cement required to meet demand for certain types of concrete. The beneficial properties of concrete mixes containing GGBFS include the following:

- **Strength Development:** Concrete containing GGBFS develops strength at a somewhat slower rate than concrete containing only portland cement, but ultimately can develop equivalent or even superior strength. The reduced early strength can be a concern where early strength development is important, such as for non-heat cured pre-cast concrete or where rapid repairs are sought on busy highway structures. Low temperatures generally have a more adverse impact on strength development with concrete containing GGBFS than concrete containing only portland cement. However, the higher ultimate strength development in concrete with GGBFS can allow for reductions in the portland cement component in a concrete mixture for a given ultimate (28-day) strength level.

- **Workability:** Concrete containing GGBFS as a partial cement replacement has longer-lasting workability and low slump loss during hot weather construction (though this can be a detriment during cold weather construction). Concrete containing GGBFS is also easier to finish.

- **Heat of Hydration:** Concrete with high replacement rates of GGBFS (i.e., approximately 70%) exhibits a lower heat of hydration than conventional portland cement concrete; this characteristic is an advantage for large mass concrete applications, but can be a disadvantage for some projects in colder climates.

- **Permeability**: Concrete containing GGBFS has significantly reduced permeability, which keeps moisture and harmful constituents out of the concrete

- **Corrosion Resistance**: The reduced permeability of concrete containing GGBFS can protect reinforcing steel in reinforced concrete from corrosion for much longer periods of time than concrete without GGBFS.

- **Alkali-Silica Reaction**: The use of GGBFS blended with portland cement in concrete reduces the alkali content of the cement paste and reduces permeability and water ingress, thus mitigating the potential of developing adverse reactions between alkalis in the cement paste and certain forms of silica present in some aggregates.[38]

- **Sulfate Resistance:** Use of GBFS with portland cement can give concrete moderate to high resistance to sulfate attack.

- **White Color**: GGBFS is a much lighter color than most other commonly used cementitious materials (i.e., grey portland cement, silica fume, coal fly ash). Thus, it measurably lightens the concrete and increases its solar reflectivity which provides benefits, such as greater safety at night, reduced lighting requirements, and preferred architectural finishes. It also can help reduce the urban heat island effect through higher albedo.

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[38] Holcim (US) Inc. commented that, in addition to the more common alkali-silica reaction, “alkali-aggregate reaction includes a particular, but little seen, reaction known as alkali-carbonate reaction,” and it was its “understanding that slag [i.e., GGBFS containing] concrete shows some effectiveness in resisting this form of alkali-aggregate reaction, but there is no large volume of work on the topic.”

According to the SCA, some laboratory testing has indicated that concrete containing GGBFS (and coal fly ash) might be more susceptible to salt scaling when deicer salts are applied and the concrete undergoes freeze-thaw cycling. On the other hand, other studies have not found this to be the case, or have even found improved performance. (Scaling is the loss of a thin layer, usually less than 1/4 inch of surface paste/mortar, sometimes exposing larger aggregates beneath.) To clarify this issue, FHWA and SCA, in conjunction with the Iowa State University's Center for Portland Cement Concrete Pavement Technology (PCC Center) are collaborating on a project to document the performance of GGBSF-containing concrete exposed to cyclical freeze-thaw cycles in the presence of deicing chemicals.[39]

2.1.1.2 Blast-furnace Slag Aggregate (Air-Cooled Blast-Furnace Slag)

BFSA, also known as air-cooled blast-furnace slag, emerges from iron furnaces in a molten state and is air-cooled. It is produced by pouring molten blast-furnace slag into outdoor pits and allowing it to cool and solidify slowly under atmospheric conditions. Small quantities of water are sprayed on top to induce fractures during the final cooling stages. Once cooled, BFSA is crushed and screened to produce a material similar to gravel that is used as a construction aggregate for road base, concrete, asphalt, rail ballast, roofing, granules for roofing shingles, and glass making.

Sales of BFSA for all uses for 2003 and 2004 are shown in Table 2-3. In 2004, BFSA sales were 8.1 million metric tons, with a total value of $49 million. Average sales prices of BFSA in 2004 were $6.50 per metric ton, with a range of $1.54 to $17.35 per metric ton. Total usage of BFSA in cement and concrete products (including clinker manufacture) for 2004 was approximately 2.08 million metric tons, which accounts for about 26% of annual U.S. sales.

Table 2-3: Sales of Blast-furnace Slag Aggregate (BFSA) by Use in 2003 and 2004

	2003		**2004*****	
BFSA Use	**Percent**	**Quantity** (million metric tons)	**Percent**	**Quantity** (million metric tons)
Ready-Mixed Concrete	9.3	0.68	20.4	1.65
Concrete Products	6.4	0.47	3.5	0.28
Clinker Raw Material	5.7	0.42	1.9	0.15
Other Uses*	78.6	5.73	74.2	6.00
Total**	**100**	**7.3**	**100**	**8.1**

Source: van Oss, 2004b

* Primarily as construction aggregate for granular and bound road base and asphalt road surfaces.

** Data may not add to total due to rounding. Data reporting on slag uses is biased towards major uses.

*** Recently received data show a total of 7.3 million metric tons of BFSA were sold in 2006, indicating declining usage.(Pulipaka, Aswani S., et.al.)

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[39] For more information, refer to: American Concrete Institute, "Proposed Changes to ACI 318-05" accessible at: http://www.concrete.org/Technical/FlashHelp/Proposed_Changes_to_318-05.htm.

As indicated in Table 2-3, 100% of BFSA is currently believed to be utilized[40], with its largest use as aggregate in road bases and surfaces, including use in asphaltic concrete. Its next largest use is primarily as an aggregate in concrete mixes and aggregate base (20.4% in 2004). When used in this capacity, it reduces the need to quarry, crush, sort, and transport virgin aggregate. Small amounts of BFSA also are used to replace raw feed in the clinker production process (less than 2% in 2004) and used as an aggregate in concrete products (3.5% in 2004).

2.1.2 Coal Fly Ash

Coal fly ash is the finely divided airborne mineral residue generated by the combustion of ground or powdered coal in coal-fired power plants. Four basic types of coal-fired boilers operate in the United States: 1) pulverized coal (PC) boilers, 2) stoker-fired or traveling grate boilers, 3) cyclone boilers, and 4) fluidized-bed combustion (FBC) boilers. The PC boiler is the most widely used, especially for large electric generating units. The other boilers are more common at industrial or cogeneration facilities. Typically, in a PC boiler, coal is pulverized and blown with air into the boiler's combustion chamber where it immediately ignites, generating heat and producing a molten mineral residue. Boiler tubes extract the heat from the boiler, cooling the flue gas and causing the molten mineral residue to harden and form ash. Coarse ash particles, referred to as bottom ash or boiler slag, fall to the bottom of the combustion chamber, and the lighter fine ash particles (coal fly ash) remain suspended in the flue gas. Prior to exhausting the flue gas to the atmosphere, coal fly ash is removed by particulate emission control devices, such as electrostatic precipitators or fabric filtration baghouses.

According to the ACAA survey data, of the 64.2 million metric tons of coal fly ash produced in the United States in 2004, approximately 40% (25.5 million metric tons) was beneficially used, while the remaining 60% (approximately 38.8 million metric tons) was disposed of in land disposal units. Utilization of coal fly ash has increased through 2006 to nearly 45%. Table 2-4 illustrates the major uses of coal fly ash for the years 2002 through 2006.

Table 2-4: Major Uses of Coal Fly Ash

	Year				
	2002	**2003**	**2004**	**2005**	**2006**
Production and Usage	--------------------*million metric tons*----------------------				
Total U.S. Production	*69.401*	*63.640*	*64.230*	*64.502*	*65.680*
Utilization:					
Concrete/Concrete Products/Grout	11.412	11.127	12.811	13.599	13.645
Cement/Raw Feed for Clinker	1.740	2.744	2.128	2.571	3.765
All Other Uses	11.006	10.388	10.525	10.246	12.004
Total Utilization	*24.158*	*24.259*	*25.464*	*26.416*	*29.414*
Percent Utilization	34.8%	38.1%	39.6%	41.0%	44.8%

Source: ACAA, 2002, 2003, 2004, 2005, and 2006.

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[40] Recently identified data indicate that BFSA may be utilized at less than 100% of generation. However, these data are from the year 2000 (Pulipaka, A. S., et. al., undated).

Typically, coal fly ash is used in construction applications. Both Class C and F coal fly ash can serve as substitutes for conventional materials in construction projects.[41] The most common beneficial use of coal fly ash is as a SCM in concrete. Coal fly ash is also used as a raw material in the production of cement clinker and as an additive to blended cements. The consistency and abundance of coal fly ash in many areas present unique opportunities for use in many construction applications, including pavements and highway and transportation structures, and can generate environmental benefits when used as a replacement for virgin materials (e.g., portland cement). Reported coal fly ash generation and use in cement manufacture and in concrete for the years 2000 through 2006 are summarized in Table 2-5.

Table 2-5: Coal Fly Ash Generation and Sales for Utilization in Cement, Clinker, and Concrete

Year	**Coal Fly Ash Generation (ACAA)**	**Coal Fly Ash Utilization in Cement and Clinker Manufacture**		**Coal Fly Ash Utilization in Concrete (ACAA)**
		USGS	**ACAA**	
	-------------------------------------*million metric tons*-------------------------------			
2000	No Data	1.77	No Data	No Data
2001	61.8	1.67	0.94	11.2
2002	69.4	2.02	1.74	11.4
2003	63.6	2.29	2.74	11.1
2004	64.2	2.97	2.13	12.8
2005	64.5	3.10	2.57	13.6
2006	65.7	------	------	13.6

Sources: ACAA, USGS, and van Oss, 2001, 2002b, 2003b, 2004; ACAA, 2001, 2002, 2003, 2004, 2005, 2006.

Certain performance benefits can be attained through the use of coal fly ash in concrete, including greater workability, higher strength, and increased longevity in the finished concrete product. Specifically:

- Spherical particle shape allows the coal fly ash to flow and blend freely in mixtures improving mixing and handling.
- Ball bearing effect creates a lubricating action when concrete is in its plastic state; as a result, pumping is easier because less energy is required and longer pumping distances are possible.
- Strength increases as it continues to combine with free lime, increasing the structural strength over time.
- Reduced permeability and increased durability.
- Reduced shrinkage from the lubricating action of coal fly ash reduces water content and drying shrinkage.

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[41] The chemical composition of coal fly ash varies greatly depending on the type of coal used. Two types of coal fly ash, Class C fly ash and Class F fly ash, are included in the American Society for Testing and Materials' technical requirements for concrete. Information on these standards is available at <www.astm.org>. Additional information on coal fly ash is provided in Appendix B. Other coal fly ash classification standards are being considered to facilitate the best uses for coal fly ash. Examples include the CSA Canadian standards.

- Reduced heat of hydration reduces thermal cracking (e.g., for dams and other mass concrete placements).
- Improved workability makes concrete easier to place.
- Where sharp, clear architectural definition is easier to achieve, finishing is improved with less concern about in-place integrity.
- Reduced susceptibility to chemical attack (e.g., sulfate attack) (IEA, 2005).

There are a few potential issues with the use of coal fly ash in concrete, including:

- Lack of uniformity and consistency between coal fly ash sources, possibly requiring users to test each source.
- Slower setting and early-are strength gain in cool weather concreting.
- Loss of air entrainment caused by the fine structure of coal fly ash and/or residual unburned carbon content; this property requires additional air entrainment to maintain concrete strength and durability.
- Reduced freeze/thaw and scaling resistance is possible when a major part of the cementitious material is replaced with coal fly ash. However, if the strength and air-void properties of the concrete mixture are kept constant, no major effect on the freeze-thaw resistance has been observed.
- Reduced abrasion resistance in concrete mixtures where coal fly ash comprises greater than 50% of the cementitious material. Concrete mixtures with coal fly ash representing less than 40% of the cementitious material show no decrease in abrasion resistance.

2.1.3 Silica Fume

Silica fume, also referred to as microsilica or condensed silica fume, is a very fine, dust-like material generated during silicon metal and ferrosilicon and related ferroalloys production. Specifically, it is produced by the reduction of high purity quartz with coal or coke and wood chips in an electric arc furnace during silicon metal or ferrosilicon alloys production. The glassy, spherical particles are extremely small, measuring less than 1 micrometer (μm) in diameter, with an average diameter of about 0.1 μm. Silica fume particles are composed primarily of silicon dioxide (usually more than 85%). The silica fume is collected in electric arc furnace stack filters and recovered for reuse as a pozzolan in high performance concrete (HPC). Silica fume is sold in the United States in powder form and is often made denser by tumbling it in a silo, which leads to the build-up of surface charges and an agglomeration of particles.

ACI estimates that global silica fume production is approximately 900,000 metric tons per year and that at least 120,000 metric tons are used in concrete worldwide (ACI, 2006). The SFA estimates that silica fume production in the United States in 2004 was between 100,000 and 120,000 metric tons. Of that amount, an estimated 20,000 metric tons were used in clinker manufacturer, while less than 3,000 metric tons were used in blended cement production and approximately 60,000 metric tons were used in concrete manufacture. The SFA also estimates that about 25,000 metric tons of silica fume were landfilled in 2004 and that less than 16,000 metric tons will be landfilled in 2006 in the U.S. (Kojundic, 2006).

Table 2-6 summarizes silica fume production and usage in cement and concrete for the years 2000 through 2004.

Table 2-6: U.S. Silica Fume Production and Usage in Cement and Concrete

	Year				
	2000	**2001**	**2002**	**2003**	**2004**
	---------------------------------*metric tons*---				
Production	No Data	No Data	No Data	No Data	100,000 - 120,000
In Clinker	18,000	19,000	19,000	19,000	20,000
In Cement	No Data	No Data	No Data	No Data	<3,000
In Concrete	55,000	56,000	51,000	53,000	60,000

Source: The Silica Fume Association accessed at www.silicafume.org and Kojundic, 8/30/2006.

Silica fume's physical and chemical properties confer several benefits to finished concrete when used with portland cement in concrete mixes, including:

- **Increased compressive strength and abrasion resistance:** Significant improvements in compressive strength can be realized through the addition of silica fume to concrete, making silica-fume concrete particularly useful in applications, such as columns in high-rise buildings, girders in HPC bridges, and abrasion-resistant pavements or floors.

- **Reduced Bleeding**: Silica fume reduces the bleeding in concrete that leads to the formation of capillary channels, which can increase chloride intrusion in finished concrete. Eliminating bleeding also allows concrete to be finished earlier.

- **Permeability**: Reduced permeability of concrete containing silica fume limits intrusion of chloride ions from deicing chemicals and helps resist attack from chemicals, such as sulfates leading to increased durability.

- **Corrosion Resistance**: Reduced chlorine ion intrusion protects the reinforcing steel from corrosion and helps extend the life of structures.

- **Single-Pass (One-Pass) Finishing**: Silica fume concrete can utilize single-pass finishing whereby the finishing is condensed into a single operation that shortens finishing time.

Increased modulus of elasticity (with use of silica fume), however, makes the concrete more brittle and can result in additional cracking.

2.2 Other RMCs Evaluated

The discussion below reviews the generation and beneficial use of the "other potential RMCs" selected for this analysis. These RMCs were identified through the screening procedures described in Section 1.3.

2.2.1 Foundry Sand

Foundry sand is high-quality silica sand used in the production of both ferrous and nonferrous metal castings. The physical and chemical characteristics of foundry sand depend on the type of casting process and industry sector from which it originates. Industry sources estimate that approximately 90 million metric tons of foundry sand are used in production annually. Of that amount, approximately 8.5 million metric tons of foundry sand are discarded as "spent" in a year; the remainder is recycled and put back and reused in the foundry process. A survey by the American Foundry Society (AFS) estimates that 2.4 million metric tons of the spent foundry sand were beneficially used, suggesting that about six million metric tons may be available to be recycled into other products or used by other industries (U.S. EPA, 2007). A small percentage (approximately 2%) of the spent foundry sand are considered hazardous waste due to metal contaminants (U.S. EPA, 1998).

Some spent foundry sands that use organic binders also have been found to contain trace amounts of hazardous organic compounds, though most of these constituents have been found to be well below regulatory levels (U.S. EPA, 2002).

Spent foundry sand can be used in the manufacture of portland cement clinker. Most foundry sands are high in silica content and can serve as a potential alternative silica source in portland cement clinker production. In addition, portland cement clinker production requires certain minerals, such as iron and aluminum oxides, both of which are found in many spent foundry sands. Some foundry sands however, can have materials in it that are not appropriate for use in kilns and therefore may not be utilized.

Combined data for total quantities of sand and calcium silicate used in the production of cement clinker in the United States are available from the USGS for the years 2000 through 2004 and are provided in Table 2-7 (van Oss, 2004, 2003b, 2002b, 2001). These data may include the beneficial reuse of spent foundry sand, although the industry does not identify the quantity of spent foundry sand being used in cement kilns. The tonnages shown in Table 2-7 primarily consist of silica sand, as the amount of calcium silicates is generally insignificant (USGS, 2001-2004).

Table 2-7: Sand and Calcium Silicate Utilization in Cement Kilns

	Year				
	2000	**2001**	**2002**	**2003**	**2004**
	-------------*million metric tons*----------				
Sand and Calcium Silicate Used	3.142	3.500	2.960	2.860	3.150

Source: USGS, 2001 – 2004 (van Oss, 2004, 2003b, 2002b, 2001).

Spent foundry sand can be reused to replace virgin sand in both the cement clinker manufacturing process and in concrete mixing. The use of spent foundry sand eliminates the need to mine and mill virgin materials, saving energy and other resources. However, the amount of available foundry sand varies widely by region of the country. In many regions, foundry sand is not available in the quantities necessary for controlled production processes.

2.2.2 Cenospheres

Cenospheres are very small (10 to 350 μm in diameter), inert, lightweight, hollow, "glass" spheres composed of silica and alumina filled with air or other gases. They occur naturally in coal fly ash and are recovered from the ash for use as aggregate (filler) in many applications such as concrete and plastic products. Cenospheres are not usually intentionally manufactured. Their principal source is coal fly ash. The characteristics of and amount of cenospheres produced in coal fly ash varies depending upon the type of coal used, the plant type, and the firing conditions under which the spheres are formed.

The percentage of cenospheres used in concrete varies depending on the application and desired performance characteristics of the concrete. However, according to industry sources, the typical content of cenospheres in concrete ranges from 10% to 40% by volume. Concrete containing cenospheres also often contains coal fly ash.

ACAA began reporting cenosphere sales in its annual coal combustion product production and use survey in 2004. ACAA reports that approximately 5,200 metric tons of cenospheres were sold in the United States in 2004, 7,000[42] metric tons were sold in 2005, and 5,000 metric tons were sold in 2006. Actual annual cenosphere production is much greater than the volumes being sold, as not all cenospheres are separated from the coal fly ash for use. No current data are available on annual cenosphere production, and it is questionable whether sufficient data exist to allow a meaningful estimate of the cenosphere content of airborne particulates (i.e., percent of cenospheres to weight of coal fly ash). However, ACAA indicated that between 570,000 and 2,900,000 metric tons of cenospheres were generated in 1998 in the United States, of which 23,000 to 41,000 metric tons were separated from coal fly ash and recycled (EPA, 2004). Cenospheres that are not separated and reused are recycled or landfilled with the coal fly ash from which they are derived.

When incorporated into concrete mixes as fillers or extenders, cenospheres increase the strength of the concrete and decrease shrinkage and weight. However, cenospheres may also react in the concrete. Cenospheres are 75% lighter than other minerals currently used as fillers, which reduces the final concrete mix's weight and increases their thermal stability and overall durability. Cenospheres can be used in concrete with other recovered materials, such as coal fly ash and silica fume.[43]

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[42] This is an adjusted figure. The 2005 ACAA report: "2005 Coal Combustion Product (CCP) Production and Use Survey" erroneously reported this figure as 70,918 metric tons (78,174 U.S. tons).

[43] Cenospheres also are often used in other industrial filler applications replacing other filler materials, such as manufactured glass, calcium carbonate, clays, talc, and other silicas.

2.2.3 Flue Gas Desulfurization (FGD) Materials

Flue gas desulfurization (FGD) byproducts are generated by air pollution control devices used at any sulfur dioxide (SO_x) producing emissions source that has an appropriate scrubber, like some coal-fired electric power plants. Power plants and other types of facilities (e.g., some cement plants) use a number of FGD processes to control sulfur oxide (SO_x) emissions from the combustion of coal. FGD processes spray lime or limestone reagents into the exhaust gas, which removes and converts the SO_2 to sludge or a semi-sludge byproduct. In 2006, more than 27 million metric tons of FGD byproducts were produced in the United States (ACAA, 2006).

FGD processes are characterized as either wet or dry processes. Wet FGD scrubbers use aqueous solutions of either slaked lime (calcium hydroxide, $Ca(OH)_2$), or limestone (principally calcium carbonate, $CaCO_3$) to saturate the exhaust gas in a spray tower. These solutions react with and oxidize the SO_2 particles creating a byproduct known as scrubber sludge. Dry FGD systems use less water and generate a byproduct with different attributes.

Two types of wet FGD processes are used today—natural oxidation and forced oxidation. In natural oxidation, only the oxygen naturally occurring in the flue gas is used to remove SO_2. The resulting byproduct consists mostly of calcium sulfite ($CaSO_3$). In forced oxidation, additional air is supplied by blowers, which creates a byproduct consisting primarily of calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), or gypsum. While FGD sludge produced using natural oxidation has limited beneficial use options, gypsum from forced oxidation (also referred to as synthetic gypsum) is readily used as a direct replacement for natural gypsum in wallboard production and grinding with clinker to produce finished cement. The Portland Cement Association (PCA) reports that in 2005, 21 portland cement plants were using FGD sludge in the manufacture of cement (see Appendix B, Figure B-8) (PCA, 2005).

Table 2-8 summarizes FGD production for the years 2001 through 2006 (ACAA, 2001, 2002, 2003, 2004, 2005, and 2006). Additional discussion of the production and uses for FGD gypsum and dry scrubber material can be found in the sections that follow. FGD sludge from natural oxidation processes is not discussed further, as this material has seen little use in cement manufacture or in concrete.

Table 2-8: U.S. Flue Gas Desulfurization (FGD) Material Production

Year	Wet Scrubber Material		FGD Dry Scrubber Material	Other FGD	Total FGD
	Forced Oxidation (FGD Gypsum)	Natural Oxidation ($CaSO_3$)			
	----------------------------------*million metric tons*-----------------------------				
2001*	No Data	No Data	No Data	No Data	**25.840**
2002	10.342	15.332	0.849	--	**26.522**
2003	10.796	15.740	1.310	0.152	**27.998**
2004	10.841	15.876	1.660	0.105	**28.482**
2005	10.864	16.057	1.295	--	**28.216**
2006	10.977	14.787	1.351	0.271	**27.386**

Source: American Coal Ash Association (ACAA), 2001, 2002, 2003, 2004, 2005, and 2006.
* No breakout of FGD materials by type was reported for 2001.

2.2.3.1 Flue Gas Desulfurization (FGD) Gypsum

According to ACAA, U.S. coal-fired power plants produced approximately 11.0 million metric tons of FGD gypsum in 2006, with approximately 8.7 million metric tons being reused—approximately 79%. Of this amount, approximately 81% is used in wallboard manufacturing, about 16% is used in concrete, concrete products and grout, and about 3% is interground with clinker to produce finished cement. This indicates that while there is FGD gypsum available for increased use, only a minimal amount may potentially be used in cement and concrete. Table 2-9 summarizes ACAA data on the production and utilization of FGD gypsum for the years 2002 through 2006 (ACAA, 2002, 2003, 2004, 2005, 2006).

Table 2-9: FGD Gypsum Production and Utilization

Production and Usage	Year				
	2002	2003	2004	2005	2006
	---------------------*million metric tons*----------------------				
Total Production	*10.3421*	*10.7957*	*10.841*	*10.8637*	*10.9769*
Utilization					
Concrete/Concrete Products/Grout	0.0550	0.0595	0.2644	0.2982	1.3988
Cement/Raw Feed for Clinker*	0.2756	0.3811	0.4074	0.3608	.2400
All Other Uses (primarily wallboard)	6.7183	7.0883	7.5338	7.7493	7.0352
Total Utilization	*7.0489*	*7.5289*	*8.2056*	*8.4083*	*8.6740*
Percent Utilization	68.2%	69.7%	75.7%	77.4%	79.0%

* FGD Gypsum is primarily interground with clinker to produce finished cement, not as a raw feed in clinker production.
Source: ACAA, 2002, 2003, 2004, 2005, and 2006.

The availability of FGD gypsum is expected to grow as more scrubbers are installed nationally, potentially allowing for increased use. According to DOE, Energy Information Administration (DOE EIA-767), 32 facilities reported that they produced approximately 9.4 million metric tons of FGD gypsum in 2004 (DOE, 2004). Table B-5, found in Appendix B, indicates production and disposition of FGD gypsum by state for 2004. Also, a listing of FGD gypsum producers in 2004 is contained in Appendix C.

The handling of FGD gypsum can be problematic because it is abrasive, sticky, compressible, and much finer than natural gypsum. These difficulties are often offset by the resource's proximity to manufacturing facilities. While the majority of FGD gypsum produced is used in wallboard production, a small percentage is used in finished cement products. In the cement production process, FGD gypsum use has the benefit of replacing virgin gypsum that is ground with clinker to regulate the setting time of finished portland cement. Gypsum cement, a strong type of plaster, can also be made from FGD gypsum.

2.2.3.2 Flue Gas Desulfurization (FGD) Dry Scrubber Material

Dry FGD systems remove SO_2 emissions, such as from coal-fired power plant flue gas by contacting a lime or limestone sorbent slurry. The most common dry FGD design is the spray dryer system in which a slaked lime slurry is sprayed into the flue gas. The dry FGD process still uses water, although much less than wet processes, and it does not saturate the flue gas as the wet processes do. The resulting byproduct, formed by the reaction of the slurry and SO_2, is dried by the heat of the flue gas and collected with the coal fly ash in a particulate control device (either a fabric filter/baghouse or an electrostatic precipitator). Some dry FGD byproducts can contain high concentrations of sulfur materials that may form ettringite, a hydrophilic material, which expands when hydrated. As a result, these byproducts may not be suitable for use in concrete and are not suitable for foundation or paving use.

In 2006, about 1.35 million metric tons of dry FGD materials were produced in the United States (ACAA, 2006) and about 9,000 metric tons of dry FGD material was used in concrete products. The material not reused is primarily stored and/or disposed of in land disposal units. Table 2-10 summarizes dry FGD material production and usage for the years 2002 through 2006 (ACAA, 2002, 2003, 2004, 2005, 2006).

Table 2-10: Dry Flue Gas Desulfurization (FGD) Material Production and Usage

Production and Usage	**Year**				
	2002	**2003**	**2004**	**2005**	**2006**
	----------------------*thousand metric tons*------------------				
Total Production	*848.6*	*1,310.2*	*1,660.0*	*1,294.8*	*1,350.8*
Utilization					
Concrete/Concrete Products/Grout	32.1	31.1	33.9	12.7	8.7
Cement/Raw Feed for Clinker	2.7	2.2	--	--	--
All Other Uses	302.1	145.9	127.1	131.7	115.2
Total Utilization	*336.9*	*179.2*	*161.0*	*144.4*	*123.9*
Percent Utilization	39.7%	13.7%	9.7%	11.2%	9.2%

Source: ACAA, 2002, 2003, 2004, 2005, and 2006.

2.2.4 Power Plant Bottom Ash

Power plant bottom ash is the coarse, solid mineral residue that results from the burning of coal in utility boilers. The material is removed from the bottom of the boilers either in a wet or dry state and transported to handling areas by conveyor or pipe. Bottom ash has a similar chemical composition to coal fly ash, but is produced in size grades ranging from fine sand to medium gravel. Although larger in particle size, bottom ash has a smaller reactive surface area than coal fly ash. Because of its much larger particle sizes, bottom ash has a smaller total reactive surface area, for the same weight, as coal fly ash. With this and other characteristics, bottom ash does not have sufficient cementitious properties to be used as a replacement for cement, although it can be used in clinker manufacture as an alternative source for silica, alumina, iron and calcium.

Due to its salt content and, in some cases, its low pH, bottom ash also can exhibit corrosive properties (FHWA, 1998). As a result, the potential for corrosion of metal structures that come into contact with bottom ash should be evaluated when using this material in structural applications.

In 2006, nearly 17 million metric tons of bottom ash were produced in the United States, 7.6 million metric tons of which were beneficially used (ACAA, 2006). Table 2-11 summarizes bottom ash production and usage in clinker production and concrete for the years 2002 through 2006 (ACAA, 2002, 2003, 2004, 2005, 2006).

Table 2-11: Power Plant Bottom Ash Production and Utilization

Production and Utilization	**Year**				
	2002	**2003**	**2004**	**2005**	**2006**
	--------------------*million metric tons*----------------------				
Total Production	*17.963*	*16.420*	*15.604*	*15.967*	*16.874*
Utilization					
Concrete/Concrete Products/Grout	0.369	0.271	0.716	0.926	0.542
Cement/Raw Feed for Clinker*	0.531 0.990[a]	0.448 1.100[a]	0.558 1.050[a]	0.852 1.210[a]	0.840
All Other Uses	6.076	6.763	6.122	5.064	6.219
Total Utilization	*6.976*	*7.482*	*7.396*	*6.842*	*7.601*
Percent Utilization	38.8%	45.6%	47.4%	42.9%	45.0%

*Bottom ash used only in clinker production.

[a] USGS 2006.

Source (unless noted): ACAA, 2002, 2003, 2004, 2005, and 2006.

In contrast to the above data from ACAA, data from DOE EIA-767 indicate that approximately 20.4 million metric tons of bottom ash were produced at 410 facilities reported to produce bottom ash in 2004 (DOE 2004).

Bottom ash can be used as a replacement for aggregate in concrete and is usually sufficiently well graded in size to avoid the need for blending with other fine aggregates to meet gradation requirements. The porous surface structure of bottom ash particles make this material less durable than conventional aggregates and better suited for use in base course and shoulder mixtures or in cold mix applications, as opposed to wearing surface mixtures. The porous surface structure also makes this material lighter than conventional aggregate and useful in lightweight concrete applications. Bottom ash also can be used as a raw material in clinker production as an alternative source of silica, alumina, iron, and calcium.

2.2.5 Power Plant Boiler Slag

Boiler slag is a byproduct of the combustion of coal in power plants. It is produced in wet-bottom boilers, which have a solid base with an orifice that can be opened to allow the molten ash that has collected at the base to flow into an ash hopper below. There are two types of wet-bottom boilers—slag-tap boilers and cyclone boilers. Slag-tap boilers burn pulverized coal (coal ground to a fine powder so that at least 70% passes through a 200-mesh sieve), while cyclone boilers burn crushed coal (coal milled to 0.25 inch maximum size) (Bolumen). In each of these types of boilers, the bottom ash is kept in a molten state and tapped off as a liquid. This molten slag is quenched with water, which causes it to fracture instantly, crystallize, and form pellets. The resulting power plant boiler slag, often referred to as “black beauty,” is a coarse, hard, black, angular, glassy material (FHWA, 1998). Owing to its abrasive properties, power plant boiler slag is used in the manufacture of blasting grit and roofing granules for asphalt shingles. However, smaller amounts of it also are used (or have been used) as an aggregate in concrete and as a raw feed for clinker production. In 2005, about 38,600 metric tons (approximately 2% of all power plant boiler slag used) were used as a raw feed in clinker production.

Utilization of power plant boiler slag, as a percentage of production, is the highest among all coal combustion products. In 2006, nearly 84% of all power plant boiler slag was beneficially used (ACAA, 2006); down from a high of nearly 97% in 2005 (ACAA, 2005). Though power plant boiler slag is in high demand for beneficial use, its supplies are expected to decrease in the future due to the removal from service of the aging power plants that produce it. Table 2-12 summarizes U.S. production and usage of power plant boiler slag for the years 2002 through 2006 (ACAA, 2002, 2003, 2004, 2005, 2006).

Table 2-12: Boiler Slag Production and Utilization

	Year				
	2002	**2003**	**2004**	**2005**	**2006**
Production and Utilization	------------------*million metric tons*----------------------				
Total Production	*1.741.4*	*1.6658*	*1.9979*	*1.7757*	*1.8380*
Utilization					
Concrete/Concrete Products/Grout	0.0082	0.0144	-	-	-
Cement/Raw Feed for Clinker*	-	0.0143	0.0304	0.0386	0.0161
All Other Uses	1.3979	1.5643	1.7599	1.6767	1.5179
Total Utilization	*1.4061*	*1.5930*	*1.7903*	*1.7153*	*1.5340*
Percent Utilization	80.7%	95.6%	89.6%	96.6%	83.46%

* Boiler slag is used only in clinker production.
Source: ACAA, 2002, 2003, 2004, 2005, and 2006.

PCA (2005b) reported that 21 portland cement plants utilized power plant bottom ash and power plant boiler slag in the production of clinker in 2005 (no further breakout by material type was provided). Figure B-9 in Appendix B shows the locations of these plants.

2.2.6 Steel Furnace Slag

Steel furnace slag, commonly referred to as steel slag, is a byproduct from either the conversion of iron to steel in a basic oxygen furnace (BOF) or the melting of scrap to make steel in an electric arc furnace (EAF). Similar to iron blast-furnace slag, steel slag is produced when slagging agents and/or fluxing materials are added to molten metals to remove impurities. Unlike iron blast furnaces, steel furnaces typically use lime as the slagging agent instead of limestone and /or dolomite. The liquid silicate slag floats on the molten metal and is separated and cooled. Steel slag is cooled in pools in a similar fashion as BFSA from iron blast furnaces.

No reliable data exist on the amounts of steel slag produced annually in the United States because not all of the slag produced during steel production is tapped, and the amount of steel slag tapped is not routinely measured. Hendrik G. van Oss (2005) estimates, however, that steel slag production is between 10% and 15% of crude steel output. This estimate translates to 11 million to 16 million metric tons produced in 2004, of which nine million metric tons were sold for reuse (van Oss, 2004b). Table 2-13 summarizes steel slag production and usage for the years 2000 through 2005, as well as steel slag usage in cement and clinker manufacture (Kalyoncu, 2001; van Oss 2002, 2002b, 2003, 2003b, 2004, 2004b). In 2004, total U.S. steel slag sales were valued at about $39 million. Sales prices for steel slag ranged from $0.22 to $7.89 per metric ton, with an average of $4.32 per metric ton (van Oss 2004b).

Table 2-13: U.S. Steel Slag Production and Usage

Year	Estimated Steel Slag Production	Estimated Steel Slag Sales	Steel Slag Usage in Cement and Clinker Manufacture
	------------------------------*million metric tons*--------------------------------		
2000	No Data	5.2	0.805
2001	No Data	6.5	0.500
2002	9-14	8.0	0.481
2003	9-14	8.8	0.448
2004	11-16	9.0	0.401
2005	10-14	8.7	0.525

Source: Kalyoncu, 2001; van Oss, 2002, 2002b, 2003, 2003b, 2004, and, 2004b.

According to USGS, steel slag was processed at 99 locations in the United States in 2004. Some duplication in these locations exists, since steel slag producers can have contracts with multiple processors at the same location (van Oss, 2004b). Table 3 in Appendix C contains additional information on these locations.

Steel slag has been successfully used as a raw material substitute in clinker manufacturing. The economic and environmental benefits of the utilization of steel furnace slag in Portland cement manufacturing may include energy savings, decreased CO_2 and NO_X emissions, and increased production capacity.

Because of its expansive characteristics, steel slag is not typically used as an aggregate in concrete for fixed-volume applications. Steel slag is useful as an aggregate in granular base applications,[44] and can be processed into a coarse or fine aggregate material for use in hot mix asphalt concrete pavements and in cold mix or surface treatment applications.

2.2.7 Cement Kiln Dust (CKD)

CKD is the fine-grained, solid, highly alkaline material removed from the cement kiln exhaust gas by scrubbers (filtration baghouses and /or electrostatic precipitators). The composition of CKD varies among plants and over time at a single plant. Much of the material comprising CKD is actually incompletely reacted raw material, including a raw mix at various stages of burning, and particles of clinker.

Because of the high percentage of raw mix and clinker in CKD, large amounts are put back into the production process through closed loop processes. CKD not returned to the production process is either landfilled or sold for other beneficial uses (PCA, 2006).

Because of the high rate of direct reuse, CKD generation rates are not routinely measured, and limited data are available. One recent estimate, based upon informal conversations with U.S. cement kiln industry personnel, is that CKD generation (including material returned to the kiln) is equivalent to approximately 15% to 20% (by weight) of total annual clinker production. This amount translates into approximately 12 million to 15 million metric tons per year (van Oss, 2005).

USGS domestic survey data show that in 2003, at least 289,000 metric tons of CKD captured by air emission control devices were used in clinker manufacture, and another 149,000 metric tons were used in cement manufacture. In 2004, these amounts were at least 333,000 metric tons in clinker manufacture and 165,000 metric tons in cement manufacture (van Oss, 2004). As discussed by van Oss (2004), and based upon PCA data and discussions with industry personnel, these figures appear to grossly underreport the actual rate of reuse. As discussed previously, direct reuse of CKD in the manufacturing process is common, but largely unreported.

Table 2-14 presents a breakdown of the amount and percent of the beneficially used CKD (and not returned to the kiln) by use in 2006 (PCA, 2006). Nearly half of the CKD beneficially used in 2006 was used for soil or clay stabilization. Approximately 16% was used as a cement additive or for blending. CKD in concrete mixes generally increases the water demand, decreases workability, retards setting time, and decreases concrete strength. Research into this use for CKD has suggested, however, that limited substitution of CKD for portland cement can create undiminished concrete mixes. Studies suggest that effective substitution rates range from as low as 5% to as much as 50% for certain concrete applications (EPA, 1993). Other beneficial uses for CKD include waste stabilization, mine reclamation, agricultural soil amendment, and in pavement manufacturing.

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[44] This use must take into account volume expansion tendencies where the granular material is confined.

Table 2-14: Estimated Beneficial Uses of CKD Beneficially Reused, 2006

Beneficial Use	Quantity (Metric Tons)	Percent of CKD Total Beneficially Used (not returned to the kiln)
Soil/Clay Stabilization	533,365	46%
Waste Stabilization/Solidification	213,675	18%
Mine Reclamation	152,756	13%
Cement Additive/Blending	183,228	16%
All Other Uses	76,987	7%
Total	**1,160,011**	**100%**

Source: Portland Cement Association. Summary of 2006 Cement Kiln Dust and Clinker Production, CKD Beneficially Reused.
Note: CKD recycled into the kiln is under a closed loop process, not removed from the kiln system, and is not considered a beneficial reuse for purposes of this document.

2.3 Summary of RMC Generation and Beneficial Use

The RMCs examined in the study vary widely in terms of their generation and beneficial use rates. Table 2-15 summarizes total generation and beneficial use (all uses) of the RMCs in 2004. By quantity, the most significant materials beneficially used are coal fly ash, BFSA, and flue gas desulfurization (FGD) gypsum. Several materials – including GGBFS, BFSA, power plant boiler slag, and steel furnace slag from electric arc furnace facilities– have beneficial use rates at or near 100%. Table 2-15 provides summary information on the generation and beneficial use for the RMCs addressed in this Report.

Table 2-15: Summary of RMC Generation and Beneficial Use (2004)

Material	**Estimated Annual Quantity Generated, 2004** ***(million metric tons)***	**Estimated Quantity Beneficially Used, 2004** ***(million metric tons)***	**Percent Beneficially Used (all uses)**	**Beneficial Use Rate in Cement or Concrete**
RMCs Named by Congress				
Ground Granulated Blast-furnace Slag (excluding lead slag)	3.60	3.60	100%	High
Coal Combustion Fly Ash	64.20	25.50	40%	Moderate
Blast-furnace Slag Aggregate (excluding lead slag)	8.10	8.10*	100%	Moderate
Silica Fume	0.10 – 0.12	0.08	67%-80%	Moderate
Other RMCs Identified by EPA				
Foundry Sand	8.5	2.40	28%	Low
Cenospheres	N.A.	0.0052 (reported sales)	N.A.	Moderate
Flue Gas Desulfurization (FGD) Gypsum	10.80	8.20	76%	Low
Flue Gas Desulfurization (FGD) Dry Scrubber Material	1.70	0.16	9%	Low
Power Plant Bottom Ash	15.60	7.40	47%	Low
Power Plant Boiler Slag	2.00	1.80	90%	Low
Steel Furnace Slag**	9.00	9.00	100%	Low
Cement Kiln Dust (CKD)	12.00 – 15.00	1.20 (excludes reuse back into kiln	N.A.	Low

Note: Data sources and caveats discussed in detail in section 1, and earlier in this section.
* Recently received information indicates that BFSA may be used at around 85% (Kiggins, 2007). However, this is based on a single data point.
** Includes both EAF and BOF steel furnace slag. BOF steel furnace slag may be used at less than 100% (Lehman, Rich. October 3, 2007)

3.0 ENERGY AND ENVIRONMENTAL BENEFITS OF RMC USE IN FEDERAL CONCRETE PROJECTS

3.1 Introduction

This section further addresses Part (A) of the Congressional mandate, which also requires EPA to quantify the energy savings and environmental benefits associated with the substitution of RMCs for portland cement. Specifically, we address three of the four RMCs identified by Congress for further study: coal fly ash, GGBFS, and silica fume.[45] The analysis provides quantified estimates of energy savings and environmental benefits resulting from the substitution of these mineral components for finished portland cement in Federal construction projects involving concrete. 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 the use of RMCs in clinker production due to current modeling limitations. The metrics used to describe impacts include resource savings (e.g., energy and water consumption), avoided air pollutant emissions, various measures of avoided GHG emissions, avoided water emissions, avoided soil emissions, and avoided end of life waste.

This section begins with a brief overview of the analytical approach and model used to respond to the Congressional mandate. We then describe the methodology used to develop estimates of the quantities of coal fly ash, GGBFS, and silica fume substituted for finished portland cement in Federal projects. We then present unit impact values related to the substitution of one metric ton of each RMC for finished portland cement in concrete. Finally, we present aggregated impact results for historical Federal RMC use quantities (years 2004 and 2005), and project RMC use quantities (years 2004 to 2015). Appendix D provides detailed results of the analysis, along with a technical discussion of the modeling inputs and calculations.

3.2 Analytical Approach and Model

Our methodology for evaluating the benefits associated with RMC use in Federal concrete applications first involves selecting an appropriate life cycle modeling tool to address a range of RMCs and impacts. We then use the model to implement a three-step analytic approach:

1) development of RMC substitution scenarios;
2) use of life-cycle inventory data to estimate environmental impacts associated with the substitution of one unit (metric ton) of RMC; and
3) calculation of the environmental impact profile for the total quantities of substituted RMCs.

We use a life-cycle analysis (LCA) approach to estimate the environmental benefits of substituting RMCs for finished portland cement. LCA allows estimation of a range of

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[45] BFSA, a material identified by Congress, is a source of aggregate in concrete and does not act as an SCM or substitute for portland cement. We focus this assessment on the benefits of substitution of portland cement. However, an illustration of the types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase, can be found in Appendix D.

environmental impacts of a product across all stages in the product's life, from resource and raw material extraction through disposal. By comparing the impacts across different beneficial use scenarios in which portland cement is being replaced, it is possible to provide an estimate of the impacts associated with increases in the beneficial use of RMCs.

The analysis relies primarily on data derived from the Building for Environmental and Economic Sustainability (BEES) model. We employ the BEES model because it can be used to evaluate three of the RMCs identified by Congress (coal fly ash, GGBFS, and silica fume), providing a consistent modeling platform and set of results across the RMCs. Our comprehensive review of existing LCA models identified a number of other models that address individual RMCs, including the Waste Reduction Model (WARM) and the Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE). Two key differences between WARM and BEES led us to select BEES for the benefits analysis in this study. First, WARM evaluates only lifecycle energy and GHG impacts in its outputs, while BEES evaluates energy, GHG, and several other environmental impacts, such as water use and pollutant emissions to air and water. In addition, the WARM model addresses only one RMC used in concrete - coal fly ash. PaLATE is another life cycle analysis tool useful for modeling energy and environmental impacts. However, at the time of this analysis, the PaLATE model had not been formerly peer reviewed under Agency guidelines. Furthermore, as with WARM, PaLATE does not allow for the consistency and comparability across all three RMCs[46]. Because these models use different data and methodologies to calculate the impacts of RMC substitution, we opted to use BEES to evaluate coal fly ash, GGBFS, and silica fume to assure consistency and comparability across the RMCs analyzed.[47]

It is important to emphasize the purpose and limitations of the application of life cycle modeling in this context. Our approach is to generally characterize the potential suite of environmental impacts related to reuse of certain materials, and to illustrate the potential magnitude of these impacts. As noted, we rely primarily on the BEES model (version 3.0) to generate this illustration, and then use the WARM model to corroborate the results for coal fly ash. The life cycle inventories of material and resource use embedded in these models are representative of productive processes in place at a given point in time. As these processes evolve, the existing life cycle inventories may become less representative and require updating.[48] As a result, the long-range projections of materials reuse and related impacts based upon current life cycle inventories should be considered with due care and in the appropriate context. For example, the

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[46] Understanding the material use, modeling, and comparative limitations, we applied the PaLATE model in an effort to estimate the potential types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase. This analysis can be found in Appendix D

[47] Appendix D of this report includes a comparison of BEES and WARM results for energy and GHG impacts when coal fly ash is used in concrete. This comparison indicates that BEES and WARM result in roughly comparable energy and GHG impacts per metric ton of coal fly ash used as an SCM in concrete. We did apply the PaLATE model in an effort to estimate the potential types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase. This analysis can be found in Appendix D

[48] For example, NIST recently released BEES version 4.0 subsequent to the completion of the analysis presented in this chapter. BEES version 4.0 utilizes updated life cycle inventories that differ in certain respects from version 3.0. These differences, however, do not yield material changes in the relative magnitude of impacts for the RMCs evaluated.

primary focus should be on the categories of impacts and their direction (i.e., positive versus negative impacts), as opposed to the absolute magnitude of impacts, which may change over time.

As noted previously, our analysis quantifies the benefits only for coal fly ash, silica fume, and GGBFS use in concrete, and further limits consideration to those benefits associated with the use of these RMCs as a replacement for portland cement in concrete as an SCM, and not an input into the clinker or cement manufacturing process. This analysis does not consider the use of other RMCs (e.g., BFSA, foundry sand, FGD gypsum, bottom ash, and power plant boiler slag) because current data and modeling capabilities do not allow the Agency to conduct a detailed analysis of these other RMCs. Finally, we are unable to extrapolate the impacts calculated for coal fly ash, GGBFs, and silica fume to these other RMCs because the impacts modeled for portland cement replacement are not representative of the processes required to use these materials in cement and concrete applications.[49]

Nevertheless, the analysis provides an estimate of a portion of the benefits associated with certain RMCs, and also reflects a transparent and readily accepted approach for estimating potential benefits.

3.3 Current and Expanded Use Scenarios

To evaluate the environmental benefits of using RMCs in concrete, both at current use levels and under Federal initiatives to increase beneficial use rates, EPA first developed projections of future RMC use through 2015 under a variety of scenarios. The current use scenarios reflect RMC use under existing conditions and initiatives. The expanded use scenarios assume implementation of Federal initiatives to increase beneficial use rates. We then apply the environmental unit impact measures to these estimates to quantify the potential environmental benefits of historical and future RMC substitution.

Our analysis uses 2004 as a base year for projections because 2004 is the most recent year for which use data are available for the three RMCs evaluated. The benefits of RMC use in Federal concrete projects are assessed for both historical (years 2004 and 2005) and projected (years 2006 to 2015) substitution levels.[50] We discuss these scenarios in further detail below.

3.3.1 Current Use Practices

To implement the analysis, we first estimate the proportion of portland cement and RMCs used in Federal concrete projects. Specifically, to estimate the proportion of RMCs used in all Federally funded concrete projects, we use an FHWA estimate that approximately 20% of U.S.

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[49] To the extent that these materials offset extraction and processing of virgin materials, however, there are likely to be positive environmental life cycle impacts associated with their use in cement or concrete. At a minimum, the environmental benefits associated with the use of other RMCs are likely to be consistent with the energy savings and reduced impacts associated with avoiding the production of an equal quantity of virgin material.

[50] 2006 is not considered a "historical year" in this analysis because at the time of this analysis, 2006 use data were not available for all three RMCs being evaluated. Thus, it was necessary to develop projections of RMC use beginning in 2006.

concrete construction projects involve Federal funds.[51] Therefore, in this analysis, we assume: (1) that Federal projects are using RMC at the same "rate" as the national average, and (2) that the Federal projects incorporate 20% of RMCs used as a substitute for finished portland cement in concrete. Appendix D presents a detailed discussion of how this estimate was derived.

We then use available data from industry and government sources on historical and future portland cement demand to develop the following approaches:

- **Future GGBFS Use:** We assume that annual demand for GGBFS will increase proportionate to the overall U.S. demand for portland cement. PCA estimates that U.S. portland cement demand will be 195 million metric tons in 2030 (PCA, 2006a). For this analysis, we assume that demand for portland cement will increase linearly to the PCA estimated rate by 2030, or approximately 2.2% per year beyond 2005 (the last year for which actual portland cement use data are available). We apply the 2.2% growth rate to the base year (2004) quantity of GGBFS used in U.S. concrete projects (3.46 million metric tons), which equals an annual increase of approximately 76,000 metric tons. While this approach does not attempt to address a number of industry-specific uncertainties related to GGBFS supply, it is generally consistent with the estimates of potential GGBFS production and sales provided by the USGS. Future GGBFS use, depends on a number of factors, including import patterns and demand for GGBFS relative to demand for BFSA and GBFS (GGBFS, GBFS and BFSA are all made from the same supply of iron slag). The SCA projects higher GGBFS use based on an assumed increase in imports and a significant investment in grinding equipment.[52] For the purposes of this report, however, we use more conservative projections based on U.S. portland cement demand that do not assume a market shift. These projections comport with a USGS estimate that a maximum of six million metric tons of GGBFS could be available in the U.S. in the next 10 to 20 years through combined imports and domestic production.[53]

- **Future Silica Fume 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 per year).[54]

- **Future Coal Fly Ash Use:** We employ a different approach to estimate future use of coal fly ash because current government and industry initiatives are designed to increase beneficial use rates. Specifically, using selected mechanisms, as outlined in Chapter 5, the C^2P^2 program has an aggressive goal of

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[51] Personal communication with Jon Mullarky, FHWA, July 17, 2007.
[52] Personal communication with Jan Prusinski, Slag Cement Association, June 6, 2007.
[53] Personal communication with Hendrik van Oss, USGS, July 12, 2007.
[54] Personal communication with Hendrik 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.

increasing coal fly ash use in portland cement to 18.6 million short tons (16.9 million metric tons) by 2011.[55] We therefore use constant progress toward this goal to estimate coal fly ash use for the years 2005 through 2011. For the years 2012 through 2015, we then estimate that coal fly ash use under C^2P^2 will increase at the same rate as U.S. portland cement demand over 2004 levels (2.2%, or approximately 333,000 metric tons per year).[56] In order to estimate coal fly ash use in the absence of C^2P^2, we also employ a current use scenario in which we assume that the use of coal fly ash as a partial portland cement replacement will increase linearly for the years 2005 to 2011 at the same rate as U.S. cement demand. This scenario recognizes that meeting the C^2P^2 goals is dependent upon overcoming a number of the barriers, as identified in Chapter 4.

3.3.2 Expanded Use Scenarios

In addition to the current use estimates, we also developed expanded use estimates for coal fly ash as an SCM in concrete to capture incremental changes in use from current levels. These scenarios are designed to provide insight into the specific impacts of ongoing and emerging efforts by EPA and other Federal agencies and stakeholders to increase the beneficial use of coal fly ash. We limit our evaluation of an expanded use scenario to coal fly ash because, unlike GGBFS and silica fume, coal fly ash is currently underutilized (with respect to supply availability) and therefore has the capacity for expanded use if barriers to its increased use are removed.[57]

We employ two expanded use scenarios to estimate the potential impacts and benefits due to initiatives to increase the use of coal fly ash. Under the first expanded use scenario (the "15 percent scenario"), coal fly ash substitution in Federal projects is assumed to increase from the current use rates (approximately 10%) to the 15% level recommended under the CPG program. Under the second alternative use scenario (the "30% scenario"), coal fly ash substitution for portland cement in Federal projects (i.e., 20% of total U.S. estimates) is assumed to increase from the current use rates to the maximum levels recommended under the CPG program (i.e., 30%).[58, 59] For non-Federal projects, our scenarios assume that RMC use would be the same as under the current use analysis. For both scenarios, we assume that the increase in use will be linear starting in the year 2009 and continuing through the year 2015.[60] Tables 3-1 and 3-2 present the current and future use estimates (incorporating the 20% adjustment factor) for coal

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[55] See www.epa.gov/epaoswer/osw/conserve/c2p2/pubs/facts508.pdf.

[56] Comments and information from Hendrik van Oss of the USGS suggest that developing any trend in future coal fly ash beneficial use is subject to significant uncertainty. We therefore use EPA goals and cement industry projections as a likely high-end estimate of potential growth.

[57] Close to 100% of GGBFS and silica fume currently generated in the U.S. is believed to be beneficially used.

[58] Note that an increase to 15% coal fly ash substitution represents an optimistic Agency goal. Therefore, the 30% scenario represents a possible, though unlikely, maximum target for increased substitution. The results of the 30% scenario should be taken as an upper bound estimate of possible environmental benefits.

[59] Both the 15% and 30% scenarios assume full attainment of the CPG recommended beneficial use levels, but do not necessarily reflect current barriers to the expanded use of coal fly ash. Additionally, the C^2P^2 scenario is an expanded use scenario using the goals set forth under the program. Therefore, the volumes beneficially used in these scenarios are optimistic Agency goals.

[60] SAFETEA-LU 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.

fly ash, GGBFS, silica fume, and total portland cement (including both “virgin” portland and blended cements), as well as the expanded use estimates for coal fly ash.

Table 3-1: U.S. Portland Cement Demand and RMC Use in Cement and Concrete Products, Under Current and Expanded Use Scenarios

	Cement	**Coal Fly Ash**				**GGBFS**	**Silica Fume**
	Total U.S. Demand	*Current Use Baseline*	*Current Use C^2P^2*	*15% Scenario*	*30% Scenario*	*All Scenarios*	*All Scenarios*
Year	*---------------------------------------million metric tons--*						
2004	122.0	12.8	12.8	12.8	12.8	3.5	0.06
2005	125.7	13.6	13.6	13.6	13.6	3.5	0.06
2006	128.5	13.9	14.2	14.2	14.2	3.6	0.06
2007	131.2	14.2	14.8	14.8	14.8	3.7	0.06
2008	134.0	14.5	15.4	15.4	15.4	3.8	0.06
2009	136.8	14.8	15.9	16.3	17.7	3.8	0.06
2010	139.6	15.1	16.4	17.2	20.0	3.9	0.06
2011	142.3	15.4	16.9	18.1	22.3	4.0	0.06
2012	145.1	15.7	17.2	18.9	24.6	4.1	0.06
2013	147.9	16	17.5	19.8	27.0	4.1	0.06
2014	150.6	16.3	17.9	20.6	29.5	4.2	0.06
2015	153.4	16.6	18.2	21.5	32.0	4.3	0.06

Notes:

(a) These figures include both Federal and non-Federal projects. For purposes of this analysis, we assume that Federal projects represent approximately 20% of the total quantities; non-Federal projects make-up the remaining 80%.

(b) The C^2P^2, 15%, and 30% scenarios represent aggressive policy goals.

Table 3-2: Federal Portland Cement and RMC Use Under Current and Expanded Use Scenarios

	Cement	Coal Fly Ash				GGBFS	Silica Fume
	Federal Demand	*Current Use Baseline*	*Current Use C^2P^2*	*15% Scenario*	*30% Scenario*	*All Scenarios*	*All Scenarios*
Year	*million metric tons*						
2004	24.4	2.6	2.6	2.6	2.6	0.7	0.01
2005	25.1	2.7	2.7	2.7	2.7	0.7	0.01
2006	25.7	2.8	2.8	2.8	2.8	0.7	0.01
2007	26.2	2.8	3.0	3.0	3.0	0.7	0.01
2008	26.8	2.9	3.1	3.1	3.1	0.8	0.01
2009	27.4	3.0	3.2	3.4	4.1	0.8	0.01
2010	27.9	3.0	3.3	3.7	5.1	0.8	0.01
2011	28.5	3.1	3.4	4.0	6.1	0.8	0.01
2012	29.0	3.1	3.4	4.3	7.2	0.8	0.01
2013	29.6	3.2	3.5	4.6	8.3	0.8	0.01
2014	30.1	3.3	3.6	4.9	9.4	0.8	0.01
2015	30.7	3.3	3.6	5.3	10.6	0.9	0.01

Notes:
These figures reflect Federal projects only.
GGBFS and silica fume data equal 20% of the USA totals.

3.4 RMC Unit Impact Savings

RMC unit impacts represent the energy and environmental effects of using one unit of coal fly ash, GGBFS, or silica fume in place of an equivalent unit of finished portland cement in a specified concrete application.[61] The unit impact values for each RMC provide a basis for converting Federal RMC use quantities in Table 3-2 into measures of environmental benefits. Table 3-3 presents the unit impact values applied in our model. These values are derived from BEES life cycle inventory data and represent the total life cycle savings of using RMCs as a replacement for one metric ton of finished portland cement in concrete.[62]

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[61] Silica fume does not replace portland cement in a 1:1 ratio (as is the case with coal 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, BEES assumes a 1:1 replacement ratio for silica fume and portland cement in concrete when modeling life cycle impacts. This is likely to over state the benefits of using this material as an SCM.

[62] See Appendix D for the detailed calculations of the RMC unit impact values.

Table 3-3: Life Cycle Impacts per Metric Ton of RMC Substituted for Finished Portland Cement in Concrete

	----------------------Material ---------------------		
Metric	**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 (Liter)	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*[e]	
Avoided CO_2 Emissions (grams)	701,377.7	668,889.1	699,923.3
Avoided CF_4 Emissions (grams)	0.0	*Not calculated*[e]	
Avoided CH_4 Emissions (grams)	594.8		
Avoided N_2O Emissions (grams)	13.2		
Passenger cars not driven for one year[d]	0.2		
Passenger cars and light trucks not driven for one year[d]	0.1		
Avoided gasoline consumption (liters)[d]	310.0		
Avoided oil consumption (barrels) [b]	1.7		
Avoided NOx 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.

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

c. Avoided CO_2 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 can be calculated from the global warming potentials of individual greenhouse gasses, using the global warming potential of $C0_2$ as the reference point. Avoided CO_2 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.

e. 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.

As shown in Table 3-3, use of one metric ton of RMC in place of one metric ton of finished portland cement results in a range of environmental benefits. For example, substituting one metric ton of coal fly ash results in 0.72 metric tons of avoided CO_2 equivalent emissions, of which 0.70 metric tons is avoided CO_2. In comparison, use of one metric ton GGBFS results in 0.67 metric tons of avoided CO_2 emissions.

For all metrics, the energy and environmental benefits of using GGBFS in concrete are less than the benefits of using coal fly ash in concrete. GGBFS generally is produced by quenching molten slag with water and then grinding the cooled material to a fine cement-like consistency. The resource use and air emissions associated with the mechanical processing of GGBFS offset some of the environmental benefits from the avoided production of portland cement. In contrast, coal fly ash generally does not require grinding prior to its beneficial use in concrete and is therefore modeled as an environmentally "neutral" input to concrete production.[63] Thus, the benefits of coal fly ash substitution directly represent the environmental benefits associated with avoiding the production of one metric ton of portland cement.

It is important to note that the unit impact values for silica fume are not directly comparable to the unit impact values for coal fly ash and GGBFS. Silica fume is not generally used as a direct, complete substitute for finished portland cement, but is instead a partial supplement that offsets some portland cement use, and also increases the strength and reduces the water permeability of concrete.[64] Substitution of silica fume in concrete can yield both positive and negative environmental impacts. For example, its use as a partial substitute can lower energy consumption and carbon dioxide emissions relative to mixes with 100% portland cement. The most significant negative impact is increased water use when silica fume is used as a partial substitute in place of portland cement in concrete. As described in Appendix B of this report, the high surface area of silica fume increases water demand in concrete.

3.5 Historical Energy and Environmental Impacts of RMC Beneficial Use

To estimate energy and environmental benefits attributable to substitution of RMCs for portland cement in Federal concrete projects, we multiply the unit impact values identified in Table 3-3 by the Federal RMC use quantities for 2004 and 2005 (presented in Table 3-2). As previously discussed, our historical impacts include both 2004 and 2005, while projections cover 2006 through 2015.

We summarize the historical energy and impact estimates briefly in the bullets below, with more detailed results presented in Table 3-4.

- **Coal Fly Ash**: Federal concrete projects used an estimated 5.3 million metric tons of coal fly ash in 2004 and 2005 combined. This substitution yields a number of environmental benefits, including avoided energy use of approximately

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[63] Coal fly ash does require some quality control prior to use in concrete. Separation and beneficiation are widely practiced in the industry, but the energy impacts of these processes do not appear to be as clear or significant as the grinding required for GGBFS. As a result, many life cycle models, including BEES, do not attribute processing energy to coal fly ash.

[64] For a further explanation of the limitations of the unit impact estimates for silica fume, see Appendix D.

25 billion megajoules; avoided water consumption of two billion liters; and avoided carbon dioxide equivalent emissions of 3.8 million metric tons.

Energy and water savings represent two significant impacts that can be monetized using market prices. Results indicate that the beneficial use of coal fly ash in 2004 and 2005 resulted in energy savings valued at approximately $0.7 billion, and water savings valued at approximately $1.2 million.

- **GGBFS**: An estimated 1.4 million metric tons of GGBFS were used in Federal concrete projects in 2004 and 2005 combined. This substitution yields a suite of positive and negative environmental impacts, including avoided energy use of approximately six billion megajoules; avoided water consumption of approximately 0.2 billion liters; and avoided carbon dioxide emissions of approximately one million metric tons. The negative benefits include increased chemical oxygen demand and increased suspended matter in water discharges.

- **Silica Fume**: The impact estimates for silica fume result from an estimated use of 24,000 tons in 2004 and 2005. Consistent with the unit impact measures, silica fume substitution results in both positive and negative impacts, including avoided energy use of approximately one billion megajoules, increased water consumption of 0.1 billion liters, and positive and negative impacts across the various air emissions metrics.

Table 3-4: Historical Impacts of Using Coal Fly Ash, GGBFS, and Silica Fume in Federal Concrete Projects (2004 plus 2005)

Environmental Metric		COAL FLY ASH	GGBFS	SILICA FUME
		Beneficial Use Quantity (metric tons, 2004 plus 2005)		
		5,282,000	1,399,000	24,000
		Historical Energy and Environmental Impacts		
Energy Savings	billion megajoules	24.8	5.9	0.8
	billion ($ 2006)	0.7	0.2	0.0
	billion ($ discounted @ 7%)	0.7	0.2	0.0
Water Savings	billion liters	2.0	0.2	-0.1
	million ($ 2006)	1.2	0.1	-0.1
	million ($ discounted @7%)	1.2	0.1	-0.1
Avoided CO_2 Equivalent (air)	million metric tons	3.8	*Not calculated*[b]	
Avoided CO_2	million metric tons	3.7	0.9	0.0
Avoided CF_4	metric tons	0.0	*Not calculated*[b]	
Avoided CH_4	thousand metric tons	3.1		
Avoided N_2O	metric tons	69.7		
Passenger cars not driven for one year	million passenger cars	0.8		
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.7		
Avoided gasoline consumption	billion liters	1.6		
Avoided oil consumption	billion barrels	0.0		
Avoided NOx (air)	thousand metric tons	11.3	2.8	0.7
Avoided PM10 (air)	metric tons	0.1	0.0	0.0
Avoided SOx (air)	thousand metric tons	8.8	2.2	1.0
Avoided CO (air)	thousand metric tons	3.5	0.9	0.1
Avoided Hg (air)	metric tons	0.2	0.1	0.0
Avoided Pb (air)	metric tons	0.2	0.0	0.0
Avoided biochemical oxygen demand (water)	metric tons	17.9	-1.1	-0.5
Avoided chemical oxygen demand (water)	metric tons	151.4	-9.1	-4.8
Avoided copper (water)	metric tons	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	81.3	-4.9	-1.3
Avoided soil emissions	metric tons	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0

Notes:

a. BEES reports CO separate from CO_2 emissions, but it is important to note that the Intergovernmental Panel on Climate Change (IPCC) considers CO emitted from portland cement manufacture a precursor to CO_2.

b. GHG equivalency metrics were not calculated for GGBFS and silica fume is part due to the fact that use of these materials is unlikely to change significantly across scenarios.

As shown in Table 3-4, the environmental benefits associated with the historical use of coal fly ash are significantly larger than the benefits associated with the historical use of GGBFS. These differences are a function of both the historical quantities of each RMC used in Federal concrete projects and the unit impacts for the use of one ton of each RMC in concrete. Specifically, greater quantities of coal fly ash have been used historically than GGBFS, and the unit impacts calculated for coal fly ash are higher than those of GGBFS.

While avoided releases of different substances, and savings in energy and water use are generally additive, a full assessment of the economic benefits would require identifying the specific receptors (i.e., populations and water bodies) whose quality has been improved. Moreover, certain GHG equivalent metrics such as "avoided oil consumption" and cars removed from the road represent different ways of describing the same impact (i.e., avoided greenhouse gas emissions), and are not additive.

3.6 Projected Energy and Environmental Impacts of RMC Beneficial Use

In addition to assessing the historical benefits of the use of RMCs, this analysis also considers how the benefits may accrue over time under projected use scenarios. As described above, for each RMC analyzed, we developed projections, through the year 2015, of potential substitution levels based upon current use, forecasted supply, and potential demand of each RMC, as well as estimates based on alternative procurement goals. The projected annual substitution levels (in metric tons) are then multiplied by the unit impact values (i.e., impacts per metric ton of RMC) to derive projected environmental benefits.

Table 3-5 below presents aggregate benefits and impacts summed across the years 2004 to 2015 under the four beneficial use scenarios developed in this analysis (i.e. the baseline scenario, the C^2P^2 goals scenario, the 15% expanded use scenario for coal fly ash, and the 30% expanded use scenario for coal fly ash). The results are presented in aggregate for the years 2004 to 2015 to show the total magnitude of possible impacts during the period of analysis. The results illustrate the incremental gains achieved by moving to higher levels of coal fly ash use. Appendix D presents these findings in more detail.

As in the historical scenario, energy and water savings represent two major impacts, and illustrate the differences between the various scenarios. Results indicate that use of the analyzed RMCs (coal fly ash, GGBFS, and silica fume) in concrete from 2004 through 2015 may result in energy savings valued at nearly $6 billion (2006 dollars) under baseline conditions. Achieving the 15% substitution rate (coal fly ash for Portland cement) for coal fly ash would increase the value of energy savings to nearly $7 billion, and achieving a 30% substitution rate would increase benefits to an estimated $9.6 billion for the three RMCs. Water savings results for the three RMCs reflect a similar pattern, showing a 30% substitution rate for coal fly ash would save approximately 25 billion litres, compared with a 14.1 billion litre savings under baseline assumptions.

Figures 3-1 through 3-3 below present graphic representations of the trends for selected energy and environmental metrics for all coal fly ash and GGBFS use scenarios.[65] Consistent with the Congressional requirement, the metrics selected - energy savings, carbon dioxide emissions, and water use impacts, represent the largest environmental benefits associated with use of the RMCs in concrete.

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[65] We do not present trend results for silica fume in these tables due to the higher degree of uncertainty associated with the silica fume analysis.

Table 3-5: Total Projected Impacts of Using Coal Fly Ash, GGBFS, and Silica Fume in Federal Concrete Projects Under Current and Expanded Rate Use Scenarios for Years 2004 – 2015 (Footnotes on next page)

Metric	Units	**Current Use Baseline Scenario**[a]	**Current Use C^2P^2 Scenario**[b]	**Incremental Impacts**[c] (Current Use C^2P^2 minus Current Use Baseline)	**Expanded Use 15% Substitution Scenario**[d]	**Incremental Impacts**[e] (15% Scenario minus Baseline Scenario)	**Incremental Impacts**[f] (15% Scenario minus Current Use C^2P^2)	**Expanded Use 30% Substitution Scenario**[g]	**Incremental Impacts**[h] (30% Scenario minus Baseline Scenario)	**Incremental Impacts**[i] (30% Scenario minus Current Use C^2P^2)	**Incremental Impacts**[j] (30% Scenario minus 15% Scenario)
Energy Savings	billion megajoules	212.1	223.2	11.2	252.5	40.4	29.3	348	135.9	124.8	95.5
	billion ($ 2006)	5.8	6.1	0.3	6.9	1.1	0.8	9.6	3.8	3.4	2.6
	billion ($ discounted @ 7%)	4.5	4.7	0.2	5.2	0.7	0.5	6.8	2.3	2.1	1.6
Water Savings	billion liters	14.1	15	0.9	17.3	3.2	2.3	25	10.9	10	7.7
	million ($ 2006)	8.7	9.3	0.6	10.7	2	1.4	15.4	6.7	6.2	4.7
	million ($ discounted @ 7%)	6.7	7.1	0.4	7.9	1.2	0.9	10.8	4.1	3.7	2.9
Avoided CO_2 Equivalent (air)[k]	million metric tons	25.7	27.4	1.7	31.9	6.2	4.5	46.5	20.8	19.1	14.6
Avoided CO_2	*million metric tons*	31.4	33.1	1.7	37.5	6.1	4.4	51.7	20.3	18.6	14.3
Avoided CF_4	*metric tons*	0	0	0	0	0	0	0	0	0	0
Avoided CH_4	*thousand metric tons*	21.3	22.7	1.4	26.4	5.1	3.7	38.5	17.2	15.8	12.1
Avoided N_2O	*metric tons*	471.9	503.3	31.4	585.4	113.5	82.2	853.7	381.8	350.5	268.3
Passenger cars not driven for one year	million passenger cars	5.7	6.1	0.4	7.1	1.4	1	10.4	4.7	4.3	3.3
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	4.7	5	0.3	5.8	1.1	0.8	8.4	3.7	3.5	2.6
Avoided gasoline consumption	billion liters	11.1	11.8	0.7	13.8	2.7	1.9	20.1	9	8.2	6.3
Avoided oil consumption	billion barrels	0.1	0.1	0	0.1	0	0	0.1	0	0	0
Avoided NOx (air)	thousand metric tons	99.1	104.1	5.1	117.4	18.3	13.3	160.8	61.7	56.6	43.3
Avoided PM10 (air)	metric tons	0.4	0.5	0	0.5	0.1	0.1	0.8	0.4	0.3	0.2
Avoided SOx (air)	thousand metric tons	81	85	4	95.4	14.4	10.4	129.4	48.4	44.5	34.1
Avoided CO (air)[l]	thousand metric tons	29.5	31.1	1.6	35.2	5.7	4.1	48.5	19	17.4	13.3
Avoided Hg (air)	metric tons	1.9	2	0.1	2.2	0.3	0.3	3.1	1.2	1.1	0.9
Avoided Pb (air)	metric tons	1.5	1.6	0.1	1.8	0.3	0.2	2.4	0.9	0.8	0.6
Avoided biochemical oxygen demand (water)	metric tons	111	119.1	8.1	140.2	29.2	21.1	209.1	98.1	90	68.9
Avoided chemical oxygen demand (water)	metric tons	936.2	1,004.40	68.2	1,183.00	246.8	178.6	1,766.20	830	761.8	583.2
Avoided copper (water)	metric tons	0	0	0	0	0	0	0	0	0	0
Avoided suspended matter (water)	metric tons	510.3	546.9	36.6	642.8	132.5	95.9	955.8	445.5	409	313.1
Avoided soil emissions	metric tons	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

Notes:

a. Calculated as the sum of impacts for coal fly ash current use baseline, GGBFS and silica fume current use scenarios, years 2004 to 2015.
b. Calculated as the sum of impacts for coal fly ash current use C^2P^2, GGBFS and silica fume current use scenarios, years 2004 to 2015.
c. Calculated as the difference between the current use baseline totals and the current use C^2P^2 totals. This represents the impacts attributable to increased coal fly ash use under EPA's C^2P^2 program.
d. Calculated as the sum of impacts for the coal fly ash 15% expanded use, GGBFS current use and silica fume current use scenarios for years 2004 to 2015. Expanded use scenarios were not developed for GGBFS and silica fume.
e. Calculated as the difference between 15% expanded use scenario totals and current use baseline totals. This represents the impacts achieved by moving from coal fly ash use levels without influence from EPA's C^2P^2 program, to coal fly ash use levels under the CGP-recommended 15% substitution.
f. Calculated as the difference between 15% expanded use scenario totals and current use C^2P^2 totals. This represents the impacts achieved by moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-recommended 15% substitution.
g. Calculated as the sum of impacts for the coal fly ash 30% expanded use, GGBFS current use and silica fume current use scenarios for years 2004 to 2015. Expanded use scenarios were not developed for GGBFS and silica fume.
h. Calculated as the difference between the 30% expanded use scenario totals and the current use baseline totals. This represents the impacts achieved by moving from coal fly ash use levels without influence from EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
i. Calculated as the difference between the 30% expanded use scenario totals and the current use C^2P^2 totals. This represents the impacts achieved by moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
j. Calculated as the difference between 30% expanded use scenario totals and 15% expanded use scenario totals. This represents the impacts of moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
k. For avoided CO_2 equivalent, CF_4, CH_4, N_2O, passenger cars removed, passenger cars and light trucks removed, and avoided gas and avoided oil consumption, impacts are attributable to coal fly ash only as these metrics were not evaluated for GGBFS or silica fume.
l. BEES reports CO separate from CO_2 emissions, but it is important to note that the Intergovernmental Panel on Climate Change (IPCC) considers CO emitted from portland cement manufacture a precursor to CO_2.

Figure 3-1: Avoided Energy Use for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)

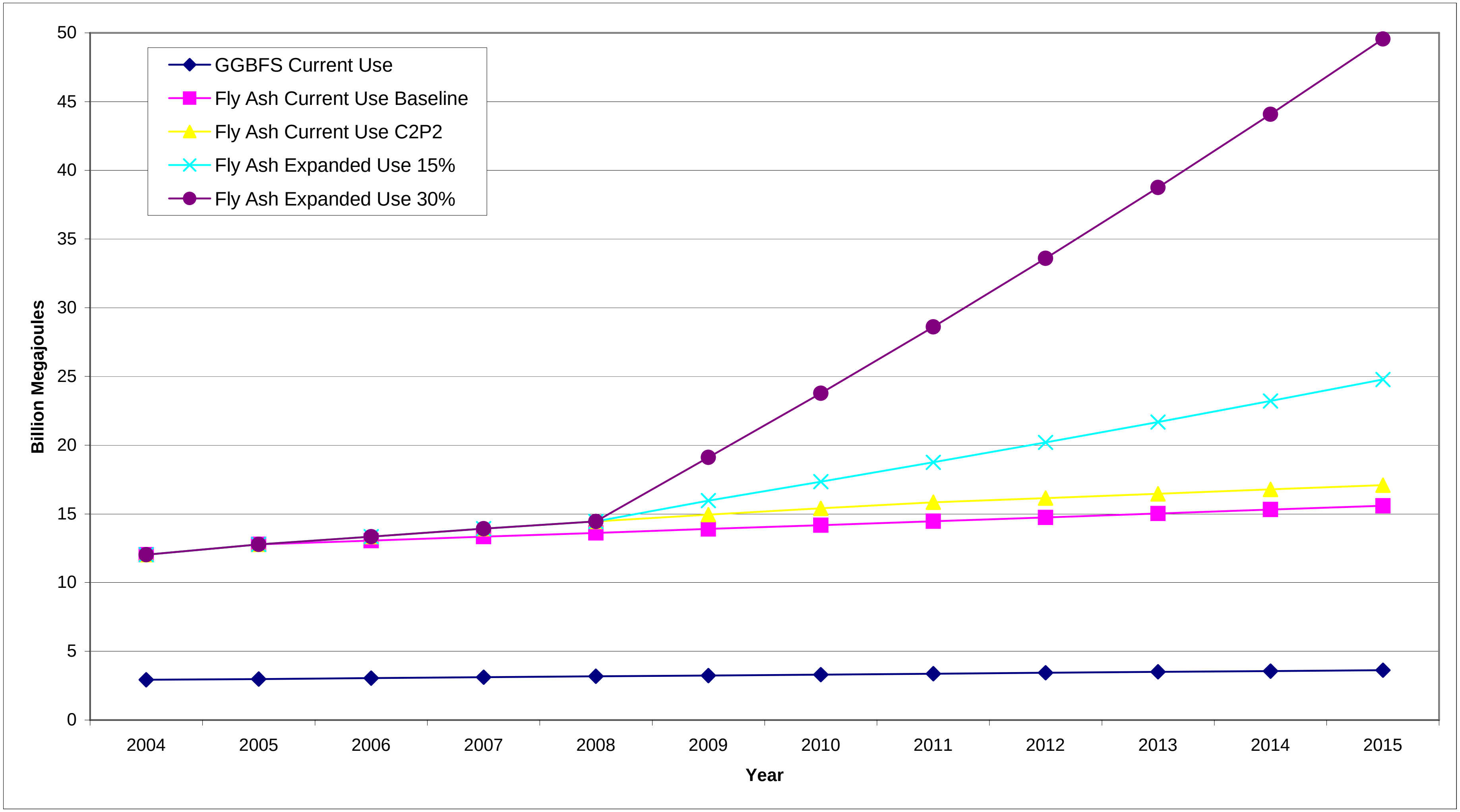


Figure 3-2: Avoided Water Use for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)

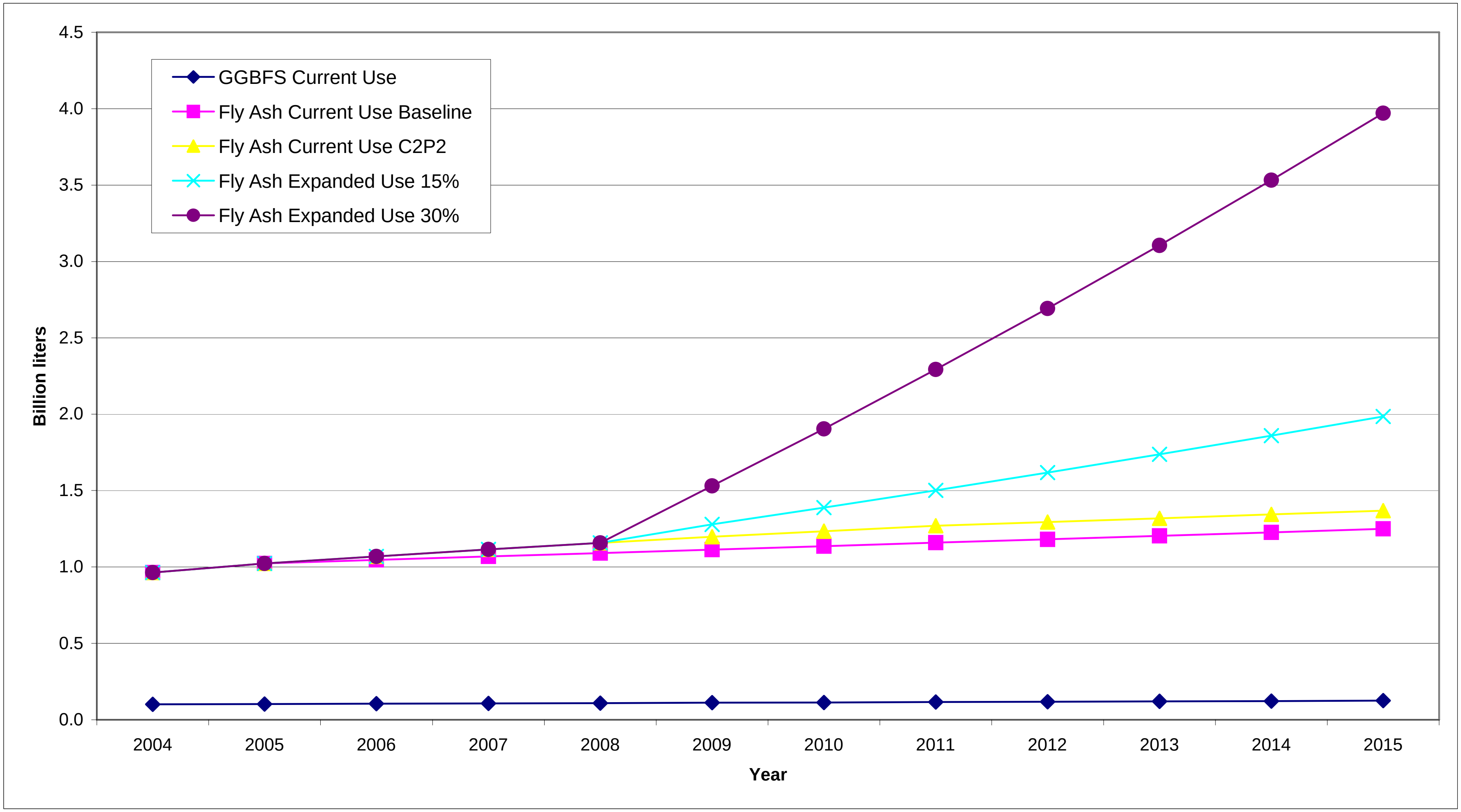
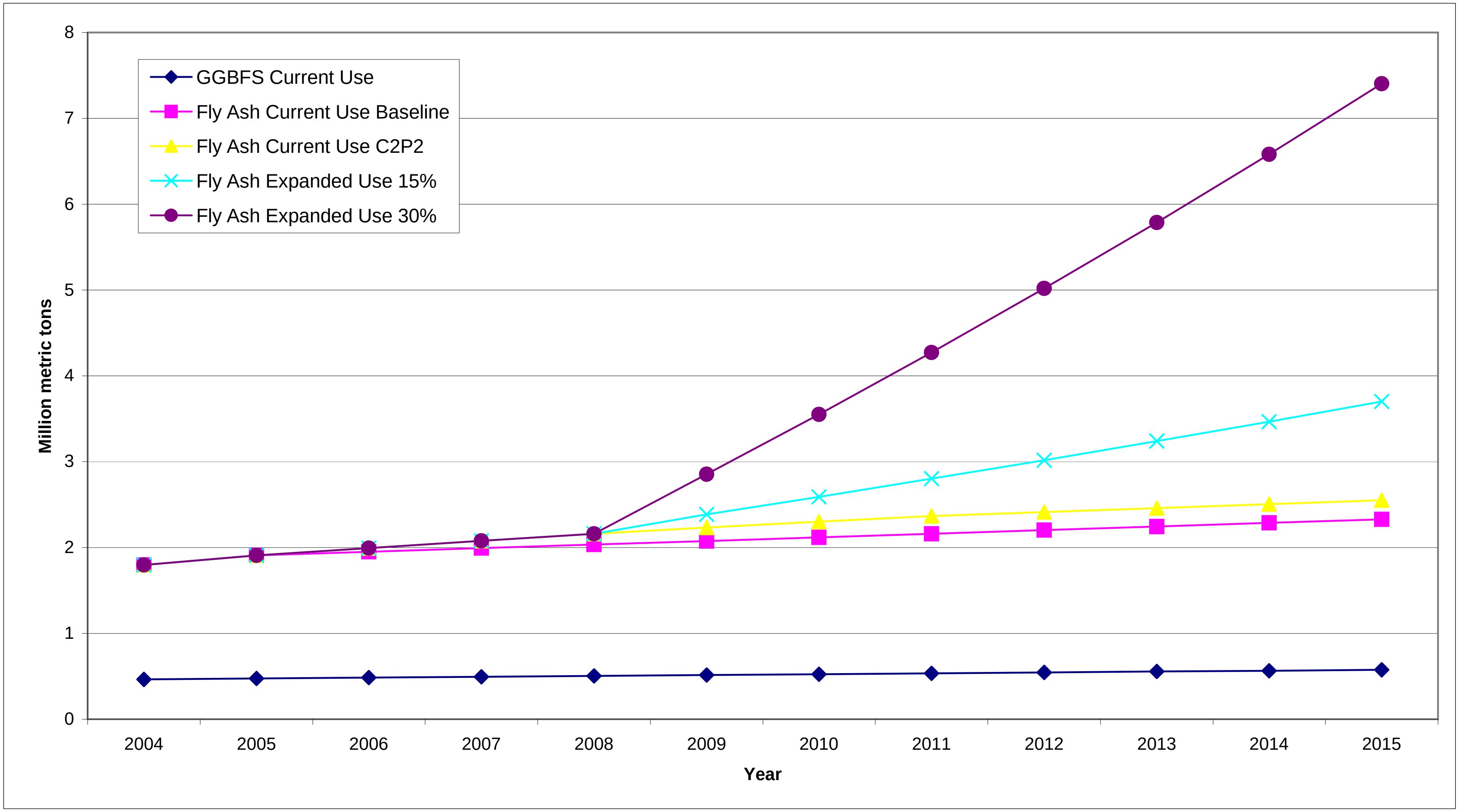


Figure 3-3: Avoided CO_2 Air Emissions for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)



4.0 BARRIERS TO INCREASED RMC SUBSTITUTION

This chapter addresses Part (B) of the Congressional mandate requiring EPA to "identify all barriers in procurement requirements to greater realization of energy savings and environmental benefits, including barriers resulting from exceptions from current law." The discussion groups these barriers into four major categories:

- Technical barriers;
- Legal, regulatory, and contractual barriers;
- Economic barriers; and
- Perceived Safety and health risk barriers

Several studies provide a discussion of barriers to increased RMC usage, especially as they apply to coal combustion products (CCPs).[66] Specifically, DOE published a report to Congress in 1994 entitled, *Barriers to the Increased Utilization of Coal Combustion/Desulfurization Byproducts by Governmental and Commercial Sectors* (DOE, 1994). The University of North Dakota Energy and Environmental Research Center (EERC) published an update to this report in 1998 (EERC, 1999). In addition, EPRI published a report in 1992 entitled, *Institutional Constraints to Coal Fly Ash Use in Construction* (EPRI, 1992). EPA prepared two reports to Congress on wastes from the combustion of fossil fuels, the first of which, published in 1988, addressed wastes generated from the combustion of coal by electric utility power plants. The second, published in 1999, addressed the remaining wastes not addressed in the 1988 report to Congress. More recently, the International Energy Agency (IEA) Clean Coal Centre published a report entitled *Cement and Concrete—Benefits and Barriers in Coal Ash Utilization* (IEA, 2005).

Building on these publications, EPA and PCA held a workshop in 2005 focused on alternative fuels and raw materials used in portland cement manufacture. During this workshop, participants discussed barriers to increased RMC usage in portland cement manufacturing. Materials discussed included steel slag, foundry sands, and CCPs (EPA, 2005b). In addition to these sources, EPA and PCA consulted cement manufacturers and trade associations to solicit their perspectives on potential barriers to increased RMC usage.

This section also incorporates additional information from research on individual state perspectives on CCP utilization. Specifically, EERC conducted state reviews addressing CCP utilization in Texas and Florida.[67] These state reviews reveal benefits associated with the use of CCPs, as well as barriers to increased use (EERC, 2005).

The following discussion contains selected excerpts from these documents, as well as industry perspectives to highlight barriers to increased RMC usage in Federally funded cement and concrete projects. Although some barriers have been reduced or eliminated since the publication of the reports identified above, a number of them still remain. Several of these barriers apply broadly to all RMCs; the discussion notes where barriers are specific to a particular material.

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[66] This study also refers to CCPs as coal combustion byproducts (CCBs).

[67] Pennsylvania was the site of the third state review in December 2006. A synthesis report on the findings across the three states is forthcoming.

Finally, not all of these barriers equally affect the level of RMC reuse, nor are they equally amenable to being addressed by policy mechanisms within the immediate purview of EPA. For example, strong technical or economic barriers to the use of a particular RMC in a specific application are generally going to be less influenced by a policy intervention than a barrier related to lack of awareness or information concerning a particular RMC use.

4.1 Technical Barriers

Technical barriers to the increased beneficial use of RMCs include:

- Performance of products containing RMCs;
- Acceptance of materials specifications; and
- Consistency of RMC supply.

4.1.1 Performance of Products Containing RMCs

Product performance and quality concerns are known to prevent some potential RMC users from incorporating these materials into their portland cement or concrete products. These concerns may be related more to traditional terminology than actual performance. The term "recovered mineral content" refers to a material with a positive or beneficial use, regardless if the material was originally generated as a byproduct or waste. However, in many states, potential users and others appear to equate these materials with "wastes," that do not or cannot have the same quality attributable to a virgin or manufactured material (Goss, 2006). Most RMCs, however, when used properly, will preserve or enhance final product quality and durability.

Some specific concerns that have been identified include:

- Some states prohibit the use of coal fly ash or slag after a certain calendar date each year (e.g., October 15), based on the concern that when coal fly ash or slag is used during cold weather, it can slow the set and strength gain of concrete and hence delay the project schedule.[68] Conventional technologies, such as using a finer ground portland cement (Type III) or additional portland cement, accelerating admixtures, or using hot water for mixing could, in many cases overcome this concern, while maintaining the slag or coal fly ash content.

- Some state DOTs limit the use of coal fly ash or GBFS due to engineering considerations such as curing time and the impact of cold weather on construction, and due to concerns about the availability of the materials that meet strict product specifications.

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[68] This belief of slowed setting and rates of strength gain when using coal fly ash and slag in cement are repeated by (Lobo, 2006).

- Use of GGBFS and coal fly ash at higher percent substitution rates for portland cement in concrete (greater than 50% for GGBFS and greater than 25% for coal fly ash) can reduce deicer salt scaling resistance (SCA, 2007).[69]

- Foundry sands are typically a fine material and might not be suitable for use in concrete unless blended with other sands. In addition, the presence of clay and contaminants in foundry sands may also limit reuse opportunities (Mullarky, 2006).

As discussed further in the following section on mechanisms to address these barriers, research, testing, and pilot programs are being conducted by various industry and governmental entities to identify proper standards and specifications for RMC use in concrete applications.

4.1.2 Acceptance of Materials Specifications

Some of the most significant technical barriers related to performance are rooted in specific material specifications and how they are (or are not) applied. For example, many state departments of transportation (DOTs) do not accept ASTM's performance specification for cement (C1157).[70] This is a technical determination made by state DOTs. Compounding this is a lack of harmonization between the AASHTO and ASTM specifications.[71] This leads to a lack of uniformity in the acceptance, specification, and utilization of RMCs among state DOTs.

4.1.3 Consistency of RMC Supply

One impediment to the increased use of coal fly ash in portland cement and concrete projects is the availability of required quantities of consistent, high-quality coal fly ash meeting the specifications for use in concrete (Mullarky, 2006). Different coal types produce different ashes, and an electric utility could switch among coal sources for various reasons (e.g., price, sulfur reduction) without consideration as to what this does to the ash characteristics. In addition, as discussed in Section 4.2.1, changes to air pollution control technology can affect the physical or chemical characteristics of RMCs. Lack of consistent quality of spent foundry sand is also likely to limit the development of its beneficial use market.

The state CCP reviews help shed light on this potential barrier. The Texas CCP review notes that CCP generators and ash marketers each have stringent quality assurance/quality control (QA/QC) protocols, yet the Texas Department of Transportation (TX DOT) and ready-mix producers indicated that coal fly ash storage capacity is limited, affecting users' ability to store consistent supplies, and the quality of coal fly ash on a truck-by-truck basis is not consistent. If there is a change in combustion operations, there is a resulting change in ash quality, making it

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[69] Ongoing research at Iowa State University, sponsored by FHWA, several state DOTs, and industry is investigating the cause of scaling in GGBFS concrete.

[70] C1157-00 - Standard Performance Specification for Hydraulic Cement

[71] ASTM and AASHTO documents are now harmonized with respect to ASTM C 150 portland cement. However, AASHTO specifications as of this review do not include a performance cement specification analogous to ASTM C 1157.

difficult to produce a consistent product. In addition, TX DOT noted instances when coal fly ash was not available, even though it had been specified for a project.

The Florida CCP review also points out that producing a good-quality, consistent CCP is not easy when plant operators at the utilities have not made this outcome a priority. Some Florida electric utilities are using or are considering investing in beneficiation systems to produce concrete-grade coal fly ash, which will allow some coal fly ashes with high unburned carbon or ammonia content to meet ASTM C618 specifications for use in concrete.[72]

4.2 Legal, Regulatory Policy, and Contractual Barriers

Laws, regulations, and contractual policies may pose inadvertent barriers to increased use of RMCs. In this section, we consider a diverse set of influences, including the following:

- Air pollution regulations;
- State solid waste regulations;
- Bidding procedures and contractual constraints; and
- Barriers associated with CPG

4.2.1 Air Pollution Regulations

Industry stakeholders, State of Florida officials (EERC, 2006), and other state agencies have stated that regulatory programs for the control of mercury and nitrogen oxides (NOx) in electric utility air emissions can result in increased carbon levels in coal fly ash that impact the ability to use the ash as a supplementary cementitious material. The increased carbon levels result from the addition of activated carbon to control mercury emissions, and low temperature boilers to control NOx emissions which also result in increased levels of unburned carbon in the ash. Industry representatives understand that there are technology choices that would minimize these impacts on the beneficial use of coal fly ash. However, they indicate that the selection of air emission controls to meet state and federal requirements is very complex, resulting in industry solutions that will be unit-specific. Industry further indicates that, in many cases, some facilities may lose anywhere between $40/ton and $80/ton of coal fly ash (Hg-CCP dialogue mtg. summary Final Draft, 1/14/08) if they are no longer able to sell high carbon fly ash as a supplementary cementitious material in the manufacture of concrete. This estimate also includes the additional costs associated with the need to dispose of a formerly marketable by-product.

The Texas CCP review also notes that emissions control in the electric utility industry has had a subsequent impact on the type, quantity, and quality of the solid materials produced at a specific power plant (EERC, 2005). Officials indicate that the reduced supply of high quality coal fly ash already poses a threat to coal fly ash use in TX DOT projects, where high volumes of consistent quality coal fly ash are needed over the duration of large, long-term projects.

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[72] One concern noted with respect to this consideration, however, is that any combustion facility associated with the use of carbon burnout (CBO) systems may be categorized by FDEP as a new NO_X source. If categorized in this manner, the installation of CBO systems may trigger New Source Review (NSR) requirements under the Prevention of Significant Deterioration provisions of the Clean Air Act.

EPA will continue to monitor the emission technologies the industry chooses to install and the impact on reuse potential. EPA believes that technology options are available to the industry, specifically for the application of NOx controls, which would minimize any impacts on the quality of fly ash. Technology solutions are being developed and deployed in the industry to minimize or avoid any such impacts from the use of mercury controls as well.

4.2.2 State Solid Waste Regulations

There are no uniform, national regulations for the beneficial use of recovered materials. Each state has its own regulatory program. Although many states are acting to facilitate the use of RMCs in concrete, some state solid waste regulations governing the management of RMCs may make it more difficult to beneficially use these materials. For example, in the Florida CCP review, some observers thought that state monitoring and other requirements were restricting beneficial use requests. In some cases, the Florida Department of Environmental Protection (FDEP) has required end users to install liners under temporary CCP storage areas as a precautionary measure. FDEP also requires the material to be covered. Additionally, there is hesitation from FDEP to allow CCP use in land applications, limiting the Florida Department of Transportation’s ability to use it in road-building applications. The Florida review notes that some commenters viewed these requirements as unnecessary because they do not apply to comparable materials, or even to materials that interviewees considered to be of greater threat of environmental contamination, such as coal or limerock. CCPs are essentially being treated as a regulated solid waste by FDEP in this regard (EERC, 2005).

Experience with Florida’s beneficial use application regulations further highlights the influence of solid waste regulation on the beneficial use of RMCs. The Florida CCP review notes that FDEP does not have a formal process for approving new beneficial use applications. Florida statutes generally define “solid waste” to include any discarded material resulting from domestic, industrial, commercial, mining, agricultural, or governmental operations. This includes CCPs. However, there is another provision in Florida’s statutes that exempts certain materials from regulation as solid waste if:

1. A majority of the industrial byproducts are demonstrated to be sold, used, or reused within one year.

2. The industrial byproducts are not discharged, deposited, injected, dumped, spilled, leaked, or placed upon any land or water so that such industrial byproducts, or any constituent thereof, may enter other lands or be emitted into the air or discharged into any waters, including groundwater, or otherwise enter the environment, such that a threat of contamination in excess of applicable department standards and criteria is caused.

3. The industrial byproducts are not hazardous wastes as defined in the 2007 Florida Statutes (Title XXIX, Chapter 403, Part IV, and Section 703.)

Currently, FDEP does not have a rule implementing this section. Sometimes, FDEP points applicants to beneficial reuse guidance documents prepared for recovered screen material and waste-to-energy ash. Until a rule is promulgated, however, beneficial use projects are evaluated on a case-by-case basis. FDEP acknowledges that the current case-by-case approval procedure for CCP beneficial reuse is unclear.

Texas was also selected as a pilot state for an in-depth review of its CCP programs, policies, and use practices because of its progressive approach to CCP utilization and its support network to implement such activities. Although the Texas state review discussed barriers for all applications, we summarize only those specific to CCP use in portland cement and concrete:

- Virtually all of the utilities, ash marketers, and ready-mix producers mentioned attitude and education as key barriers. District and local highway personnel, architects, engineers, and contractors cited unfamiliarity, lack of knowledge, or unwarranted negative feelings toward CCPs as barriers to greater CCP utilization.

- CCP generators and ash marketers each have stringent quality assurance/quality control (QA/QC) protocols, yet TX DOT and ready-mix producers indicated that fly ash storage is limited, and the quality on a truck-by-truck basis is inconsistent. If there is a change on the combustion side, there is a resulting change in ash quality, making it difficult to produce a consistent product. In addition, TX DOT noted instances when coal fly ash was specified for a project, but was not available.

- By classifying CCPs as products, the material has the same advantages as all other recycled materials. However, liability lies primarily with generators and users because generators assume the responsibility of classifying the material in accordance with 30 Texas Administrative Code (TAC), Chapter 335.4, Subchapter R, and users take on the liability of using the material properly.

In addition to identifying existing impediments, the Texas state review identified several emerging issues that may affect CCP use in the future. These include new pollution control requirements (as discussed in Section 4.2.1) and the ability to retain institutional knowledge of CCPs as staff is turned over at the Texas Commission on Environmental Quality (TCEQ) and the Texas Department of Transportation.

4.2.3 Bidding Procedures and Contractual Constraints

Bidding procedures and contractual rigidities associated with procurement of portland cement and other RMC-related products may inadvertently constrain the use of RMCs. Industry sources note that contracts generally discourage changes in cement mix design. To counter these concerns and provide a consistent product, a contractor might default to a portland-only mix or one that contains less of the RMC (e.g., out of a concern for seasonal shortages of the RMC).

Contract specifications may force more competition among RMCs than necessary. Specifically, some specifiers (particularly some state DOTs) do not allow ternary mixtures (three-cementitious components) in concrete, so concrete is “forced” to use either coal fly ash or slag cement, if RMCs are to be used. However, ternary mixtures often provide performance benefits in concrete. Allowing ternary mixtures provides the possibility of using both coal fly ash and slag cement at significant rates in concrete, and also provides a way to replace greater levels of portland cement than just coal fly ash substitution alone. For instance, the Iowa DOT typically uses a mix of 15% coal fly ash and 20% slag cement; coal fly ash alone would likely not be used at a 35% replacement rate, but the two materials in combination works well for this DOT (SCA, 2007).

In some cases, the beneficial use of RMCs is constrained by the lack of familiarity with the RMC or preference for a well-known RMC, and these tendencies are reflected in procurement procedures. For example, specifiers often do not understand the difference between slag cement and coal fly ash. Since slag cement is generally a “newer” material in markets, these practitioners are often reluctant to allow slag substitution rates at their optimal level (up to 50% for pavements and up to 80% for mass concrete). They are more accustomed to coal fly ash substitution rates of 15% to 30%. This is reflected in a number of State DOT specifications that do not allow more than 25% slag cement (Arkansas, Illinois, Missouri, New York, and Vermont). SCA is working with FHWA to produce a users’ manual for highway engineers about slag cement (SCA, 2007).

4.2.4 Barriers Associated With CPG

The CPG for cement and concrete require Federal agencies to give a procurement preference for recycled materials and products containing RMCs, when possible. However, a procuring agency might not always be able to purchase a CPG-designated item containing RMCs. RCRA Section 6002(c)(1) allows a procuring agency the flexibility not to purchase an EPA-designated item with recovered materials content. According to the statute, the decision not to procure such items must be based on a determination that such procurement items:

1. Are not available within a reasonable period of time;
2. Fail to meet the performance standards set forth in the applicable specifications;
3. Fail to meet the reasonable performance standards of the procuring agencies; or
4. Are only available at an unreasonable price.[73]

Over or inappropriate use of these exemptions could contribute to unnecessarily reduced RMC usage. Similarly, management inattention to the statutory procurement requirements could lead to failure to use RMCs.

4.3 Economic Barriers

Economic barriers to increased RMC utilization represent a key factor affecting the use of RMCs. The sections below present a brief discussion of the key economic barriers affecting increased RMC use. The following barriers are discussed:

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[73] RCRA Section 6002, http://epa.gov/epaoswer/non-hw/procure/pdf/rcra-6002.pdf

- Transportation costs and geographic distribution;
- Importance of RMCs as a revenue stream;
- Cost-effectiveness; and,
- RMC disposal costs.

4.3.1 Transportation Costs and Geographic Distribution

RMCs are not necessarily generated in the vicinity of cement kilns or major construction projects or, in the case of foundry sands, are generated by a relatively large number of generators producing relatively small quantities. The costs of collecting and transporting these materials from their points of generation can render them uncompetitive with virgin materials at a specific site. For example, the ACAA notes that transportation costs are the primary economic impediment to the reuse of CCPs. ACAA estimates that such costs generally limit the shipment of CCPs to a 100-mile radius around a power plant. In addition to the problems posed by distance, using railcars to transport RMCs also presents issues because railcar availability is limited, and rail transportation rates are high in certain markets. This issue also applies to virgin materials; however, the geographic distribution and specific transportation costs are likely to vary from those for CCPs.[74]

Studies have noted the sub-optimal geographic location of RMC supplies, particularly coal fly ash and bottom ash. The best example of the lack of local availability is in California, where essentially no coal-fired power plants and no blast furnaces exist. However, depending on the size and scale of the project, the lack of proximate coal fly ash and related transportation costs may be overcome. For example, the large CalTrans Bay Bridge project imported coal fly ash from Washington and Wyoming, and the additional cost of transportation was minimal when compared to the entire project budget.[75]

As discussed in Section 4.1.3, different coals produce different ashes and an electric utility could switch among coal sources for various reasons (price, transportation costs, sulfur reduction, etc.) without consideration as to what this does to the ash. In an October 29, 2001, letter to EPA, DOE commented that “DOE sites have expressed concerns about the proposed concrete additives. An operations office in the western part of the country has stated…that cenospheres and silica fume additives for concrete may not be as readily available in all locations as EPA suggests” (DOE, 2001). This overbalance can be an impediment, as only certain areas of the country have access to RMCs, and transportation costs are too great to move the materials to areas with a relatively low supply of RMCs.

Likewise, slag granulation facilities are principally in the East, Midwest and South, so for adequate slag cement to reach more remote areas, like the West Coast, imports become essential. Bulk transportation over water is significantly less costly and energy intensive than transportation by highway or rail. Additional slag granulation facilities, if constructed in the

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[74] ACAA reports: As the value of coal fly ash has risen in the last two years, ash is typically trucked up to 100-150 miles without difficulty. Rail shipments have increased to more than 1200 miles.

[75] Personal communication with Tom Pyle, California Department of Transportation (CalTrans), August 30, 2007.

Midwest or East, would help improve the geographic distribution somewhat, but not to the Rocky Mountain or West Coast states (SCA, 2007).

In addition, seasonal factors can influence both the amount of RMCs produced (e.g., increased summer and winter power demands result in seasonal increased CCP production) and the demand for building materials (EPA, 2005b). Lack of product availability in certain markets can be a significant impediment to greater reuse. The shortage of coal fly ash in the Pacific Northwest in 2006 illustrates the impact of product non-availability. Construction specifications are prepared years in advance of construction. If an RMC is abundant, and included in the specification, but availability declines when construction starts, it may become a frustrating and costly problem for the contractor. Such an event could cause an agency to be cautious about including the RMC in future specifications.

The Texas state review (EERC, 2005) echoes the importance of transportation costs to the beneficial use of CCPs. In Texas, power plants are located in areas that are not heavily populated, so long distance transportation is necessary to get to major CCP markets. Some electric utilities also have limited infrastructure, making it difficult to transport their materials by anything other than by truck. In many instances, it is simply not economical to use CCPs due to these costs.

Finally, in relation to transportation costs and GGBFS distribution, foreign sources of RMCs can influence the reuse rate of domestic supplies. For example, the U.S. currently imports significant quantities of GGBFS from overseas because of low rates of slag granulation in the U.S., as well as that it is more economical on the West Coast to import GGBFS from the Far East than to ship it across the United States. (See further discussion below regarding the Cost of Increasing Slag Granulation Capacity.) Furthermore, bulk transportation over water is significantly less costly and energy intensive than transportation by highway or rail. Availability of foreign sources may enhance the economic disadvantage introduced by overland transportation costs.

4.3.2 Importance of RMCs as a Revenue Stream

The way in which utilities, and all RMC generators, account for costs is critical to RMC utilization (EERC, 1999). For example, for many utilities, the sale of CCPs is generally seen as merely a means of reducing operational costs through avoided disposal costs. When ash management is considered “an operational cost avoidance” rather than a revenue stream, the incentives for increased CCP utilization are reduced as compared to it being a source of revenue.

The market value of RMCs is critical to how a supplier views the management of these materials. For coal-fired electric utilities, the revenue produced by the sale of CCPs is often insignificant in relation to the revenue stream provided by the sale of electricity. The prices received for CCPs may be too low to justify a commitment to material marketing.

4.3.3 Cost-Effectiveness

The high price of some RMCs can be an impediment to their greater use. In a letter sent from DOE to EPA on October 29, 2001, a DOE northwest office advises that “…Unlike fly ash where the cost with or without fly ash is the same, including silica fume increases the cost by about $1 per pound. A typical [cubic] yard of concrete will use nearly 50 pounds of silica fume, which would increase the cost roughly 50%-65% for each [cubic] yard of concrete used" (DOE, 2005b).[76]

It is noteworthy, however, that RMCs with high unit prices (e.g., GGBFS and silica fume) also can have high reuse rates. Therefore, high prices may often be a reflection of the high inherent value that some of these materials have as portland cement and concrete additives.

It should also be noted that some individual foundries may choose to engage in a partnership with an intermediary as a cost-effective way to market and sell its spent foundry sand. The costs to market the sand may be higher than the firm is willing to spend and will look to a middleman to conduct the sales transactions. If the costs of selling were lower, or if the selling price were higher, the foundries may be more willing to handle the process themselves.

Finally, slag granulation in the U.S. affects the cost-effectiveness of this material for use as an RMC. The slag granulation rate in the U.S. is considerably lower than other industrialized nations. In the U.S., only 25% of slag is granulated, while in Europe and Japan, nearly 80% of blast furnace slag is granulated. Several reasons for the low U.S. granulation rate exist, including uncertainty and consolidation in the steel industry; capital cost of installing granulation/grinding facilities; and availability of foreign slag granules (SCA, 2007).

4.3.4 RMC Disposal Costs

The relatively low cost of disposal tends to discourage the expanded use of many RMCs in cement and concrete. Disposal costs are a function of available disposal sites. For Electric Utilities, as part of the permitting process for any new facility or upgrade to an existing facility, the permit must describe what is anticipated for any waste or byproduct streams. Existing plants typically have sites near the plant for disposal, if needed. They may be owned by the utility (most common) or nearby, such as a locally managed landfill (not necessarily a municipal solid waste landfill), most likely a monofill. Given the nature of privately-owned and industrial waste landfills, total available capacity at these sites is uncertain. However, according to the National Solid Wastes Management Association, as of November 2006 there were approximately 1,654 Subtitle D landfills operating in the 48 contiguous states.[77] Furthermore, on a national level, the current municipal solid waste landfills have 20 years worth of disposal capacity available.

For many RMC generators, the market value of the material does not make up for the handling, processing, and marketing costs of selling the material for beneficial use. Current beneficial use

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[76] SFA indicates that "the primary impression of silica fume as a raw material and silica fume concrete in general is that 'silica fume is quite expensive' and as a concrete 'more difficult' and 'costly' to finish as compared to concrete containing no silica fume. This industry impression as an expensive material has limited the use of silica fume and is the primary obstacle to further expanding the use of silica fume in concrete" (Kojundic, 12/13/2006). (Note: USGS reports that further use of silica fume is primarily limited by the inelastic supply of silica fume, as a result of the relatively inelastic global supply of silicon metal and ferrosilicon and related ferroalloys production. (Personal communication with Hendrik van Oss, USGS, July 12, 2007.))

[77] National Solid Wastes Management Association, November 8, 2006, "MSW (Subtitle D) Landfills." Available at: http://wastec.isproductions.net/webmodules/webarticles/anmviewer.asp?a=1127

programs from states, Associations, and EPA are helping to expand the beneficial use of these materials. However, as long as it is more economical to dispose of the RMCs in land disposal units than to use them beneficially or to sell them as a marketable product, use rates will likely be limited.

4.4 Perceived Safety and Health Risk Barriers

Another barrier to the expanded beneficial use of RMCs concerns the safety and health risks – real or perceived – associated with these materials, i.e., the environmental risks associated with exposure to these industrial materials if they enter the environment through leaching into soil or other pathways. The issue of risk continues to be evaluated by the Agency. However, targeted risk analyses conducted to-date indicate that risks associated with the identified RMCs in cement and concrete are likely to be insignificant. For example, in the Agency's May 2000 Regulatory Determination for fossil fuel combustion wastes, EPA's risk evaluation of the beneficial use of CCPs in cement and concrete concluded that national regulation under the Resource Conservation and Recovery Act (RCRA) is not warranted.[78] This final Regulatory Determination additionally notes a previous Regulatory Determination in 1993 (see 58 FR 42466; August 9, 1993), an EPA-proposed risk-based set of standards for CKD (see 64 FR 45632; August 20, 1999), and an unpublished report as of May 22, 2000 from the National Academy of Sciences presenting "a comprehensive review of mercury and recommendations on appropriate adverse health effects levels for this constituent." Additional research concerning steel slag includes a study conducted by Deborah M. Proctor, et al.: "Assessment of Human Health and Ecological Risks Posed by the Uses of Steel-Industry Slags in the Environment," 2002. *Human and Ecological Risk Assessment* Vol. 8, No. 4, pp. 681-711.

Findings from these analyses did not identify significant risks to human health and the environment associated with the beneficial uses of concern. In addition, we identified no documents providing evidence of damage to human health and the environment from these beneficial uses. Our overall conclusions from these efforts, therefore, are that encapsulated applications, including cement and concrete uses, appear to present minimal risk.

EPA has also supported risk analyses associated with the beneficial use of foundry sand. The Agency concluded that the use of foundry sand as a substitute for natural silica sand in making clinker, as a substitute for natural sand in cement, or in other uses in concrete manufacture, appears to present minimal risk to human health and the environment.

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[78] http://www.epa.gov/epaoswer/other/fossil/ff2f-fr.pdf

5.0 MECHANISMS TO INCREASE THE BENEFICIAL USE OF RMCs

This section addresses Part (C) of the Congressional mandate requiring EPA to identify potential mechanisms to achieve greater substitution of RMCs in cement and concrete products. The discussion covers a broad suite of existing and potential mechanisms, and contemplates mechanisms that are both within and beyond the immediate purview of EPA and its partner agencies. To help align these mechanisms with the barriers described in Section 4, we group the discussion into three categories followed by a generalized set of mechanisms:

- Procurement policies and material use standards;
- Education, technical assistance[79], and recognition programs; and
- Economics

Several of the mechanisms described within each category are generally applicable to most types of RMCs.[80] Consistent with the Congressional charge, however, we also focus on certain RMCs that have historically only been beneficially used at lower levels than other RMCs. For example, the discussion under "Education, technical assistance, and recognition programs," covers programs focused on increasing the use of coal fly ash and foundry sand in cement and concrete.

As presented, many of the mechanisms described in this section apply to non-Federal, as well as Federal projects. The amount of RMCs produced annually in the U.S. surpasses the amount that can be incorporated into Federal cement and concrete projects alone. Thus, we consider this broader application of potential mechanisms due to the fact that increasing reuse rates to higher levels will require greater reuse among both Federal and non-Federal cement and concrete projects.

Finally, this section represents the collective input of a variety of different stakeholders, and includes a wide range of options that have been proposed in various contexts.[81] Some of these options may be outside the scope of the mechanisms and issues that EPA has control over. Further, several of the mechanisms outlined in this chapter may require additional resources to complete and sustain into the future. However, we include this broad range of ideas for the purpose of documenting and briefly discussing the various options contemplated.

5.1 Procurement Policies and Material Use Standards

Procurement policies offer the opportunity to stimulate demand for products making beneficial use of RMCs. We consider several aspects of procurement policies:

- We first review implementation of EPA's CPG and efforts to assess their impact on the beneficial use of RMCs;

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[79] Includes technical research.

[80] Several of the mechanisms discussed in this chapter are similar in nature to those proposed by: Buckley, Tera D., and Debra F. Pflughoeft-Hassell, "National Synthesis Report on Regulations, Standards, and Practices Related to the Use of Coal Combustion Products," Energy & Environmental Research Center, University of North Dakota. Draft Final Report, July 2007.

[81] The full set of mechanisms identified by industry representatives is summarized in Appendix E to this report.

- Next, we consider efforts to revise engineering and procurement standards to optimize the substitution of RMCs in concrete and cement; and
- Finally, we examine how modifying building and construction standards could help increase the beneficial use of RMCs.

5.1.1 Influence of EPA's CPGs on RMC Beneficial Use

Since its inception, procuring agencies, including EPA, have developed a multi-faceted approach to implement RCRA section 6002 and the CPG program. Components of this approach have both broad and specific relevance to the use of RMCs in Federal concrete projects, including: (1) expanding the number of RMCs covered by the CPG; (2) strengthening and streamlining policy guidance related to green purchasing requirements, implementation, and reporting; and (3) developing and delivering information resources, training, and outreach activities.

With respect to item (1) above, the RMCs currently covered by the CPG include coal fly ash, GGBFS, silica fume and cenospheres. Specifically in 1983, EPA's original procurement guideline designated cement and concrete containing coal fly ash. EPA subsequently amended the designation in May 1995 (CPG III) to include cement and concrete containing GGBFS, and again in April 2004 (CPG IV) to add silica fume and cenospheres.[82]

To translate the CPG designation of an item into actual purchases, procuring agencies are subject to a number of implementation and reporting statutory requirements. For example, procuring agencies that purchase more than $10,000 of a CPG item are required, by RCRA Section 6002, to establish (within one year after the item has been listed) an affirmative procurement program for that item. An affirmative procurement program is an agency's strategy for maximizing the purchase of an EPA-designated item. Affirmative procurement programs should be developed in a manner that assures that items composed of recovered/recycled materials are purchased to the maximum extent practicable. Over the years, these programs have been bolstered by a number of Executive Orders; the most recent, Executive Order 13423, requires that Federal agencies promote the purchase of energy efficient, recycled content, biobased, and environmentally preferable products through their purchasing requirements.[83]

With particular relevance to RMC use in Federal cement and concrete projects, the FHWA and other DOT grant programs are explicitly included as purchasing agencies under RCRA Section 6002, as explained by the conference committee report from the Hazardous and Solid Waste Amendments of 1984 (Cong. Rec. H 11138 [October 3, 1984]):

> *To assure the fullest participation by procuring agencies, the Conferees wish to resolve any ambiguity with respect to §6002's coverage of the Department of Transportation, in particular the Federal Highway Administration (FHWA). The*

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[82] U.S. EPA, Comprehensive Procurement Guidelines, About CPG/RMAN, from http://epa.gov/cpg/about.htm.

[83] Adapted from: "Fact Sheet: Executive Order 13423 Strengthening Federal Environmental, Energy, and Transportation Management," The Office of the Federal Environmental Executive. OFEE and OMB require agencies to have holistic green purchasing plans that include the EPA-designated recycled content products with other green products and services, rather than a separate affirmative procurement program just for the EPA-designated products.

> *FHWA is a "procuring agency" under the Solid Waste Disposal Act and is therefore fully responsible for implementing the guidelines and other requirements of §6002. It is the intent of Congress that both FHWA's direct procurement and indirect Federal-aid programs (Federal Highway Trust Fund) be covered by the requirements of §6002 as amended by this Act. Indirect purchases by the Federal Aviation Administration are also covered under Section 6002 in the same manner as is the FHWA. Coverage of the FHWA's direct and indirect procurement activities under this amendment extend to the review of procurement specifications pursuant to Section 6002(d), as amended, in addition to the affirmative procurement program required under this section.*

Recent efforts have also focused on improving the quality of procurement data and streamlining the reporting process for Federal agencies. For example, in an effort to increase Federal purchasing of energy efficient, recycled content, biobased, and environmentally preferable products, E.O. 13423 and related guidance require agencies to integrate four existing disparate purchasing requirements into an integrated Federal purchasing effort that applies to all types of acquisitions of goods and services.[84] The Order requires every year that agencies track and report on their purchases of EPA-designated recycled-content items.[85]

Section 6002 of RCRA requires the Office of Federal Procurement Policy (OFPP) to report to Congress every two years on the actions taken by Federal agencies to implement Section 6002. When it became clear that it was not possible to gather accurate information on every agency's purchases of individual EPA-designated products, OFPP and OFEE convened a workgroup to create a new reporting format. Materials, such as concrete, are supplied or used as part of construction contracts. Contractors generally do not report on the volume of materials supplied or used, let alone the recycled content of materials. For this reason, agencies now provide other evidence of compliance in the annual data reports.

The reporting questionnaire focuses on compliance, training, and auditing and trends analysis to foster increased accountability for program implementation. In the case of construction products, it asks agencies to "Demonstrate how your agency complies with the requirements to purchase EPA-designated construction products containing recovered materials, to the maximum extent practicable. Examples include integrating specific, recycled-content products requirements with the use of the U.S Green Building Council's Leadership in Energy and Environmental Design (LEED), incorporating recycled-content product requirements into design specifications, and inserting recycled-content product requirements into design/build contracts."

To optimize program performance, implementation and reporting procedures are supplemented with information resources and training activities. Outreach and inter-agency collaboration activities also occur on an ongoing basis.[86]

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[84] Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," Fact Sheet.

[85] Strengthening the Federal Environment, Energy, and Transportation Management, January 27, 2007.

[86] For a more detailed discussion of these efforts, see, for example: Office of Management and Budget; Office of Federal Procurement Policy, "Resource Conservation and Recovery Act: A Report on Agencies' Implementation for Fiscal Years 2002 and 2003," October 2005.

This multi-faceted approach to green purchasing has led to many successes, including influencing the amount of RMCs procured for use in concrete products. As one example, for agencies that gather data for specific designated items, for FY 2003, more than 80% of the concrete purchases made by NASA, DOE, and GSA contained coal fly ash or slag. The CPG program, therefore, represents a critical mechanism to achieve higher RMC reuse levels.

To continue and expand upon this progress, however, the procurement guidelines and their implementation are the focus of ongoing improvement efforts. These efforts cover the facilitation role played by EPA, OFPP, and OFEE under the auspices of RCRA 6002 and the Executive Orders, and extend to on-the-ground decision-making of Federal procurement entities and their reporting obligations. We discuss these issues in further detail below.

5.1.2 Discussion of Response to CPGs for RMCs in Concrete and Cement

A number of governmental reports and reviews have commented on the efficacy of purchasing programs for recycled-content products, including, by implication, concrete products containing RMCs.[87] The conclusions drawn in these commentaries focus on two general limitations: (1) the lack of robust reporting data on volumes of purchased products and related inability to link such volumes to the influence of procurement requirements; and (2) the need for expansion of guidance and tools to facilitate the procurement of products with recycled content. In addition, with respect to RMC reuse and procurement requirements, several stakeholders have suggested that addressing various issues related to material standards and specifications, along with contract bidding procedures, may positively influence reuse rates.

5.1.2.1 Data Limitations

The extent to which the major Federal procuring agencies have purchased products containing RMCs is difficult to measure because few data systems clearly identify purchases of recycled-content products. In addition, agencies do not receive complete data from their headquarters and field offices or their contractors and grantees. As a result, they generally provide estimates, not actual first-hand data, to the OFPP and OFEE.[88]

Industry commenters (e.g., Holcim, Ltd.) emphasized the need for a centralized reporting system that tallies the amount and type of recycled cement/concrete products used in Federally-funded projects. In addition, GAO issued the report “Federal Procurement: Better Guidance and Monitoring Needed to Assess Purchases of Environmentally Friendly Products” in 2001 to evaluate the status of, and barriers to, Federal agencies’ efforts to implement RCRA requirements for procuring products with recycled content. The GAO report contained suggestions focusing on improving procurement processes, guidance, and data systems.

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[87] See, for example, Statement for the Record by David G. Wood, Director, Natural Resource and Environment Issues, US General Accounting Office, July 11, 2002 (GAO-02-928T).

[88] June 2001, GAO report, “Federal Procurement- Better Guidance and Monitoring Needed to Assess Purchases of Environmentally Friendly Products”

Improvements in data collection also were highlighted in “Leading By Example: A Report to the President on Federal Energy and Environmental Management (2002-2003).”[89]

One example of how relevant procurement data are difficult to both derive and interpret involves the recent analysis of agencies’ Federal Procurement Data Systems (FPDS) data. This review indicated that recycled content products were not being supplied or used in more than 95% of the contracting actions in FY 2002 and FY 2003. While the agencies have not completed their assessment of the FPDS data, EPA believes that the amount of material procured does not accurately reflect the range of products that can be supplied or used as part of support services contracts.

Better reporting, resulting from the initiatives noted above, should yield a more comprehensive information resource to evaluate the performance of the CPG program and identify further areas for targeted improvement.[90] Detailed data from each contract on the materials, sources, tonnages, haul distances, and mixture proportions would significantly improve the documentation and assessment of RMC benefits in Federal concrete projects. It is important to note, however, that with respect to RCRA Section 6002; EPA, OFPP, and OFEE provide only a facilitation role, and have no oversight or compliance assurance authority. These obligations fall to the individual procuring agencies.

One option for increasing compliance could include OFEE using an awards program to focus on Agencies’ efforts to purchase products with RMCs. OFEE and OFPP can provide negative and positive recognition during the annual Federal budget process. Agencies implementing the CPG guidelines and the EO goals and policies can be rewarded.

5.1.2.2 Procurement Facilitation

The ability of agencies to procure recycled content products is subject to a number of considerations related to information availability, logistics, and costs, among others. EPA and partner agencies continue efforts to provide agencies with the information necessary to effectively promote the purchase of products with recycled content. These efforts focus on outreach, training, and education, along with making relevant information more readily accessible. For instance, one area of concern is that green purchasing mandates may not be effectively extended to government contractors or grantees. As one measure to address this concern, OFEE has revised its training for contracting personnel to emphasize that recycled content and other green products are often supplied or used. Contracting personnel are taught that contracts should require a contractor to supply or use green products.

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[89] “Leading By Example: A Report to the President On Federal Energy and Environmental Management (2002-2003).” October 2004, from http://ofee.gov/final_report1.pdf.

[90] For example, with more robust reporting data, the RCRA agency data report could be amended to include more specific questions for agencies regarding their purchases and usage of RMCs in construction projects. Currently, due to data limitations, it only asks for a prepared document generally discussing efforts of the agency and not the specific quantities of material used.

5.1.3 Specifications and Bidding Procedures

Another set of suggested mechanisms to increase the use of RMCs focuses on the development of engineering and procurement standards to optimize the substitution of RMCs in concrete and cement. Industry representatives consulted for this report offered observations on how the CPGs could be made more effective. For example, SCA stated that the CPGs should have more explicit requirements regarding replacement rates and the use of ternary mixtures. In addition, the CPGs could have a greater impact if several actions were taken when the review protocol recommends specification changes: (1) reissue the specifications if there is time prior to the project bid date; (2) if the project has already been bid, then require re-bidding; and (3) withhold Federal funding if the project specifiers do not change the specifications.

Some efforts are already underway to implement these mechanisms. For instance, the cement industry has recently promoted the acceptance of the Standard Performance Specification for Hydraulic Cement ASTM C1157 to the DOT's FHWA, Federal Aviation Administration (FAA), Corps of Engineers, and Bureau of Reclamation; however, to date, the effort has met with limited success. There also is a separate effort to harmonize the AASHTO and ASTM standards via an ASTM/AASHTO Task Group, but successful completion of this effort will also take time. In the interim, some companies have modified specifications to their cement to address early strength issues. For example, Holcim has decreased the slag content in its IS blended cement to address seasonal concerns, and the company is currently evaluating the use of different grinding aids that will address the perceived set/strength issue. The cement industry as a whole has taken measures to emphasize the need for proper finishing and curing techniques to offset the scaling issue.

In general, the development of standards for optimized substitution is feasible, provided that the effort is based on a process where the stakeholders with concerns about quality, cost, and risk can participate and identify solutions that address the priorities of each group. However, this process, as noted above, can require significant time to arrive at an acceptable solution, and will require participation of enough government and industry leaders to provide momentum for moving toward a nationally consistent application of standards in different state and local jurisdictions.

5.1.4 Building Standards

Standards for building and construction offer another avenue for increasing the beneficial use of RMCs. First, integrating environmental building requirements into Federal, state, and local public building standards could help promote the use of RMC-based materials. Second, specifications outlining the use of RMCs could be integrated into building contracts. In conjunction with the economic measures described below, the incorporation of additional RMCs into building standards could potentially have a large impact on increased RMC use. We discuss these options below.

5.1.4.1 Building and Construction Industry Practices

The U.S. Green Building Council's LEED Green Building Rating System® is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings.

RMC use constitutes only one LEED credit; however, the reduction in GHG that may result from increased RMC could satisfy other credits.

The potential for building industry standards such as LEED to be written into Federal, state, and local public building standards offers a simple method for increasing SCMs in cement and concrete (PCA, 2003). By explicitly identifying building standards that include the use of RMC-based cement and concrete, the building and construction industry will likely become more familiar with these materials and increase their use. In fact, certain Federal agencies already use LEED and have found that familiarity with sustainable design and green materials among architects and construction contractors has been increasing. Modification of building standards could be further pursued in concert with broader green building efforts. Projects, such as the Green Building Initiative, for example, "work with builders and their associations to facilitate understanding and acceptance of sensible green building practices."[91]

Furthermore, continued CPG implementation by FHWA and additional promotion of the Green Highways Partnership are likely to alter current transportation construction practices as RMC use is increased as a result of new practices and usage patterns. See Section 5.2.3 for information on the Green Highways Partnership.

5.1.4.2 Specifications within Building Contracts

EPA and other stakeholders have recognized the need for a guide for procuring green building products and construction services through Federal contracts. In response, EPA has partnered with the Federal Environmental Executive and the Whole Building Design Guide (WBDG) to develop the *Federal Green Construction Guide for Specifiers*.[92] This guide helps Federal agencies meet their project-specific environmental goals and mandates, and includes the following components:

- Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding;
- EPA's Final Guidance on Environmentally Preferable Purchasing;
- Greening of Government Executive Orders;
- EPA's CPGs for recovered content;
- USDA's Biobased Purchasing Program;
- ENERGY STAR® & DOE Federal Energy Management Program (FEMP) Product Efficiency Recommendations;
- Energy Policy Act of 2005;
- ASTM, LEED, Green Globes, and other rating systems and standards; and
- Other "best practices" as determined via industry and public comment.

One effort in particular, the Federal Leadership in High Performance and Sustainable Buildings MOU, guides 19 Federal agencies in the design, construction, and operation of buildings.

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[91] The Green Building Initiative, "The GBI – A Better Way to Build." Accessed July 18, 2007 at http://www.thegbi.org/gbi/whatwedo.asp.

[92] See details at: http://www.wbdg.org/design/greenspec.php.

Among other recommendations, the MOU guiding principles include reducing the environmental impact of materials; concrete with RMCs is consistent with this objective. E.O. 13423, "Strengthening Federal Environmental, Energy, and Transportation Management," January 24, 2007, expanded the applicability of the sustainable building MOU's guiding principles from the 19 MOU signatory agencies to all Federal agencies.

Another effort, the Unified Facilities Guide Specifications (UFGS) is a joint effort of the U.S. Army Corps of Engineers, the Naval Facilities Engineering Command, and NASA. UFGS are for use in specifying construction for the military services. They include a guide specification for obtaining LEED certification, a general guide specification for referencing the EPA-designated products, and guide specifications for using RMCs in concrete, including coal fly ash, ground iron blast furnace slag, and silica fume.[93]

5.1.5 Summary of Potential Mechanisms Related to Procurement Policies and Material Use Standards

Below, we summarize the potential set of mechanisms contained in the above discussion. As indicated, in some instances, a lead role can be played by EPA, OFPP, and OFEE as part of their Section 6002 facilitation efforts, while other mechanisms require collaboration across multiple agencies, or a lead role by procuring entities. In addition, certain mechanisms may merit statutory authorization. The potential mechanisms include:

- Integrate and improve procurement systems, allowing for identification and tracking of cement and concrete purchases using RMCs and the RMC volumes utilized. As reporting systems allow, modify the RCRA agency data report to include more specific questions for agencies regarding their purchases and usage of RMCs in construction projects.

- Review all available options for oversight with the implementation guidelines of the CPG. This may involve working to increase awareness of CPG requirements and products and to change the perception that CPG is not mandatory. As a related matter, clarify the CPG clauses to RMC use and other technical standards associated with RMC use. Other options may include a system of negative or positive recognition in the annual Federal budget process, and through relevant recognition programs.

- Continue to work with other Federal agencies to implement policies favoring purchases of recycled materials. Several agencies (e.g., FHWA and DoD) already have such policies in place. In addition, increase outreach to vendors explaining the benefits to CPG material use.

- Develop effective information resources to promote RMC use, including (1) update and maintain the CPG Supplier Database[94] on a regular basis; (2) issue

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[93] For more information, see: http://www.wbdg.org/ccb/browse_org.php?o=70.

[94] EPA's CPG Supplier Database is a searchable database of vendors who sell or distribute CPG-designated products with recycled content. This tool allows users to search for vendors of a specific CPG product, product category, or

purchasing guidance documents RMANs recommending recovered material content ranges for CPG products based on the most recent information about commercially available products; and (3) develop other information tools as available resources allow.

- Expand training and outreach with OFPP, OFEE, and various green purchasing programs to provide training to Federal agency contracting, purchase card, and program personnel,[95] including more targeted training related to RMC procurement.

- Identify and develop optimization protocols for improved performance and increased benefits while increasing RMC use in cement and concrete.

- Continue to harmonize the AASHTO and ASTM standards.

- Promote the use of ternary mixtures in the CPG providing the possibility of using both coal fly ash and slag cement

- Continue to work with the Federal Environmental Executive and the WBDG to develop and promote the Federal Green Construction Guide for Specifiers.

- Aid in multi-agency based efforts to integrate environmental building requirements into Federal, state, and local public building standards, including, for example, industry standards such as LEED being written into Federal, state, and local building standards.

5.2 Education, Technical Assistance, and Recognition Programs

Education, research, technology development, demonstration, and outreach programs have the potential to improve the understanding of RMCs and their benefits, and to promote their beneficial use. Numerous government agencies (e.g., FHWA, USDA, EPA) have noted how these types of programs can help address perceptions that RMCs and associated products are inferior or deleterious to health and safety, and how they can improve the information base on which economic and technical decisions are made. Likewise, industry representatives (National Ready Mixed Concrete Association (NRMCA), the SFA, Headwaters, Inc.) consulted for this study have emphasized the importance of education programs for ensuring that end users (e.g., local and state transportation agencies) understand the reliability of RMC-based products.

Together with a number of industry, Federal, and state partners, EPA is undertaking a variety of research, education, and recognition efforts to increase RMC markets and use by improving the availability and flow of information about the beneficial use of a range of industrial materials. The discussion below examines several ongoing and prospective initiatives:

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type of material. In addition, users can search directly for a specific vendor by typing all or part of the vendor's name in a search field.

[95] See, for example, the training programs offered by OFEE at http://ofee.gov/gp/training.asp.

- The EPA coal combustion products outreach efforts;
- The EPA foundry sand outreach efforts; and
- Recent industry and public/private collaborations and research.

While the impact of these initiatives is still emerging, they illustrate programs EPA is conducting with the potential to increase the beneficial use of RMCs.

5.2.1 EPA Coal Combustion Products Outreach Efforts

The C^2P^2 is a collaborative partnership program with EPA, DOE, FHWA, ACAA, USDA, EPRI, USWAG and more than 150 partners. This partnership is currently working towards two goals. The first goal is to increase the beneficial use of CCPs from 31% in 2001 to 50% in 2011. The second goal is to increase the use of coal fly ash in concrete from 14 million U.S. tons in 2002 to 18.6 million U.S. tons by 2011.

With other partners, EPA is undertaking a number of research, education, and recognition efforts to improve the availability and flow of information about the beneficial use of CCPs. For example, a 2005 publication created by EPA, DOE, ACAA, FHWA, and USWAG, "Using Coal Ash in Highway Construction: A Guide to Benefits and Impacts," has helped to explain the environmental benefits and risks associated with the use of coal fly ash in construction applications. EPA also partnered with FHWA to write and publish, "Fly Ash Facts for Highway Engineers." This technical guide document has been widely distributed. In addition, over the last several years, the C^2P^2 partners have developed a set of projects to increase the amount of CCPs that are beneficially used. These projects include an awards program, which recognizes CCP users, as well as mechanisms designed to allow for a better understanding of the obstacles to the beneficial use of CCPs, and to identify both governmental and private initiatives to address these obstacles.[96] Some of these activities include sponsoring workshops, publishing information materials, and participating in information exchange forums.

The ACAA's annual CCP Production and Use Survey is the primary measurement instrument for C^2P^2 goals. EPA will report the amounts and types of CCPs reported by applicants to the C^2P^2 Awards Program. EPA works with ACAA to review the results of this survey, assessing trends in generation and beneficial use, with the ultimate goal of tracking the partners' progress toward achieving the 50% CCP usage goal by 2011. Through publication of case studies, EPA highlights current practices that result in the successful use of CCPs.

As previously noted, three state reviews have been conducted that examine CCP utilization practices and identify the specific factors that encourage or discourage the beneficial use within each state. These reviews bring together key stakeholders to discuss factors that affect increased CCP utilization. Upon completion of these reviews, EPA will compile the findings in a broader publication.[97]

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[96] In addition to C^2P^2 projects, EPA's regions have initiated their own projects that will also assist the beneficial use of CCPs.

[97] Texas and Florida reviews have been completed and released, and a review of Pennsylvania was completed in 2007.

In collaboration with the C^2P^2 partners, EPA has also held two C^2P^2 award presentations to recognize those partners who have made exceptional progress in promoting the beneficial use of CCPs. The C^2P^2 web includes fact sheets on project activities, as well as case studies, increasing the availability of information easily accessible online.[98] Further research and technical assistance is available via the construction initiative, created in partnership with DOE, FHWA, states, trade associations, and other parties, to facilitate the beneficial use of RMCs in large construction projects.

These collective efforts to increase the beneficial use of CCPs are likely helping to increase the amount of CCPs beneficially used each year. According to ACAA survey data, CCP beneficial use has increased from 32% in 2001 to 43% in 2006.[99]

5.2.2 EPA Foundry Sand Outreach Efforts

EPA has initiated several efforts to increase the reuse of foundry sand. For example, EPA has compiled and published the 2002 *Beneficial Use of Foundry Sand: A Review of State Practices and Regulations.* In addition, EPA partnered with FHWA to write and publish, "Foundry Sand Facts for Civil Engineers." This technical guide has been widely distributed. Moreover, EPA's Sector Strategies Division published, *State Toolkit for Developing Beneficial Reuse Programs for Foundry Sand,* in July 2006 (Toolkit).[100] Designed specifically to assist states that wish to develop or improve their foundry sand beneficial use programs, the Toolkit provides program options to states according to their desired preferences and available resources. Starting with a series of questions to help states determine what type of program to design, the Toolkit guides users through a three-stage, six-step roadmap for creating a foundry sand beneficial use program.[101] The Toolkit was developed through multiple Foundry Sand stakeholder meetings in 2005 and 2006.

5.2.3 Other Public/Private Collaboration and Research

A number of additional initiatives are being pursued by a variety of industry, not-for-profit, and governmental entities. We describe several such initiatives below.

The Green Highways Partnership. The Green Highways Partnership (GHP) is a public/private effort established to incorporate environmental considerations into the design, construction and operation of roads, beginning with the Mid-Atlantic Pilot. Environmental considerations include practices, such as using RMCs when constructing roads and buildings. RMCs can be used in all aspects of road construction – as a base layer, in the pavement, and in embankments. The Green Highway Partnership is now expanding into a national program designed to emphasis the use of recycled materials in highway construction. This new effort should also help focus the engineering, environmental, and economic reasons to use RMCs[102].

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[98] The C^2P^2 web site is at: http://www.epa.gov/epaoswer/osw/conserve/c2p2/.

[99] For more facts on C^2P^2, refer to http://www.epa.gov/epaoswer/osw/conserve/c2p2/pubs/facts508.pdf.

[100] The Toolkit is available at: http://www.epa.gov/sectors/metalcasting/foundry.html, accessed November 14, 2006.

[101] EPA has also published a document providing general information on foundry sand recycling which is available at: http://www.epa.gov/epaoswer/osw/conserve/foundry/foundry-st.pdf

[102] Information on the Green Highways Partnership can be found at: http://www.greenhighways.org.

FHWA has been instrumental in assisting EPA in making contacts with state highway officials. Starting in the mid-Atlantic region, EPA and FHWA have hosted several workshops for State environmental and transportation officials and road builders to exchange information and share success stories and concerns about RMCs in road building.

The Federal Highway Administration (FHWA). The FHWA has been successful in promoting RMC use in road construction. Their research, development, and technology transfer efforts have been instrumental in advancing the use of RMCs in road projects. In addition, FHWA has recently undertaken a refocus of their recycling program with a stronger emphasis on environmental stewardship/leadership, which intends to address such items as CO_2 gas reduction, National Green Highway Partnership, storm water management, and pollution reduction through improved pavement design. The Recycled Materials Policy established by the FHWA Administrator clearly links recycled materials (e.g., asphalt, concrete) to the preservation and improvement of the national highway system.

FHWA has been conducting outreach to the road-building community (the states, local governments, and the construction industry) showing that the engineering feasibility of using RMCs has been demonstrated in research, field studies, experimental projects and long-term performance testing and analysis. In addition, to help foster the use of RMCs, the Administrator of the FHWA issued a national policy memorandum expressing the views of the Agency in this regard.

In addition to the above, EPA and FHWA are working with representatives from several by-product generators to cooperate on workshops and technical information needs in an effort to effectively increase the use of these materials in cement substitution, as well as other civil engineering applications.

The Industrial Resources Council (IRC). IRC is an organization designed to promote the use of products, by-products, co-products or other non-hazardous materials in various industrial activities, focusing on advancing the management and use of these materials in ways that are environmentally responsible, technically sound, commercially competitive and publicly accepted. EPA is collaborating with this group, which includes: the Construction Materials Recycling Association (CMRA); ACAA; the Foundry Industry Recycling Starts Today (FIRST); the National Council for Air & Stream Improvement (NCASI); NSA; SCA; and the Rubber Manufacturers Association (RMA). The goals of the IRC are to:

- Stimulate the transfer of information related to the recovery, use, reuse and recycling of industrial resources that can be used by planners, designers, specifiers, regulators, purchasers, manufacturers and constructors or other stakeholders;

- Participate in the development of appropriate codes, specifications and guides for the use of these industrial resources on par with competing materials and products;

- Facilitate awareness and understanding of the environmental, economic, engineering, manufacturing and societal benefits derived from the recovery, use, reuse and recycling of industrial materials; and

- Share experiences of effective strategies that lead to increased utilization of these industrial materials, including changes in codes, guides and specifications.

The Silica Fume Association (SFA). Industry members are spearheading educational efforts to address concerns about the utilization of silica fume. For example, Midwest contractors have reported finishing silica fume concrete parking decks at 85% of the cost of conventional concrete using the single-pass finishing technique. In addition, FHWA's publication IF-05-016, "Silica Fume User's Manual," includes a chapter of "how to" contractor training. SFA supports this chapter with educational videos in an effort to train contractors on how to properly and economically use silica fume concrete (Kojundic, 12/13/2006). Together, these efforts could help address the concerns of contractors resistant to using non-virgin materials.

The Recycled Materials Resource Center (RMRC). RMRC is a national center that promotes the appropriate use of secondary materials, including waste materials and by-product materials, in the highway environment. The Center is an active and viable partnership between FHWA, the University of New Hampshire (UNH), and the University of Wisconsin-Madison.

The Center has a unique role in the growing field of recycled materials use in highway construction—to serve as a catalyst to reduce barriers to the appropriate use of recycled materials. The Center seeks to provide a cohesive approach to the complex engineering and environmental issues surrounding the use of recycled materials, and to serve as a principal outreach organization and evaluator of information, as well as the principal point of contact for information.

The mission of the Center is to promote activities designed to ensure that:

- policymakers at the federal, state, and local levels have the education and technical information needed to formulate policy permitting recycled materials to be considered on equal footing with conventional construction materials;

- a voice dedicated to informing persons that recycled materials exist is present in each of the technical organizations associated with transportation infrastructure;

- existing information on recycled materials is organized and structured into standards, specifications, and typical engineering properties that can be used directly by the design and construction community;

- new and innovative applications of recycled materials are continuously developed; and,

- industries and transportation agencies have the logistical tools needed to connect sources of recycled materials, applications in the transportation infrastructure, and entities involved in supply/delivery.

The RMRC is committed to increasing the wise use of recycled materials and will be working to track various metrics of its impact and resulting changes in recycled materials use in the coming years

5.2.4 Summary of Potential Mechanisms Related to Education, Technical Assistance, and Recognition Programs

Below we summarize the potential set of mechanisms related to the above discussion. As indicated, in some instances, a lead role can be played by EPA and FHWA as part of their facilitation efforts, while other mechanisms require collaboration across multiple public and private entities. The potential mechanisms include:

- Support and expand the C^2P^2 program, as well as continue EPA foundry sand outreach efforts.

- Continue and expand collaboration with DOT on the Green Highways Partnership, incorporating environmental streamlining and stewardship efforts into all aspects of the highway lifecycle. Continue and expand collaborative work with DOE on increased CCP use.

- Work with the IRC to promote the use of products, by-products, co-products or other non-hazardous materials in various industrial activities.

- Work with industry members and trade associations to address barriers.

- Conduct additional state reviews to foster a broader understanding RMC utilization practices.

- Publicize the energy savings and GHG reductions achievable through RMC use.

- Pursue ways to change the perception that anything that was a by-product or waste from an industrial process does not or cannot have the same quality attributable to a virgin or manufactured material.

- Expand current research and data collection efforts. Among other research efforts, RMRC and FHWA are conducting ongoing research on the beneficial use of RMCs in highway construction projects. These efforts include primary research of material specifications and guidance on their use. (www.fhwa.dot.gov/pavement/recycling)

- Pursue a collaborative government-industry research effort to develop concrete air entrainment additives that are compatible with coal fly ash generated by mercurycompliant power plants. EPA and OFEE are well positioned to convene government agencies, the concrete industry, and the electrical power industry to jointly sponsor such research.

- Increasing EPA outreach and assistance to the coal combustion industry to foster use of mercury controls such that the recyclability of ash is not jeopardized. From developing the mercury standards, EPA's Office of Air and Radiation is well-positioned with the technical awareness and industry relationships needed to mount a program of assistance. Explore new pollution control technologies for mercury emissions that do not render coal fly ash potentially unsuitable for beneficial use.

- Continue to review and analyze life cycle performance and risk assessments of RMC use in cement and concrete.

5.3 Economics

Chapter 4 (Barriers to Increased RMC Substitution) highlights a variety of economic factors that influence RMC substitution levels. As noted in that chapter, the market for RMCs is characterized by small price differences. In addition, the perceived cost savings potentially enjoyed by producers and consumers of RMCs can be limited by the regional variation in the supply of RMCs and transportation costs and constraints. Even where cost savings exist, they may not be deemed sufficient to overcome potential externalities and justify changes in practice. This may occur as a result of barriers related to misinformation, quality concerns, and standard operating procedures that may constrain their use.

Given these market complexities, it is relevant to consider specifically whether and how economic mechanisms implemented by Federal, state, or local governments could potentially motivate increased levels of RMC substitution by minimizing any negative externalities associated with increased RMC use. Particularly with respect to the substantial GHG benefits associated with the use of CCPs, the development of targeted tax credits or accelerated depreciation for necessary infrastructure would be beneficial.

On a basic level, an economic influence in this context would seek to reduce the price of concrete manufactured with RMCs relative to concrete manufactured using virgin materials. In theory, these incentives could be applied anywhere along the material flow of concrete and concrete inputs - at the virgin material or RMC production phase; at the manufacturing phase; or at the end-user phase. The discussion below focuses on transportation funding mechanisms and various other incentives for RMC users.

5.3.1 Transportation Funding Mechanisms

Economic influences aimed at reducing the effective price of RMC substitution could rely on a variety of tax credits and other incentive mechanisms. At the project level, the Federal government could use matching requirements for federally funded highway construction projects to encourage the use of RMCs by reducing any perceived externalities of RMC use by the project's contractors. For most Federally-funded highway projects, Federal law requires states or localities to match a certain percentage of the construction funds provided by the Federal government. In an effort to encourage greater RMC use, this percentage could be reduced for those projects meeting RMC substitution targets. Improved data collection is critical to the success of transportation funding mechanisms.

5.3.2 Mechanisms for Increased Industry RMC Use

Another set of economic mechanisms would directly sponsor industry in ways that encourage the beneficial use of RMCs. Examples of approaches that would influence the behaviour and decisions of cement producers and other RMC users include the following:

- The introduction of tax credits or accelerated depreciation for installed equipment could enable continued and expanded rates of beneficial use of RMCs. For example, tax credits for investment in slag granulation capacity could help address lower U.S. granulation rates (as noted by SCA).

- Industry observers (e.g., SFA) recommend that when awarding Federal projects, Federal agencies give weighted financial credit to concrete firms practicing the beneficial use of RMCs. This could include the exploration of other various incentive mechanisms, such as tax deductions or credits for firms that meet RMC substitution targets.

- Further research and development (R&D) on the substitution of RMCs could make RMC use more economically viable. Potential incentives for increased R&D on RMC use could include tax breaks or credits of varying sizes depending on the amount of resources expended by each firm.

- Promote the increased use of "green bonds" that are tax-exempt when used for qualified green building and sustainable design projects, as designated by the Secretary of the Treasury and the EPA Administrator.[103] Under Section 701 of the American Jobs Creation Act of 2004, up to $2 billion of the bonds can be awarded.

- Within the context of the potential development of a carbon dioxide cap and trade program, consider how emissions credits could be applied toward RMC use.

- Encourage utilities and coal ash marketers to increase utilization rates by investing in storage and distribution assets that increase the availability and reliability of coal fly ash supplies in construction markets. Investment tax credit and/or the accelerated depreciation of capital expenditures for these types of investments would send an economic signal favoring utilization over disposal.

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[103] Provus, Stan. "CDFA Spotlight: Green Bonds," July 2005, http://www.cdfa.net/cdfa/cdfaweb.nsf/pages/july2005tlc.html.

5.3.3 Caveats

Any potential economic mechanisms discussed in this section would be subject to relevant statutory, regulatory, and budgetary constraints and considerations. The transportation funding and tax related incentives presented in this section are for Congressional consideration only. We recognize that the Department of Transportation does not currently have the legal authority to use transportation funding mechanisms to help increase RMC use. In addition, many of these mechanisms would likely require improved data collection on materials used in Federal construction projects, and additional information regarding documentation of inventories and annual production of various RMCs.

6.0 CONCLUSIONS

This study provides information in response to specific provisions in the SAFETEA- LU. Consistent with the statutory direction, this report addresses the following issues:

(A) Quantify (i) the extent to which recovered mineral components are being substituted for portland cement, particularly as a result of current procurement requirements, and (ii) the energy savings and environmental benefits associated with that substitution;

(B) Identify all barriers in procurement requirements to greater realization of energy savings and environmental benefits, including barriers resulting from exceptions from current law; and

(C) (i) Identify potential mechanisms to achieve greater substitution of recovered mineral component in types of cement or concrete projects for which recovered mineral components historically have not been used or have been used only minimally; (ii) evaluate the feasibility of establishing guidelines or standards for optimized substitution rates of recovered mineral component in those cement or concrete projects; and (iii) identify any potential environmental or economic effects that may result from greater substitution of recovered mineral component in those cement or concrete projects.

With respect to the first question – the degree of beneficial use and its impact – we identify several conclusions:

- **Volumes of RMCs being substituted for portland cement.** For the four congressionally-identified RMCs, along with the additional eight RMCs identified by EPA for further evaluation, we document current production or sales, and generally capture or estimate usage rates, which are generally indicative of the extent of substitution. While data quality varies across RMCs, several materials show relatively high rates of substitution; these include RMCs, such as blast furnace slag and silica fume. Substitution rates for other high-quantity RMCs, such as coal fly ash, are lower.

- **Substitution resulting from current procurement requirements.** For all of the RMCs, complete procurement data are unavailable to estimate the total volume of RMCs used in Federal concrete projects. It follows that these information gaps preclude the Agency from establishing a causal relationship between the CPG and levels of RMC substitution in Federal concrete projects. Despite these data limitations, we have identified a number of successful efforts on the part of procuring agencies to purchase products with RMCs. The lack of a comprehensive information resource related to RMC procurement primarily results from disparate and incomplete procurement data systems, reporting burdens, and lack of reporting compliance. Improvements in procurement data systems and reporting would allow a better understanding of the incremental effects of procurement requirements for cement and concrete projects.

- **Energy savings and environmental benefits associated with substitution.** RMC use yields positive environmental benefits through lower resource consumption. To overcome the procurement data limitations noted above, for GGBFS, coal fly ash, and silica fume, we derive estimates of their use in Federal projects by roughly apportioning total volumes to Federal and non-Federal projects (based upon the estimated proportion of total cement demand related to federally-funded projects). For the years 2004 and 2005, our life cycle analysis indicates that the use of GGBFS and coal fly ash in Federal concrete projects alone resulted in significant reductions of GHG emissions, criteria air pollutants, and energy and water use. For these two years combined, the analysis suggests reduced energy use of 31.5 billion megajoules, avoided CO2 equivalent air emissions of 3.8 million metric tons, and water savings of 2.1 billion liters. We further illustrate how these benefits may accrue over a longer time period (through 2015) given alternative use scenarios. This aspect of the analysis also links to issue C (iii) noted above.

With respect to the issues identified under parts (B) and (C), the report identified a number of barriers which impede the beneficial use of RMCs through procurement requirements. A variety of potential mechanisms exist for addressing these barriers. Specifically:

- **Procurement policies and material standards** initiatives, including an ongoing assessment and refinement of EPA’s CPGs, refinement of engineering standards governing the substitution of RMCs, and development and application of green building standards.

- **Education, technical assistance, and recognition programs,** such as the Green Highways Partnership, EPA’s foundry sand outreach efforts, and public/private partnerships, such as C^2P^2 encourage the beneficial use of CCPs; in addition, ongoing research and pilot projects are critical to advancing the use of RMCs.

- **Economic influences,** such as using transportation funding mechanisms to increase RMC use and providing tax credits, accelerated depreciation, tax-exempt bonds and other influences related to various components of the RMC generation and use chain.

Table 6-1 summarizes the barriers itemized in Chapter 4 and characterizes the linkages with the possible mechanisms for increasing the use of RMCs and these barriers. These linkages are complex, covering a spectrum of stronger and weaker barriers coupled with a suite of potential mechanisms of varying effectiveness given a particular context. For example, in instances where the use of an RMC is cost prohibitive (for example, where it is in short supply or requires extensive transport), it is unlikely that adjustments to the procurement guidelines or technical assistance programs would substantially affect the RMC's utilization. In contrast, these mechanisms may be more effective in instances where barriers related to perceptions of material performance or standard operating procedures are present. As another example, EPA's efforts in C^2P^2 are primarily focused on outreach and technical assistance. However, C^2P^2 also includes research to advance coal fly ash uses; therefore, technical or economic barriers could be partly addressed by a program that is largely an education initiative. Similarly, EPA's foundry sand program includes guidance for states on creating foundry sand beneficial use programs, directly influencing procurement/contractual barriers.

With respect to barriers in procurement requirements, we have noted several concerning data reporting, material specifications and standards, contract and bidding procedures, and general program awareness. Anecdotal information indicates that these barriers may contribute, in some instances, in not using RMCs in making procurement decisions. As noted in Chapter 5, a wide range of mechanisms are applicable to these issues. Furthermore, to implement these mechanisms fully will require broad participation and effort on the part of federal, state, and private entities.

Table 6-1: Summary of Barriers and Mechanisms for Increasing Beneficial Use of RMCs

Barrier Category	Barrier	Applicable Types of Mechanisms	Example Applications of Specific Mechanisms
Economic Barriers	Transportation costs and geographic distribution RMC as minor component of producers overall revenue Poor cost-effectiveness of RMC utilization Low cost of RMC disposal	▪ Economic incentives ▪ Procurement policies and building standards ▪ Education, technical assistance, and recognition	**Economic**: Fees to increase cost of RMC disposal could increase beneficial use incentives. **Procurement**: In general, CPGs help promote demand for RMCs and increase beneficial use. However, improved data collection would allow assessment of CPG impacts and refinement of CPG. **Education**: C^2P^2 research helps identify areas with coal fly ash shortages, helping address geographic distribution barriers.
Legal, Regulatory, and Contractual Barriers	Federal air pollution regulations State and Federal solid waste regulations Bidding procedures and contractual constraints	▪ Procurement policies and building standards ▪ Education, technical assistance, and recognition	**Procurement**: Integrate green building standards into Federal, state, and local procurement policies to better focus attention on RMC-based products. **Education**: EPA's foundry sand program includes guidance on development of beneficial use programs.
Technical Barriers	Performance of products containing RMCs Acceptance of materials specifications Variation in the quality of RMC supplies	▪ Education, technical assistance, and recognition ▪ Economic incentives	**Education**: Establish baseline data and goals for RMC beneficial use rates (e.g., coal ash under EPA's C^2P^2). **Economic**: Sponsor and/or conduct research and development to minimize variation in RMC quality. **Research:** Ongoing
Safety and Health Risk Perception Barriers	Perceived risk associated with products containing RMCs	▪ Education, technical assistance, and recognition	**Education**: As a means of increasing acceptance, educate end users regarding risks associated with RMC-based products.

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GLOSSARY

The following terminology is used throughout this report.

Aggregate
A rock material such as sand, gravel, or crushed rock with which cement or bitumen is mixed to form a mortar or concrete.

Air-Cooled Blast Furnace Slag
(see Blast Furnace Slag Aggregate)

Alkali-Silica Reaction
A concrete pathology due to chemical reactions involving reactive silica from reactive aggregates and the inner solution of concrete. Main effects are swelling, cracking, and reduction in the mechanical properties of affected concretes.

Ash Reburn
Either fly ash or bottom ash or a mixture of both is added in a fine particle condition to the furnace of a pulverized coal boiler in a small proportion to the pulverized coal fed to the furnace. The fuel value that remains in the high carbon coal ash is utilized for heat and steam generation, and the ash is transformed from a material that must be landfilled to one that can be sold and utilized.

Beneficiation
The second step in hard rock mining (extraction being the first); it is the initial attempt at liberating and concentrating the valuable mineral from the extracted ore. Includes the following activities: crushing, grinding, washing, dissolution, crystallization, filtration, sorting, sizing, drying, sintering, pelletizing, briquetting, calcining to remove water and/or carbon dioxide, roasting in preparation for leaching, gravity concentration, magnetic separation, electrostatic separation, flotation, ion exchange, solvent extraction, electrowinning, precipitation, amalgamation, and heap, dump, vat, tank, and in situ leaching.

Blast Furnace Slag
Produced during the production of iron from iron ore when slagging agents (primarily limestone or dolomite) or fluxing materials are added to iron ores in blast furnaces to remove impurities from iron ore. In this process of reducing iron ore to iron, the molten slag forms as a non-metallic liquid that floats on top of the molten iron. The molten slag is then separated from the liquid metal and cooled.

Blast Furnace Slag Aggregate
Blast furnace slag aggregate (BFSA), also referred to as air-cooled blast furnace slag (ACBFS), is produced by allowing the molten slag from iron production to cool and solidify slowly under atmospheric conditions. Once cooled, it is crushed, screened and used as aggregate in applications such as base, concrete, asphalt, rail ballast, roofing, shingle coating, and glass making.

Boiler Slag
Boiler slag is a byproduct from the combustion of coal in power plants. It is melted and fused particles of ash that collect on the bottom of the boiler. Slag forms when operating temperatures exceed ash fusion temperature.

Bottom Ash
Bottom ash (also called power plant bottom ash) is the coarse, solid mineral residue that results from the burning of coal in utility boilers. Bottom ash does not melt and therefore remains in the form of unconsolidated ash that settles on the bottom of a boiler.

Carbon Burnout
A process that combusts fly ash with high carbon, using that carbon as fuel, and produces a premium quality fly ash that can be readily sold to concrete 'ready-mix' facilities.

Cement Kiln Dust
The fine-grained, solid, highly alkaline material removed from cement kiln exhaust gas by air pollution control devices. Much of the material comprising CKD is actually unreacted raw material, including raw mix at various stages of burning and particles of clinker.

Cementitious
Having the property of or acting like cement.

Cenospheres
Very small (10 to 350 microns in diameter), inert, lightweight, hollow, "glass" spheres composed of silica and alumina and filled with air or other gases. They occur naturally in coal fly ash and are recovered from the ash for use as aggregate (filler) in concrete production.

CERCLA
Comprehensive Environmental Response, Compensation, and Liability Act of 1980, also known as Superfund.

Char
To reduce to carbon or charcoal by incomplete combustion.

Clinker
Clinker is an intermediate product of hydraulic cement manufacture. Clinker is produced in a kiln and consists of semifused nodules that contain a controlled and intimate mix of clinker (or cement) minerals. Portland cement clinker consists, chiefly, of the four minerals tricalcium silicate (C_3S), dicalcium silicate (C_2S), tricalcium aluminate (C_3A), and tetracalcium aluminoferrites (C_4AF). Clinker is finely ground to make finished cement; in the case of cement, the clinker is interground with a small amount of gypsum and/or anhydrite.

Coal Combustion Products (CCPs)
The materials produced primarily from the combustion of coal as a part of the coal fired power plants operating processes. CCPs include fly ash, bottom ash, boiler slag, flue gas desulfurization materials, and other types of material such as fluidized bed combustion ash,

cenospheres, and scrubber residues. The characteristics and physical properties of CCPs vary. In general, the size, shape, and chemical composition of these materials determines their beneficial reuse as a component of building materials or as a replacement to other virgin materials such as sand, gravel, or gypsum.

Comprehensive Procurement Guidelines
Program authorized by Congress under Section 6002 of RCRA and Executive Order 13101 that requires EPA to designate products that are or can be made with recovered materials, and to recommend practices for buying these products. Once a product is designated, procuring agencies are required to purchase it with the highest recovered material content level practicable.

Concrete
Concrete is a building material made by mixing a cementing material (such as portland cement) along with aggregate (such as sand and gravel) with sufficient water and additives to cause the cement to set and bind the entire mass.

Cyclone Boiler
A coal combustion technology that creates a cyclone-like air circulation pattern causing smaller particles to burn in suspension, while larger particles adhere to a molten layer of slag that forms on the barrel walls.

Flotation
A process in which the minerals floated gather in and on the surface of bubbles of air or gas driven into or generated in the liquid in some convenient manner.

Flue Gas Desulfurization
Process and technologies by which sulfur oxides are removed from flue gas (the gaseous products of combustion that exit a boiler through a flue or stack) after combustion.

Fluidized-Bed Combustion (FBC)
A coal combustion process in which fuel is burned on a bed of incombustible material (e.g., sand and limestone) while combustion air is forced upward at high velocities, making the particles flow as a fluid.

Fluxing Materials
A material used to remove undesirable substances as a molten mixture. It may also be used to prevent the formation of, or to dissolve and facilitate the removal of, oxides and other undesirable substances.

Coal Fly Ash
Coal fly ash is the finely divided mineral residue that results from the combustion of ground or powdered coal in coal-fired power plants. It consists primarily of glassy, spherical particles comprised of silicon, aluminum, iron, calcium, and magnesium. The majority of the fly ash generated by combustion is removed from stack emissions using electrostatic precipitators or fabric-filter bag houses. Some varieties of fly ash are useful as pozzolans or SCM and others can be used as raw material for clinker manufacture and as fine-grained construction aggregates.

Foundry Sand
High quality silica sand that is a byproduct from the production of both ferrous and nonferrous metal castings. The physical and chemical characteristics of foundry sand depend on the type of casting process and industry sector from which it originates.

Granulated Blast Furnace Slag
A sand-sized glassy, granular product produced during the production of iron from iron ore. It is formed by quickly quenching (chilling) molten slag. Can be ground very finely into ground granulated blast furnace slag (GGBFS) giving it moderate hydraulic cementitious properties.

High-Performance Concrete
A concrete: made with appropriate materials combined according to a selected mix design; properly mixed, transported, placed, consolidated and cured so that the resulting concrete will give excellent performance in the structure in which it is placed, in the environment to which it is exposed and with the loads to which it will be subject for its design life.

Low-NO_x Burners
A type of gas burner that significantly reduces the formation of oxides of nitrogen.

Micrometer
A widely used device in mechanical engineering for precisely measuring thickness of blocks, outer and inner diameters of shafts and depths of slots.

Particulate Matter
Fine liquid or solid particles such as dust, smoke, mist, fumes, or smog, found in the air or emissions.

Portland Cement
Portland cement is a type of hydraulic cement composed primarily of hydraulic calcium silicates. Hydraulic cements are the binding agents in concretes and most mortars. Portland cement is a generic term for the type of cement used in most concrete. Portland cement is produced by pulverizing clinker that consists primarily of hydraulic calcium silicates. Clinker also contains some calcium aluminates and calcium aluminoferrites and one or more forms of calcium sulfate (gypsum) are interground with the clinker to make the finished product.

Strictly, the term portland cement in the United States is limited to the Types I through V varieties (and their air-entrained variants) as defined in ASTM C- 150; these types are also collectively called straight portland cement. Apart from the straight varieties, “portland cement” when used loosely (a common industry practice) can also include a number of similar hydraulic cements, including blended cements that are based on portland cement clinker plus gypsum.

Powdered Activated Carbons
Made up of crushed or ground carbon particles, 95%–100% of which will pass through a designated mesh sieve or sieve. It is generally added directly to other process units, such as raw water intakes, rapid mix basins, clarifiers, and gravity filters.

Pozzolan
A pozzolan is a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementing properties (ASTM C-618).

Pozzolana
A pozzolanic volcanic ash or tuff.

Pulverized Coal Boiler
A coal combustion technology that burns finely ground (powdered) coal in suspension.

RCRA Subtitle D
The portion of the Resource Conservation and Recovery Act regulations that primarily address non hazardous solid wastes.

Selective Non-Catalytic Reduction
A method for reducing nitrogen oxide emissions in conventional power plants that burn biomass and coal. The process involves injecting either ammonia or urea into the firebox of the boiler at a location where the flue gas is between 1600 ^oF and 2100 ^oF to react with the nitrogen oxides formed in the combustion process. The resulting product of the chemical reaction is elemental nitrogen (N_2), carbon dioxide (CO_2), and water (H_2O).

Selective Catalytic Reduction
a process where a gaseous or liquid reductant is added to the flue or exhaust gas stream and is absorbed onto a catalyst. The reductant reacts with NO_x in the exhaust gas to form water vapor and nitrogen gas.

Silica Fume
Also referred to as microsilica or condensed silica fume, ultrafine particles of disordered silica formed as a byproduct of the manufacture of silicon metal, silicon carbide, and silicon alloys (e.g., ferrosilicon). It is used as a pozzolan or SCM.

Slag
Slags are valuable co-products of iron and steel production. Ferrous slags are produced by adding slagging agents (chiefly limestone or dolomite) and/or fluxing materials to blast furnaces and steel furnaces to strip the impurities from iron ore, steel scrap, and other iron or steel feeds. The molten slag forms as a liquid silicate melt that floats on top of the molten crude iron or steel and is tapped from the furnace separately from the liquid metal

Slag Cement
Slag cement is the manufactured product from granulated blast-furnace slag governed by ASTM C 989. Increasingly on the U.S. market, the term slag cement is used for a 100% GGBFS product that is sold as an SCM.

Slagging Agents
A material, such as limestone, dolomite, lime, and silica sand, which serves, through the formation of a slag, to strip impurities from ores, during the smelting of metallic ores. Slagging agents commonly perform a dual function as a flux.

Sorbent Injection
Involves the addition of an alkaline material (usually hydrated lime or soda ash) into the gas stream to react with the acid gases. The sorbent can be injected directly into several different locations: the combustion process, the flue gas duct (ahead of the particulate control device), or an open reaction chamber (if one exists). The acid gases react with the alkaline sorbents to form solid salts that are removed in the particulate control device.

Steel Furnace Slag
A molten or fused solid byproduct from the processing of iron or scrap steel in a basic oxygen furnace or electric arc furnace produced as limestone or dolomite is used as a flux to remove impurities. Steel furnace slag is cooled similarly to air-cooled blast furnace slag, has similar properties to it, and is used for many of the same purposes. Steel slags containing large amounts of dicalcium silicate are prone to expansion and commonly are cured in piles for some months to allow for this and for leaching out of lime.

Supplementary Cementitious Material(s) (SCM)
SCMs are materials that can be incorporated within blended cements or in concrete mixes as partial substitutes for portland cement. Common examples are GGBFS, fly ash, silica fume, and pozzolana.

ABBREVIATIONS AND ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ACAA	American Coal Ash Association
ACBFS	air-cooled blast furnace slag
ACI	American Concrete Institute
AFS	American Foundry Society
ASTM	American Society for Testing and Materials
BEES	Building for Environmental and Economic Sustainability
BFSA	blast furnace slag aggregate
C^2P^2	Coal Combustion Products Partnership
$Ca(OH)_2$	Slaked lime, when solide, the mineral portlandite
$CaSO_3$	calcium sulfite
$CaSO_4$	calcium sulfate
$CaSO_4 \cdot 2H_2O$	calcium sulfate dehydrate; the mineral gypsum
CBO	carbon burnout
CCP	coal combustion product
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CKD	cement kiln dust
CPG	Comprehensive Procurement Guidelines
DOE	Department of Energy
DOT	Department of Transportation
EERC	Energy & Environment Research Center
EIA	Energy Information Administration
EO	Executive Order
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act of 2005
EPRI	Electric Power Research Institute

FAA	Federal Aviation Administration
FBC	fluidized-bed combustion
FDEP	Florida Department of Environmental Protection
FEMP	Federal Energy Management Program
FGD	flue gas desulfurization
FHWA	Federal Highway Administration
FIRST	Foundry Industry Recycling Starts Today
FPDS	Federal Procurement Data System
FY	Fiscal Year
GAO	Government Accountability Office
GBFS	granulated blast furnace slag
GGBFS	ground granulated blast furnace slag
GHP	Green Highways Partnership
HPC	high-performance concrete
IEA	International Energy Agency
IRC	Industrial Resources Council
LCA	Life cycle analysis
LEED	Leadership in Energy and Environmental Design
MOU	Memorandum of Understanding
MPa	megapascal
NO_x	nitrogen oxides
NRMCA	National Ready Mixed Concrete Association
NSR	New Source Review
OFEE	Office of the Federal Environmental Executive
OFPP	Office of Federal Procurement Policy
OMB	Office of Management and Budget
OSW	Office of Solid Waste
PAC	powdered activated carbon
PC	pulverized coal
PCA	Portland Cement Association
PM	particulate matter

QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act
RMANs	Recovered Materials Advisory Notices
RMC	recovered mineral component
RMRC	Recycled Materials Resource Center
SAFETEA- LU	The Safe Accountable Flexible Efficient Transportation Equity Act: A Legacy for Users
SCM	supplementary cementitious materials
SFA	Silica Fume Association
SO_2	sulfur dioxide
SO_x	sulfur oxides
TCAUG	Texas Coal Ash Utilization Group
TCEQ	Texas Commission on Environmental Quality
TxDOT	Texas Department of Transportation
USGBC	United States Green Building Council
USGS	U.S. Geological Survey
USWAG	Utility Solid Waste Activities Group
WBDG	Whole Building Design Guide
μm	micrometer

APPENDIX A:

OVERVIEW OF PORTLAND CEMENT AND CONCRETE

Overview of Portland Cement and Concrete

Although the terms "cement" and "concrete" are often used interchangeably, cement is actually an ingredient of concrete. Cements are binding agents in concretes and mortars. Concrete is an artificial rock-like material, basically a mixture of coarse aggregate (gravel or crushed stone), fine aggregate (sand), cement, air, and water. The term portland cement is a general term used to describe a variety of cements used today. Portland cements are hydraulic cements, which means they will set and harden by reacting chemically with water through hydration.

Current (2004) world total annual production of hydraulic cement is about 2 billion metric tons (Gt), with production spread unevenly among more than 150 countries. This quantity of cement is sufficient for about 14 to 18 Gt/yr of concrete (including mortars), and makes concrete the most abundant of all manufactured solid materials. The current yearly output of hydraulic cement is sufficient to make about 2.5 metric tons per year (t/yr) of concrete for every person worldwide (van Oss, 2005).

Cement and Cement Manufacturing

Hydraulic cements are the binding agents in concretes and most mortars and are thus common and critically important construction materials. Hydraulic cements are of two broad types: those that are inherently hydraulic (i.e., require only the addition of water to activate), and those that are pozzolanic. The term pozzolan (or pozzolanic) refers to any siliceous material that develops hydraulic cementitious properties in the presence of lime [$Ca(OH)_2$]. This includes true pozzolans and latent cements. The difference between these materials is that true pozzolans have no cementitious properties in the absence of lime, whereas latent cements already have some cementitious properties, but these properties are enhanced in the presence of lime. Pozzolanic additives or extenders can be collectively termed supplementary cementitious materials (SCM). (van Oss, 2005)

Portland cement is the most commonly manufactured and used hydraulic cement in the United States (and the world). It is manufactured through the blending of mineral raw materials at high temperatures in cement rotary kilns. Rotary kilns produce an intermediate product called "clinker." Clinker is ground to produce cement. By modifying the raw material mix and, to some degree, the temperature of manufacture, slight compositional variations in the clinker can be achieved to produce portland cements with varying properties

Similar varieties of portland cement are made in many parts of the world but go by different names. In the United States, the different varieties of straight portland cement are denoted per the American Society for Testing and Materials (ASTM) standard C-150 as:

- Type I: general use portland cement. In some countries, this type is known as ordinary portland cement.
- Type II: general use portland cement exhibiting moderate sulfate resistance and moderate heat of hydration.
- Type III: high early strength portland cement.

- Type IV: portland cement having a low heat of hydration.
- Type V: portland cement having high sulfate resistance.

For Types I, II, and III, the addition of the suffix A (e.g., Type IA) indicates the inclusion of an air entraining agent. Air entraining agents impart a myriad of tiny bubbles into the concrete containing the hydrated cement, which can offer certain advantages to the concrete, especially improved resistance to freeze-thaw cracking. In practice, many companies market hybrid portland cements; Type I/II is a common hybrid and meets the specifications of both Types I and II. Another common hybrid is Type II/V.

Blended Cements

Blended cements (called composite cements in some countries) are intimate mixes of a portland cement base (generally Type I) with one or more SCM extenders. The SCM commonly makes up about 5% to 30% by weight of the total blend, but can be higher.

In blended cements, the SCM (or pozzolans) are activated by the high pH resulting from the hydroxide ions released during the hydration of portland cement. The most commonly used SCM are volcanic ashes called pozzolana, certain types of fly ash (from coal-fired power plants), ground granulated blast furnace slag (GGBFS)—now increasingly being referred to as slag cement—burned clays, silica fume, and cement kiln dust (CKD). In general, incorporation of SCM with portland cement improves the resistance of the concrete to chemical attack, reduces the concrete's porosity, reduces the heat of hydration of the cement (not always an advantage), potentially improves the flowability of concrete, and produces a concrete having about the same long-term strength as straight portland cement-based concretes. However, SCM generally reduce the early strength of the concrete, which may be detrimental to certain applications (van Oss, 2005).

Blended cements either can be prepared at a cement plant for sale as a finished blended cement product, or by doing the blending within a concrete mix. In fact, most of the SCM consumption by U.S. concrete producers is material purchased directly for blending into the concrete mix. Concrete producers in the United States buy relatively little finished blended cement.

The designations for blended cements vary worldwide, but those currently in use in the United States meet either ASTM Standard C-595, C 989 or C-1157. ASTM Standard C-595 defines several types of blended cements. The main designations include (van Oss, 2005):

- Portland blast furnace slag cement (IS). Contains 25% to 70% GGBFS.
- Portland-pozzolan cement (IP and P). Contains a base of portland and/or IS cement and 15% to 40% pozzolans.
- Pozzolan-modified portland cement (I(PM)). The base is portland and/or Type IS cement with a pozzolan addition of less than 15%.
- Slag-modified portland cement (I(SM)). Contains less than 25% GGBFS.

- Slag cement (S).[1] GGBFS content of 70% or more. Type S can be blended with portland cement to make concrete or with lime for mortars; the latter combination would make the final cement a pozzolan-lime cement.

Chemical Composition of Portland Cement

Modern straight portland cement is a very finely ground mix of portland cement clinker and a small amount (typically 3% to 7%) of gypsum (calcium sulfate dihydrate) and/or anhydrite (calcium sulfate). Cement chemistry is generally denoted in simple stoichiometric shorthand terms for the major constituent oxides. Table A-1 provides the shorthand notation for the major oxides in the cement literature. Table A-1 also shows the typical chemical composition of modern portland cement and its clinker. For clinker, the oxide compositions would generally not vary from the rough averages shown by more than 2% to 4%. The oxide composition of portland cement would vary slightly depending on its actual gypsum fraction or whether any other additives are present.

Table A-1: Chemical Shorthand and Composition of Clinker and Portland Cement

Oxide Formula	Shorthand Notation	Percentage by Mass in Clinker	Percentage by Mass in Cement*
CaO	C	65	65.0
SiO_2	S	22	22.0
Al_2O_3	A	6	6.0
Fe_2O_3	F	3	3.0
MgO	M	2	2.0
$K_2O + Na_2O$	K + N	0.6	0.6
Other (including SO_3^-)	…(…$\bar{S}$)	1.4	3.6
H_2O	H	“nil”	1.0

* Based on clinker shown plus 5% addition of gypsum ($CaSO_4{\cdot}2H_2O$).

Source: van Oss, 2005

Mineralogy of Portland Cement and Its Clinker

The major oxides in clinker are combined essentially into just four cement or clinker minerals, denoted in shorthand: tricalcium silicate or ‘alite’ (C_3S); dicalcium silicate or ‘belite’ (C_2S); tricalcium aluminate (C_3A); and tetracalcium aluminoferrite (C_4AF). These formulas represent averages, ignoring impurities commonly found in actual clinker. It is the ratios of these four minerals (and gypsum) that determine the varying properties of different types of portland cements. Table A-2 provides the chemical formulas and nomenclature for the major cement oxides as well as the function of each in cement mixtures.

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[1] True Type S cements are no longer commonly made in the United States. Instead, the name slag cement (but with no abbreviation) is now increasingly given to the unblended 100 % GGBFS product (van Oss, 2005). ASTM C989 now governs slag cement (GGBFS).

Table A-2: Typical Mineralogical Composition of Modern Portland Cement

Chemical Formula	Oxide Formula	Shorthand Notation	Description	Typical Percentage	Mineral Function
Ca_3SiO_5	$(CaO)_3SiO_2$	C_3S	Tricalcium silicate (‘alite’)	50-70	Hydrates quickly and imparts early strength and set
Ca_2SiO_4	$(CaO)_2SiO_2$	C_2S	Dicalcium silicate (‘belite’)	10-30	Hydrates slowly and imparts long term (ages beyond 1 week) strength.
$Ca_3Al_2O_6$	$(CaO)_3Al_2O_3$	C_3A	Tricalcium aluminate	3-13	Hydrates almost instantaneously and very exothermically. Contributes to early strength and set.
$Ca_4Al_2Fe_2O_{10}$	$(CaO)_4Al_2O_3Fe_2O_3$	C_4AF	Tetracalcium aluminoferrite	5-15	Hydrates quickly. Acts as a flux in clinker manufacture. Imparts gray color.
$CaSO_4 \cdot 2H_2O$	$(CaO)(SO_3) \cdot (H_2O)_2$	$C\bar{S}H_2$	Calcium sulfate dihydrate (gypsum)	3-7	Interground with clinker to make portland cement. Can substitute anhydrite ($C\bar{S}$). Controls early set.
$CaSO_4$	$(CaO)(SO_3)$	$C\bar{S}$	Anhydrous calcium sulfate	0.2-2	

Source: van Oss, 2005.

As indicated in Table A-2, some of the minerals in clinker serve different functions in the manufacturing process while others impart varying final properties to the cement. The proportion of C_3S, for example, determines the degree of early strength development of the cement. The “ferrite” mineral’s (C_4AF) primary purpose, on the other hand, is to lower the temperature required in the kiln to form the C_3S mineral, and really does not impart a specific property to the cement. Table A-3 presents the common mineralogical compositions of Types I through IV cements and the unique properties of each type.

Table A-3: Typical Range in Mineral Composition in Portland Cements

ASTM C-150 Cement Type	Clinker Mineral Percent*				Properties of Cement
	C_3S	C_2S	C_3A	C_4AF	
I	50-65	10-30	6-14	7-10	General purpose
II	45-65	7-30	2-8	10-12	Moderate heat of hydration, moderate sulfate resistance
III	55-65	5-25	5-12	5-12	High early strength**
IV	35-45	28-35	3-4	11-18	Low heat of hydration
V	40-65	15-30	1-5	10-17	High sulfate resistance

* Range of minerals is empirical and approximate rather than definitional.
** High early strength is typically achieved by finer grinding of Type I cement.

Source: van Oss, 2005.

Physical Properties of Portland Cement

Portland cement consists of individual angular particles with a range of sizes, the result of pulverizing clinker in the grinding mill. Approximately 95% of cement particles are smaller than 45 micrometers, with the average particle around 15 micrometers. The fineness of cement affects the amount of heat released during hydration. Greater cement fineness (smaller particle size) increases the rate at which cement hydrates and thus accelerates strength development. Except for AASHTO M 85, most cement standards do not have a maximum limit on fineness, only a minimum. The fineness of Types I through V portland cement are shown in Table A-4 (Kosmatka, 2002). Values are expressed according to the Blaine air-permeability test (ASTM C 204 or AASHTO T 153), which indirectly measures the surface area of particles per unit mass.

Table A-4: Fineness of Portland Cement

ASTM C - 150 Cement Type	Fineness (cm^2/g, Blaine)	
	Range	Mean
I	3,000-4,210	3,690
II	3,180-4,800	3,770
III	3,900-6,440	5,480
IV	3,190-3,620	3,400
V	2,750-4,300	3,730

The specific gravity of portland cement typically ranges from 3.10 to 3.25, with an average of 3.15. Bulk densities can vary significantly depending on how the cement is handled and stored. Reported bulk densities range from 830 to 1,650 kg/m^3 (Kosmatka, 2002).

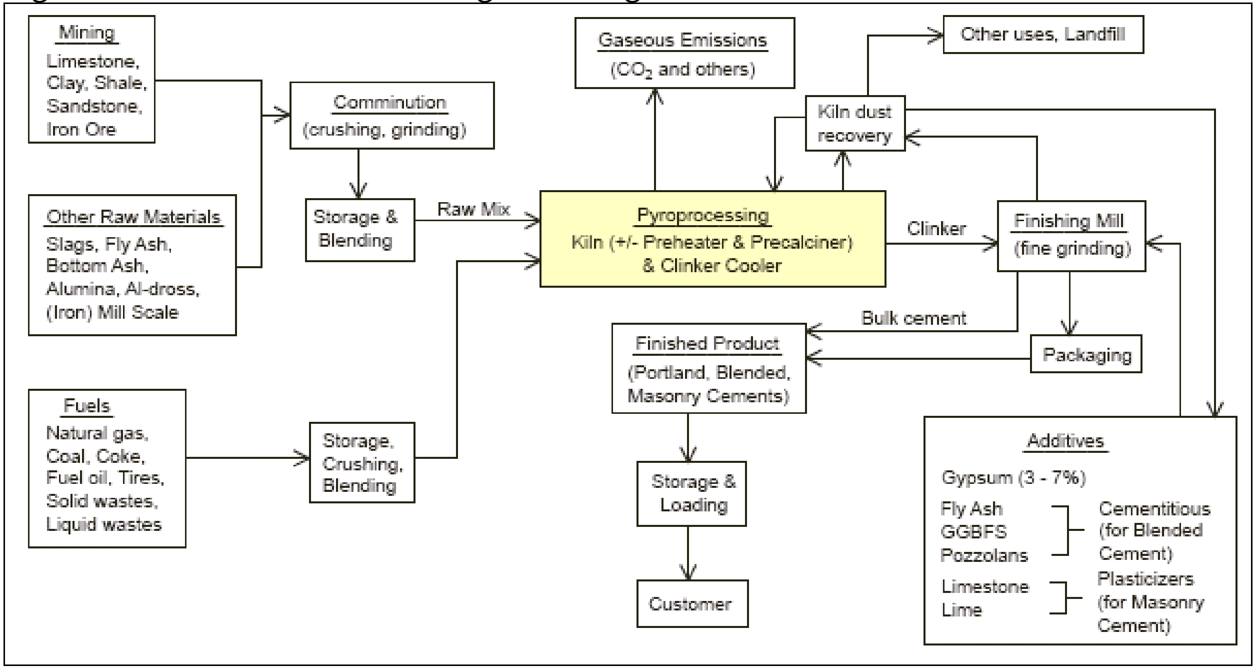
The Clinker Manufacturing Process

Portland cement manufacturing is a two-step process beginning with the manufacture of clinker followed by the fine grinding of the clinker with gypsum and other additives to make the finished cement product. Grinding can occur on site or at offsite grinding plants.

The first step in clinker manufacture is the quarrying, crushing, and proportioning of raw materials. Due to the low unit value of these raw materials, they typically are mined within a few miles of the cement plant. The cost of transport renders long-distance transport of these low-cost raw materials uneconomical.

Once the raw mix, or raw meal, is prepared, it is fed into a cement kiln and converted into the clinker minerals through a thermochemical conversion, referred to as pyroprocessing because it involves direct flame interaction. Figure A-1 provides a generalized flow diagram of the cement manufacturing process (van Oss, 2005).

Figure A-1: Cement Manufacturing Flow Diagram



The raw materials for clinker manufacture consist primarily of materials that supply four primary oxides: Calcium oxide (CaO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and ferric oxide (Fe_2O_3). The composition of the raw mix typically includes about 80% calcium carbonate, about 10% to 15% silica, and small amounts of alumina and iron. Depending on the quality and quantity of these oxides available to the facility, other raw materials, referred to as accessory or sweetener materials, are added to correct for any deficiencies in the primary raw materials. Certain types of fuel burned in the cement kiln can also contribute oxides (e.g., ash from coal combustion contributes silica oxides, steel belts in waste tires contribute iron oxide).

Calcium oxide (CaO or simply C in shorthand) is the primary ingredient in clinker, comprising about 65% of clinker by mass. A cement plant typically examines its source of C (typically limestone, marl, or chalk) and determines what other oxides need to be added to achieve the desired clinker composition. Clay, shale, slate, or sand provide the silica and alumina component, while iron, mill scale, or other ferrous materials provide the iron content. Preparing the raw mix for clinker production requires constant sampling, chemical testing, and adjusting of the inputs to maintain the desired clinker composition.

On average, it takes about 1.7 tons of nonfuel raw materials to produce 1 ton of clinker. Of the 1.7 tons of raw materials, approximately 1.5 tons is limestone or calcium oxide rich rock (van Oss, 2005). The lost mass takes the form of carbon dioxide (CO_2) driven off by the calcination of limestone and the generation of CKD. Nearly one ton of CO_2 is produced for every ton of clinker manufactured (van Oss, 2005). The CKD that is produced during clinker manufacture is carried "up the stack" and captured by emission control devices. A large portion of the CKD, though not all of it, is returned to the kiln as part of the feed stream.

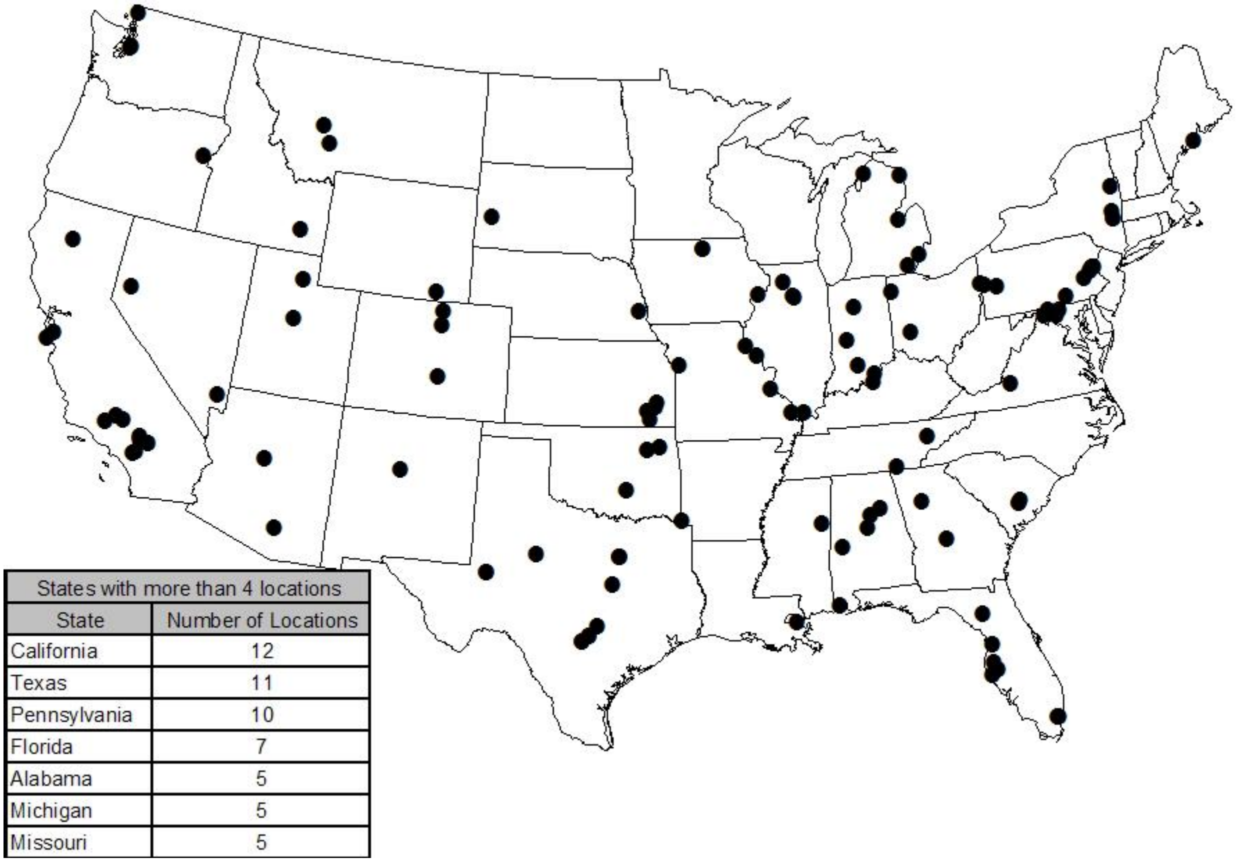
Manufacture of Finished Cement from Clinker

After clinker has been cooled to about 100°C, it is ready to be ground into finished cement in a grinding mill, more commonly referred to as a finish mill. Generally, separate grinding and/or blending finish mill lines will be maintained at a plant for each of its major product classes (finished portland cements, blended cements, masonry cements, ground slag). Additives that commonly require grinding at the mill include gypsum, limestone, granulated blast furnace slag, and natural pozzolans. Additives that generally do not require significant grinding include coal fly ash, GGBFS, and silica fume, but the finish mill does provide intimate mixing of these with the portland cement base.

Production

The U.S. Geological Survey (USGS) estimated that in 2005 approximately 97.5 million metric tons (Mt) of portland plus masonry cement was produced at 113 plants in 37 states in the United States. The reported final production of masonry plus portland cement was 99.3 Mt, with portland cement alone accounting for 93.9 Mt of this total (van Oss, 2007). Figure A-2 shows the locations of U.S. cement plants in 2005 based on information provided by the Portland Cement Association (PCA, 2006). Appendix C contains a listing of cement plants operating in the United States in 2005. The estimated value of cement production for 2005 was about $8 billion. The final reported actual value for portland plus masonry cement production in 2005 was $11.6 billion. Of this total, $10.9 billion was for portland cement alone (van Oss, 2007). Most of the cement was used to make ready mixed concrete (75%), while 14% went to concrete manufacturers, 6% to contractors, 3% to building materials dealers, and 2% to other users. Clinker production occurred at 107 plants, with a combined annual capacity of about 103 million tons. Actual U.S. cement imports in 2005 were reported at 30.4 Mt (excluding Puerto Rico), and clinker imports were 2.86 Mt (van Oss, 2007). Average mill prices for cement in 2005 were about $84 per ton. More than 172 million tons of raw materials were used to produce cement and clinker in the United States in 2004. Table A-5 summarizes U.S. cement statistics for the years 2000 through 2005 (USGS, 2001; 2002; 2003; 2004; 2005; 2006). Table A-6 summarizes raw materials used in the United States in 2003 and 2004 to produce cement and clinker (van Oss, 2004).

Figure A-2: U.S. Cement Plants



States with more than 4 locations	
State	Number of Locations
California	12
Texas	11
Pennsylvania	10
Florida	7
Alabama	5
Michigan	5
Missouri	5

Table A-5: U.S. Cement Statistics

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
	--------------------------*million metric tons*----------------------------					
Estimated Cement Production	87.8	88.9	89.7	92.8	97.4	97.5*
Clinker Production	78.1	78.8	81.5	81.9	86.7	87.4
Imports of Cement	24.6	23.7	22.2	21.0	25.4	29.0
Imports of Clinker	3.7	1.8	1.6	1.8	1.6	2.8
Exports of Cement and Clinker	0.74	0.75	0.83	0.84	0.82	0.80
Average Price, Mill Value, $/ton	78.56	76.50	76.00	75.00	79.50	84.00

* Actual total masonry plus portland cement final production for 2005 is reported at 99.3 Mt, of which 93.9 Mt was for portland cement alone.

Table A-6: Raw Materials Used in Producing Clinker and Cement in the United States

Raw Materials	**2003**		**2004**	
	Clinker	**Cement**	**Clinker**	**Cement**
	-----------------------*thousand metric tons*-------------------			
Limestone	109,000	1,530	125,000	1,810
Cement rock	12,700	44	12,700	2
Cement kiln dust	289	149	333	165
Lime	22	27	24	29
Other calcareous	235	32	23	19
Clay	3,950	--*	4,740	--
Shale	2,630	8	3,700	29
Other aluminous	618	--	661	--
Ferrous, iron ore, pyrites, millscale, other	1,340	--	1,340	--
Sand and calcium silicate	2,860	2	3,150	--
Sandtone, quartzite soils, other	587	2	878	6
Coal Fly ash	2,250	39	2,890	77
Other ash, including bottom ash	1,100	--	1,050	--
Granulated blast furnace slag	17	333	104	345
Other blast furnace slag	214	--	189	--
Steel slag	448	--	401	--
Other slags	113	--	53	--
Natural rock pozzolans	--	25	--	6
Other pozzolans	129	49	114	19
Gypsum and anhydrite	--	5,000	--	5,300
Other, not elsewhere classified	70	68	106	98
Clinker, imported	--	4,240	--	7,530
Total	**139,000**	**11,500**	**157,000**	**15,400**

*-- Indicates none reported.

Concrete

Concrete is basically a mixture of two components: aggregate and cement paste. The cement paste, comprised of a binder (usually portland cement) and water, binds the aggregates (usually sand and gravel or crushed stone) into a rocklike mass as the paste hardens. The paste hardens because of a chemical reaction, called hydration, between the cement and water.

The National Ready Mixed Concrete Association (NRMCA) estimates that ready mixed concrete production in the United States was approximately 349 million cubic meters in 2005. NRMCA estimates that there are approximately 6,000 ready mixed concrete plants in the United States, and that annual ready mixed concrete production is valued at more than $30 billion. Table A-7 shows ready mixed concrete production by state in 2005 as reported by NRMCA. USGS estimates that total concrete production in the United States in 2005 was valued at more than $48 billion (USGS, 2006). Although there are no data available on the amount of concrete placed annually in the United States, based on U.S. cement sales it can be estimated to be nearly one billion metric tons per year.

Table A-7: Ready Mixed Concrete Production by State (2005)

State	Production (million cubic meters)	Percent of National Production	State	Production (million cubic meters)	Percent of National Production
Alabama	4.9	1.4%	Nebraska	3.8	1.1%
Alaska	0.5	0.1%	Nevada	7.3	2.1%
Arizona	13.1	3.8%	New Hampshire	0.6	0.2%
Arkansas	3.4	1.0%	New Jersey	5.5	1.6%
California	43.4	12.4%	New Mexico	2.5	0.7%
Colorado	7.3	2.1%	New York	8.9	2.6%
Connecticut	2.2	0.6%	North Carolina	8.2	2.4%
Delaware	0.6	0.2%	North Dakota	1.0	0.3%
District of Columbia	0.6	0.2%	Ohio	10.9	3.1%
Florida	31.6	9.1%	Oklahoma	4.5	1.3%
Georgia	12.4	3.6%	Oregon	3.5	1.0%
Hawaii	1.2	0.3%	Pennsylvania	9.3	2.7%
Idaho	2.0	0.6%	Puerto Rico	5.2	1.5%
Illinois	11.6	3.3%	Rhode Island	0.5	0.1%
Indiana	6.1	1.8%	South Carolina	5.0	1.4%
Iowa	5.4	1.6%	South Dakota	1.4	0.4%
Kansas	4.3	1.2%	Tennessee	6.0	1.7%
Kentucky	4.2	1.2%	Texas	40.8	11.7%
Louisiana	5.5	1.6%	Utah	4.3	1.2%
Maine	0.7	0.2%	Vermont	0.4	0.1%
Maryland	4.4	1.3%	Virginia	7.5	2.1%
Massachusetts	3.5	1.0%	Washington	6.3	1.8%
Michigan	8.2	2.4%	West Virginia	1.4	0.4%
Minnesota	5.7	1.6%	Wisconsin	6.6	1.9%
Mississippi	3.0	0.9%	Wyoming	1.3	0.4%
Missouri	8.0	2.3%	Other	1.2	0.3%
Montana	1.1	0.3%	**Total**	**348.8**	**100.0%**

The character of concrete is determined by the quality of the cement paste (i.e., the cement and water mixture). The water to cement ratio—the weight of the mixing water divided by the weight of the cement—plus the quality and type of cement determines the strength of the paste, and hence the strength of the concrete. High-quality concrete is produced by lowering the water-cement ratio as much as possible without sacrificing the workability of fresh concrete. Generally, using less water produces a higher quality concrete provided the concrete is properly placed, consolidated, and cured.

For a typical concrete mix, 1 metric ton of cement (powder) will yield about 3.4 to 3.8 cubic meters of concrete weighing about 7 to 9 metric tons (i.e., the density is typically in the range of about 2.2 to 2.4 metric tons per cubic meter). Although aggregates make up the bulk of the mix, it is the hardened cement paste that binds the aggregates together and contributes virtually all of the strength of the concrete, with the aggregates serving largely as low cost fillers. The strengths of the cement paste is determined by both the quality and type of the cement and the water-to-cement ratio (van Oss, 2005).

APPENDIX B:

BACKGROUND OF RECOVERED MINERAL COMPONENTS

Background of Recovered Mineral Components

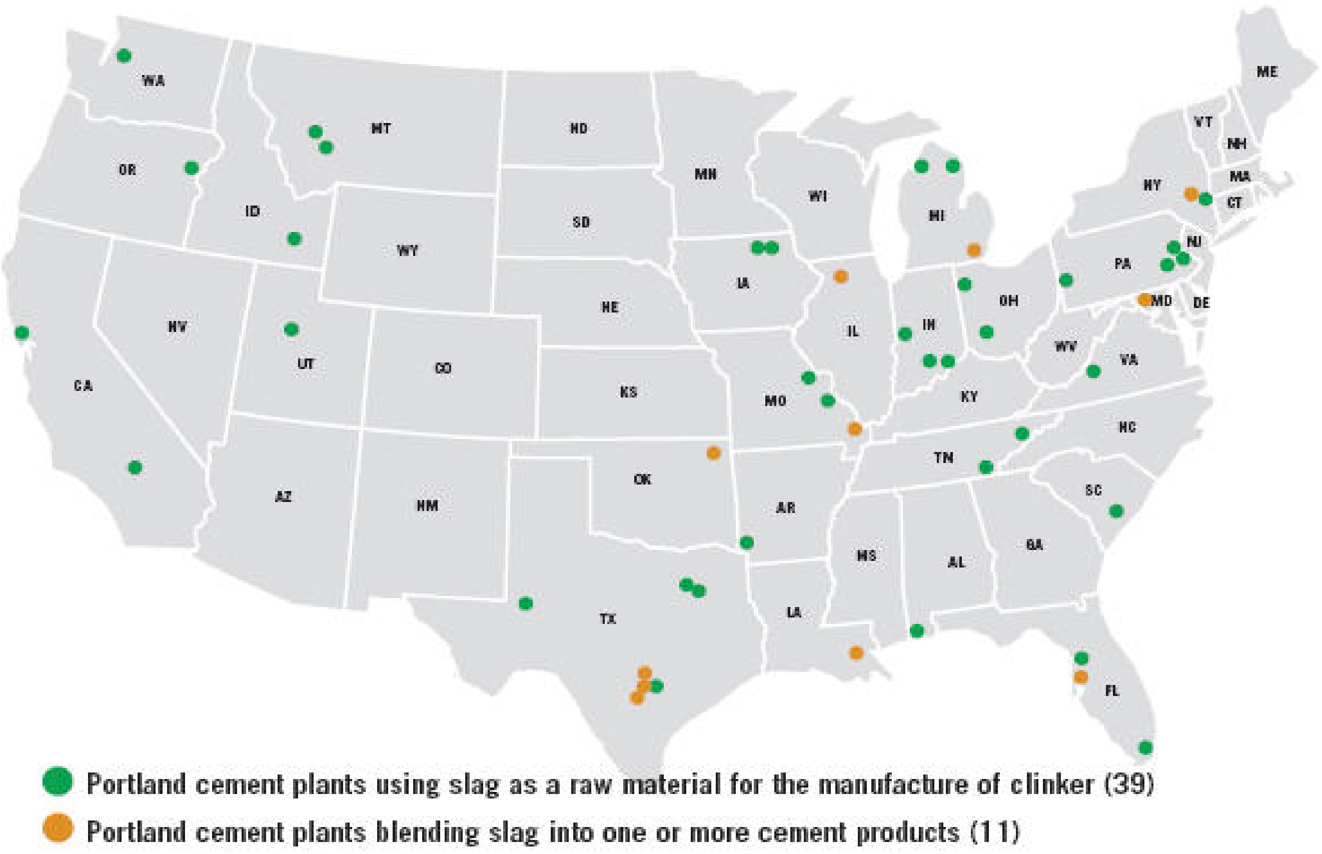
B.1 Iron and Steel Slags

Ferrous slags are by-products from iron and steel manufacturing. There are two main types of ferrous slags produced in the United State—blast furnace slags and steel slags. Blast furnace slags are produced during smelting of iron ore or iron pellets with coke and a flux, such as limestone or dolomite. The calcium in the stone combines with the aluminates and silicates in the ore and ash from the coke to produce this non-metallic material. The slag is removed from the furnace for further processing. Blast furnace slag has many uses, including the production of clinker and blended cements, and as an aggregate in portland cement concrete.

Steel slag is a byproduct from the processing of iron in a basic oxygen furnace (BOF) or scrap steel in an electric arc furnace (EAF). Steel slags also can be used in the manufacture of clinker. More information on steel slag is provided in section B.9. There is still some minor open hearth (OH) furnace material resident in slag piles that is occasionally sold. However, no OH slag is being produced anymore in this country.

In 2005, PCA estimates that 39 cement plants were using slag as a raw material the manufacture of clinker, and 11 plants were blending it into one or more cement products (see Figure B-1) (PCA, 2005).

Figure B-1: Portland Cement Plants Utilizing Slag



B.2 Blast Furnace Slag

Figure B-2: U.S. Blast Furnace Slag Producers

The chemical composition of blast furnace slag varies, but Table B-1 presents a typical range of values (FHWA, 1998).

Table B-1: Typical Chemical Composition of Blast Furnace Slag

Constituent	Mean	Range
	-------------------------*percent by weight*--------------------------	
Calcium Oxide (CaO)	39.0	34 - 43
Silicon Dioxide (SiO_2)	36.0	27 - 38
Aluminum Oxide (Al_2O_3)	10.0	7 - 12
Magnesium Oxide (MgO)	12.0	7 - 15
Iron (FeO or Fe_2O_3)	0.5	0.2 - 1.6
Manganese Oxide (MnO)	0.4	0.15 - 0.76
Sulfur (S)	1.4	1.0 - 1.9

The National Slag Association provided data on slag usage in concrete as aggregate and as a SCM for the years 1996 through 2005, which is summarized in Table B-2. These data were not broken out by slag type (i.e., granulated vs. air-cooled).

Table B-2: Blast Furnace Slag Production and Usage (National Slag Association Data)

Year	Estimated Slag Production	Slag Used as Concrete Aggregate	Slag Used as Supplementary Cementitious Material
	--------------------------------------*million metric tons*--------------------------------------		
1996	NA*	NA	1.0
1997	NA	1.27	1.2
1998	NA	1.27	1.4
1999	NA	1.36	1.6
2000	10.9	1.27	1.8
2001	9.5	1.36	2.2
2002	9.2	1.36	2.6
2003	9.3	1.36	2.7
2004	9.3	1.45	3.2
2005	10.3	NA	3.3

*NA = data not available

GBFS is a glassy granular material, consisting mainly of silicates and aluminosilicates of calcium. The particle distribution, shape, and grain size of GBFS vary, depending on the chemical composition and method of production, from coarse, popcornlike friable particles to dense, sand-size grains. Whereas portland cement typically is ground to around 3,000-3,500 cm^2/g (Blaine) in the United States, granulated slag is typically ground even finer (to about 4,000 – 5,000 cm^2/g (Blaine) to achieve satisfactory reactivity.

ASTM C 989 (AASHTO M302) classifies slag by its increasing level of reactivity as follows:

- Grade 80 - slags with low activity index
- Grade 100 - slags with a moderate activity index
- Grade 120 - slags with high activity index

GGBFS is a hydraulic material with inherent cementious character, that is, it will set up and gain strength on its own when mixed with water. In the presence of alkalis such as may be present in a concrete mix with portland cement, these alkalis will accelerate the hydration of the slag cement to levels similar to that of portland cement. Because of its cementitious nature, it should be noted that 70% slag cement concrete mixtures are usually used to control heat of hydration in mass concrete placement. GGBFS has been used for many years as a SCM in portland cement concrete, either as a mineral admixture or as a component of blended cement. GGBFS slag, when used in general purpose concrete in North America, typically constitutes between 30% and 45% of the cementitious material in the mix. Some slag concretes have a slag component of 70% or more of the cementitious material (Kosmatka, 2002). GGBFS is used in making blended Portland blast furnace slag cement (IS). The use of GGBFS in blended cement is governed by ASTM C-595. The specific gravity of GGBFS is in the range of 2.85 to 2.95, and the bulk density varies from 1,050 to 1,375 kg/m^3 (Kosmatka, 2002).

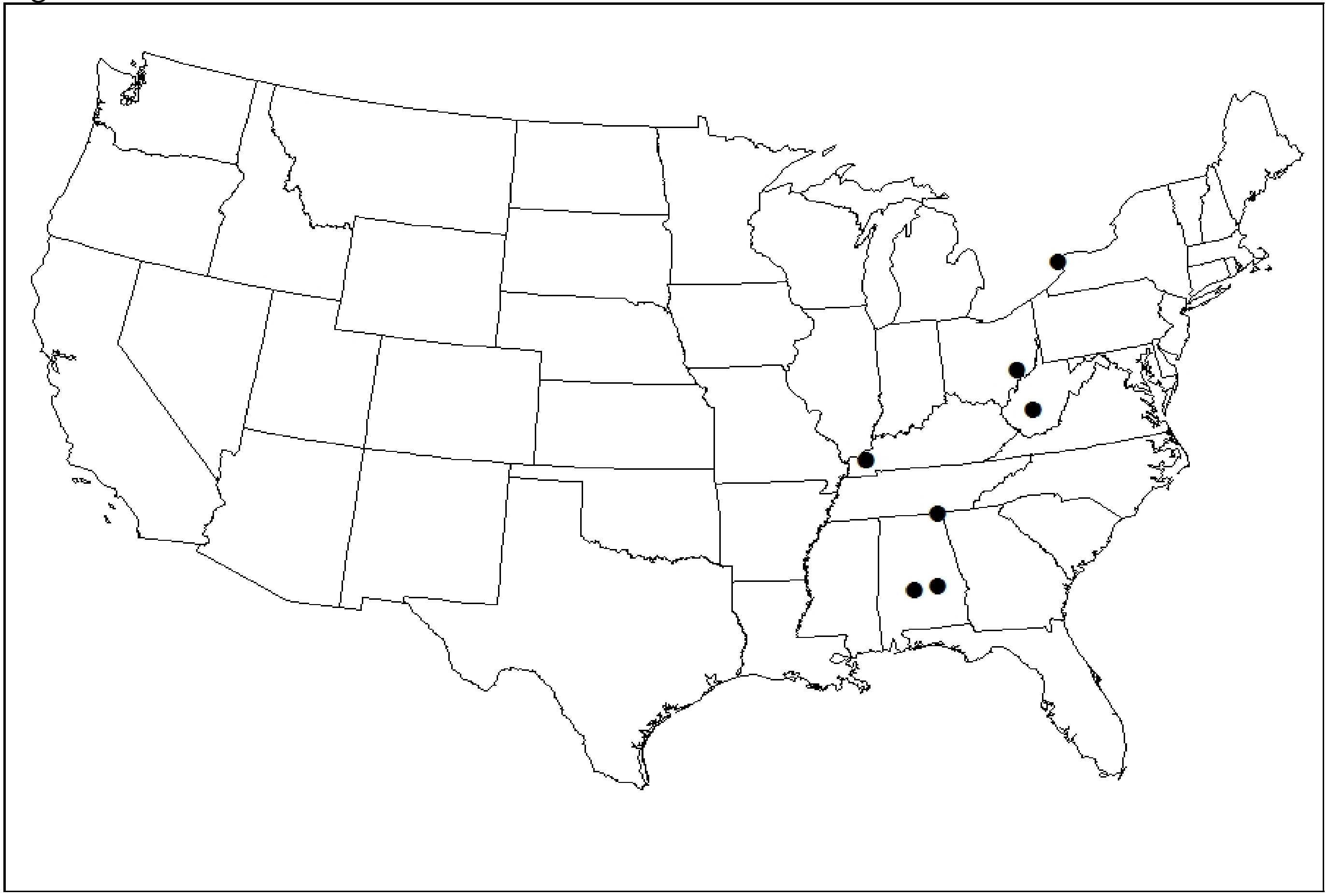
Performance Record

Florida, Maryland, New Hampshire, and Oregon state agencies are reported to be investigating the use of GGBFS as a SCM. At least 11 states (Delaware, Florida, Indiana, Maryland, Massachusetts, Michigan, New Hampshire, North Carolina (limited use on experimental basis), Pennsylvania, South Carolina and Virginia) currently have specifications covering the use of GGBFS as a partial replacement for portland cement. Some state agencies have reported durability problems (decreased salt scaling resistance) with exposed concrete containing blast furnace slag where the amount of GGBFS exceeds about 25% of the total cement.

B.3 Silica Fume

According to the Silica Fume Association, there are five companies producing silica fume in the United States. USGS data indicate that in 2004, silicon alloys and/or silicon metals were produced at six plants, and that a seventh plant was idle in 2004 (Corathers, 2004). Demand for silica fume is high, and the United States is currently importing silica fume from Venezuela, Spain, Argentina, Norway and Iceland. U.S. companies also export silica fume to Canada, Central America, and South America. Figure B-3 illustrates the location of silica fume producers in the United States. Appendix C contains a listing of U.S. silica fume producers.

Figure B-3: U.S Silica Fume Producers



Silica fume has been known to be a beneficial admixture to concrete since the late 1940's. However, silica fume did not become widely used until the development of high-range water-reducing admixtures or superplasticizers. These admixtures are necessary because the high surface area of silica fume increases water demand in concrete, which can have a detrimental effect on concrete properties. The use of water-reducing admixtures or superplasticizers can improve workability and placement of concrete at lower water contents, offsetting the need for additional water in mixes containing silica fume.

The addition of silica fume to concrete mixes improves finished concrete properties through both physical and chemical mechanisms. Physically, the extremely small size of silica fume particles allows them to occupy spaces between cement grains, an arrangement typically referred to as particle packing or micro-filling. Chemically, silica fume particles are highly pozzolanic (i.e., they react with calcium hydroxide (hydrated lime) to produce highly cementitious compounds) due to their high amorphous silicon dioxide content. Therefore, when portland cement releases calcium hydroxide as it hydrates, silica fume reacts with the calcium hydroxide to form additional binder material (DOT, 2005).

The addition of silica fume has two main effects on fresh concrete. First, it makes the concrete more cohesive, which reduces segregation and improves the efficiency of shotcreting. Second, silica fume reduces the bleeding in concrete by reducing porosity and reacting with lime. Bleeding leads to the formation of capillary channels, which can increase chloride intrusion in finished concrete. In addition, eliminating bleeding allows concrete to be finished earlier, which is advantageous in projects where durability is important, such as in bridge decks or parking structures.

The percentage of silica fume used in high performance concrete (HPC) varies depending on the application and desired performance characteristics of the concrete, but typically ranges from 5% to 20% on a dry weight basis. HPC containing silica fume also often contains coal fly ash. Silica fume also can be used in concrete with other recovered materials such as GGBFS and cenospheres. Because silica fume costs more than portland cement and there are relatively low volumes available, its use is limited primarily to HPC.

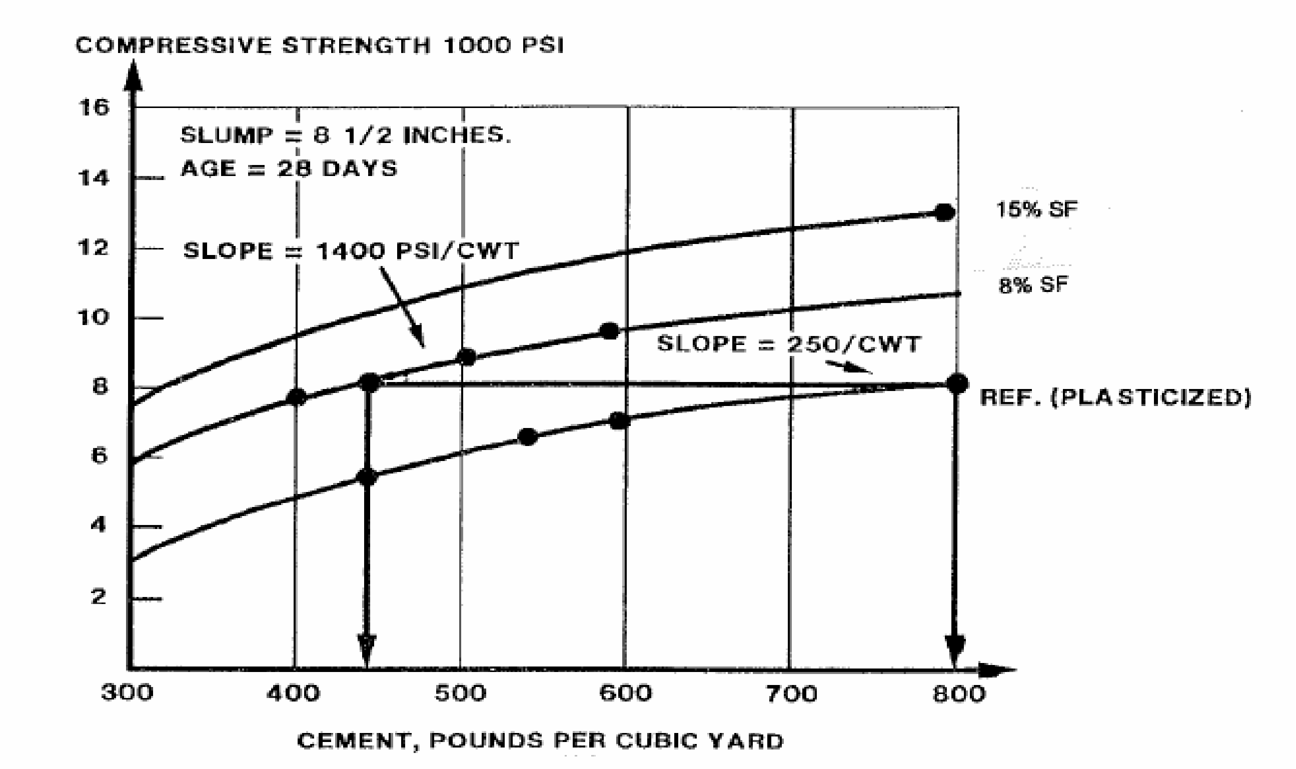
The increased strength of finished concrete with silica fume can mean that less cement is required in concrete mixes, though silica fume is usually used in addition to the standard amounts of portland cement.

Further, silica fume concrete only requires “single-pass” or “one-pass” finishing whereby the finishing is condensed into a single operation. In single-pass finishing, placement, consolidation, surface-closing, and texturing operations follow one another in succession. The concrete is then cured immediately. The total time from placement to final curing is recommended by the Federal Highway Administration (FHWA) to be less than 20 minutes. This rapid finishing technique is cost efficient, but quite different than normal construction practices used over the past 50 years.

Specifications regarding the use of silica fume in concrete can be found in ASTM C1240 (AASHTO M307). ACI 234R-06 describes the physical and chemical properties of silica fume, how silica fume interacts with portland cement, the effects of silica fume on the properties of fresh and hardened concrete, typical applications of silica fume concrete, and recommendations on proportions, specifications, and handling of silica fume in the field.

The Figure B-4 below shows typical concrete made with cement and 15% coal fly ash as substitution for cement. To this reference mix, 8% and 15% silica fume, based on cement weight, was added.

Figure B-4: Cement Mix Continuum



The figure above shows that the efficiency of a pound of cement to concrete strength increases significantly when 8% silica fume, by weight of cement, was added to the mix. The ability to generate increased strength from each pound of cement used means that less cement can be used to achieve a required compressive strength. Also, as the rate or 'slope' is reduced from 1400 to 250psi / cwt, the quality control necessary to achieve that strength becomes more difficult to implement.

B.4 Coal Fly Ash

The U.S. Department of Energy (DOE) conducts several annual surveys to collect data on electric power plants. One such survey (EIA-860: Annual Electric Generator Report) (U.S. DOE, 2004) includes data about generators in electric power plants owned and operated by electric utilities and nonutilities. These data indicate that in 2004 there were 1,526 generating units at facilities that used coal[2] as a primary fuel source. Of these units, 1,220 were classified as NACIS 22 (electric, gas and sanitary services). It is likely that this represents the universe of U.S. generators that would produce coal combustion products, including coal fly ash.

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[2] This includes facilities that burn anthracite, bituminous and subbituminous coal, lignite, waste coal and synthetic coal.

Another annual DOE survey (U.S. DOE, 2004b) collects data from organic-fueled or combustible renewable steam-electric power plants with a rating of 10 or more megawatts. This survey (EIA-767: Annual Steam-Electric Plant Operation and Design Data) gathers information on, among other things, coal combustion product production. In 2004, 426 facilities reported data on coal fly ash production. These data indicate that approximately 69.8 million metric tons of coal fly ash was produced in 2004 at these facilities.

The American Coal Ash Association (ACAA) also conducts an annual survey of coal combustion product production. ACAA estimates that in 2004 approximately 64.2 million metric tons of coal fly ash were produced in the United States. (ACAA, 2004)

Coal fly ash is produced in abundant quantities and in all areas of the United States. Figure B-5 illustrates the geographic distribution of facilities that produce coal fly ash by state, based on the 2004 EIA-767 data files. Table B-3 shows the number of facilities producing coal fly ash, and coal fly ash production and disposition by state. Additional details on these facilities are included in Appendix .C

Figure B-5: U.S. Coal Fly Ash Producers by State

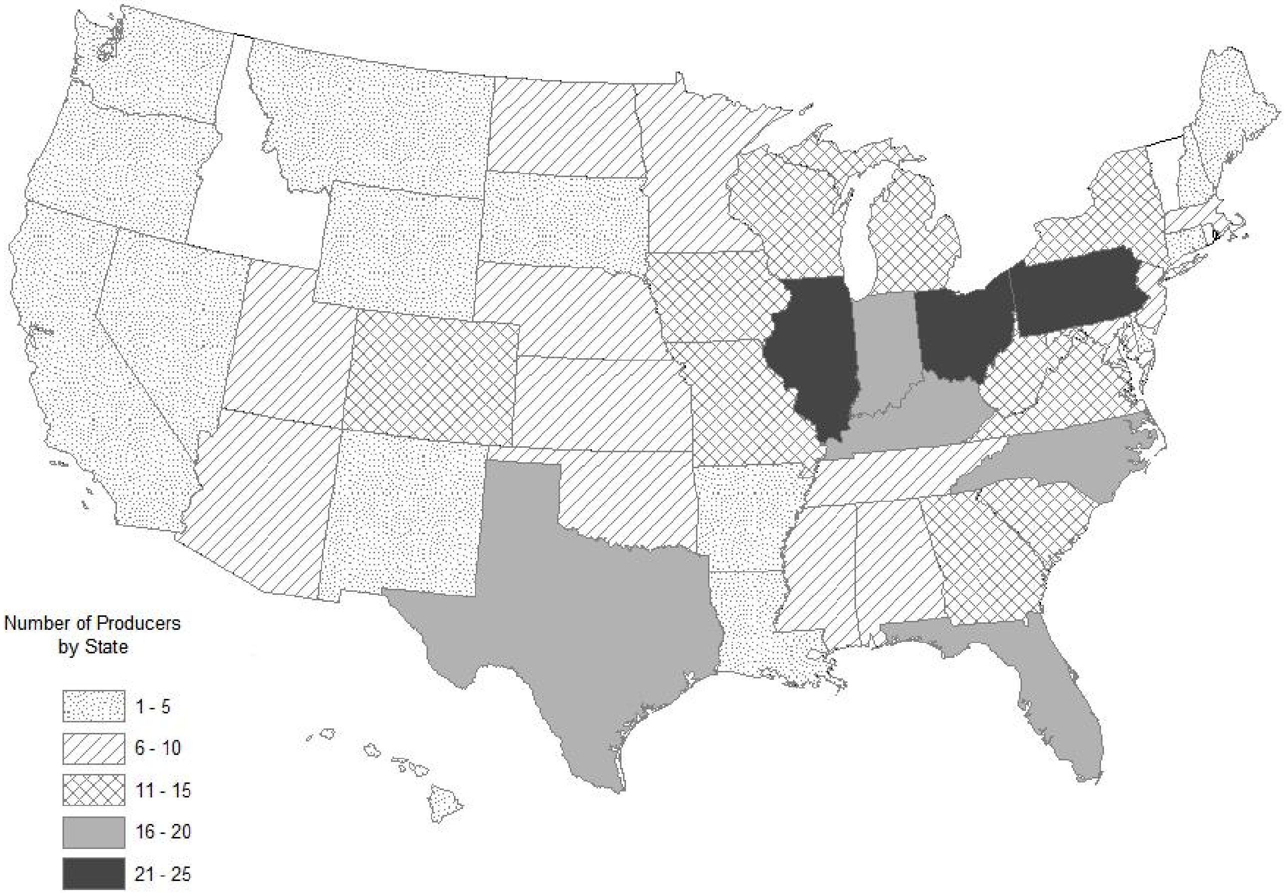


Table B-3: Coal Fly Ash Production and Disposition, by State (2004)*

State	Number of Plants	Total Fly Ash Production	Fly Ash Landfilled	Fly Ash Ponded	Fly Ash Used or Stored On-Site	Fly Ash Sold	Fly Ash Disposed Off-site
		----------------------------------	----------	*thousand metric tons*	----------	----------	----------------------------------
AL	10	2,150	672	982	--	396	99
AR	3	455	189	--	--	266	--
AZ	6	1,800	550	178	--	1,050	23
CA	1	46	46	--	--	--	--
CO	11	1,090	484	3	41	141	421
CT	4	75	--	--	--	--	75
DE	2	3,269	114	--	3,075	--	81
FL	17	2,658	732	62	42	1,230	593
GA	11	2,369	540	1,054	--	721	54
HI	1	7	--	--	--	--	7
IA	12	838	125	34	59	447	173
IL	23	2,060	18	365	163	683	831
IN	20	4,410	704	2,531	663	382	130
KS	7	642	250	83	--	279	31
KY	19	3,490	1,718	1,172	153	181	266
LA	4	997	383	160	10	445	--
MA	6	248	--	--	4	76	168
MD	9	1,403	381	20	--	379	624
ME	3	578	557	--	--	--	20
MI	15	1,590	656	535	67	289	44
MN	10	860	314	389	--	146	11
MO	15	1,252	206	409	6	560	70
MS	6	1,396	742	79	90	431	54
MT	2	613	--	572	16	24	--
NC	17	2,796	389	900	830	524	153
ND	7	1,299	843	--	48	354	54
NE	6	321	91	--	7	216	8
NH	3	78	13	--	--	3	62
NJ	6	400	--	--	--	--	400
NM	3	2,449	--	397	92	442	1,518
NV	3	553	269	--	--	284	--
NY	12	739	293	--	1	157	287
OH	22	4,124	1,249	1,504	--	555	814
OK	7	926	149	18	19	461	278
OR	1	64	--	--	--	64	--
PA	25	4,262	1,928	578	416	855	484
SC	13	1,177	135	253	--	751	38
SD	1	33	25	--	--	8	--
TN	8	1,758	662	493	35	373	195
TX	20	5,837	2,209	76	9	3,042	501
UT	6	1,355	771	11	333	240	--
VA	15	1,573	730	263	34	17	528
WA	1	463	143	--	--	320	--
WI	14	961	74	--	95	780	14
WV	14	3,201	1,871	721	213	346	51
WY	5	1,125	478	81	--	461	105
Total	**426**	**69,791**	**21,702**	**13,921**	**6,519**	**18,383**	**9,266**

Source: U.S. Department of Energy (DOE), 2004b. "Annual Steam-Electric Plant Operation and Design Data". EIA-767 data files available at http://www.eia.doe.gov/cneaf/electricity/page/eia767.html

* No coal fly ash production was reported in Alaska, Idaho, Rhode Island, or Vermont

Coal fly ash is a finely divided powder resembling portland cement. Most of the coal fly ash particles are solid spheres and some are hollow cenospheres. Plerospheres are also present, which are spheres containing smaller spheres. The particle sizes in coal fly ash vary from less than 1 μm (micrometer) to more than 100 μm with the typical particle measuring under 20 μm. Only 10% to 30% of the particles by mass are larger than 45 μm. The surface area of coal fly ash is typically 3,000 to 5,000 cm^2/gm, although some fly ashes can have surface areas as low as 2,000 cm^2/gm and as high as 7,000 cm^2/gm. For coal fly ash without close compaction, the bulk density can vary from 540 to 860 kg/m^3, but with close packed storage or vibration, the range can be 1,120 to 1,500 kg/m^3. The specific gravity of coal fly ash generally ranges between 1.9 and 2.8 (Kosmatka, 2002).

Coal fly ash consists primarily of silicate glass containing silica, alumina, iron and calcium. Minor constituents are magnesium, sulfur, sodium, potassium and carbon. This makeup gives coal fly ash its pozzolanic properties, meaning that it reacts with water and free lime (calcium oxide) to produce a cement-like compound. ASTM C 618 (AASHTO M295) classifies coal fly ash as Class C and Class F based on their pozzolanic and cementitious properties. Some coal fly ash meets both Class C and F classifications.

- **Class C Coal Fly Ash** is high-calcium, containing typically 10% to 30% calcium oxide with carbon contents less than 2%. Many Class C ash exhibits both cementitious and pozzolanic properties.
- **Class F Coal Fly Ash** is generally low-calcium, with less than 10% calcium oxide, with carbon contents usually less than 5%, but may have carbon contents as high as 10%. Many Class F ashes have pozzolanic properties—they require addition of lime to form cementitious compounds.

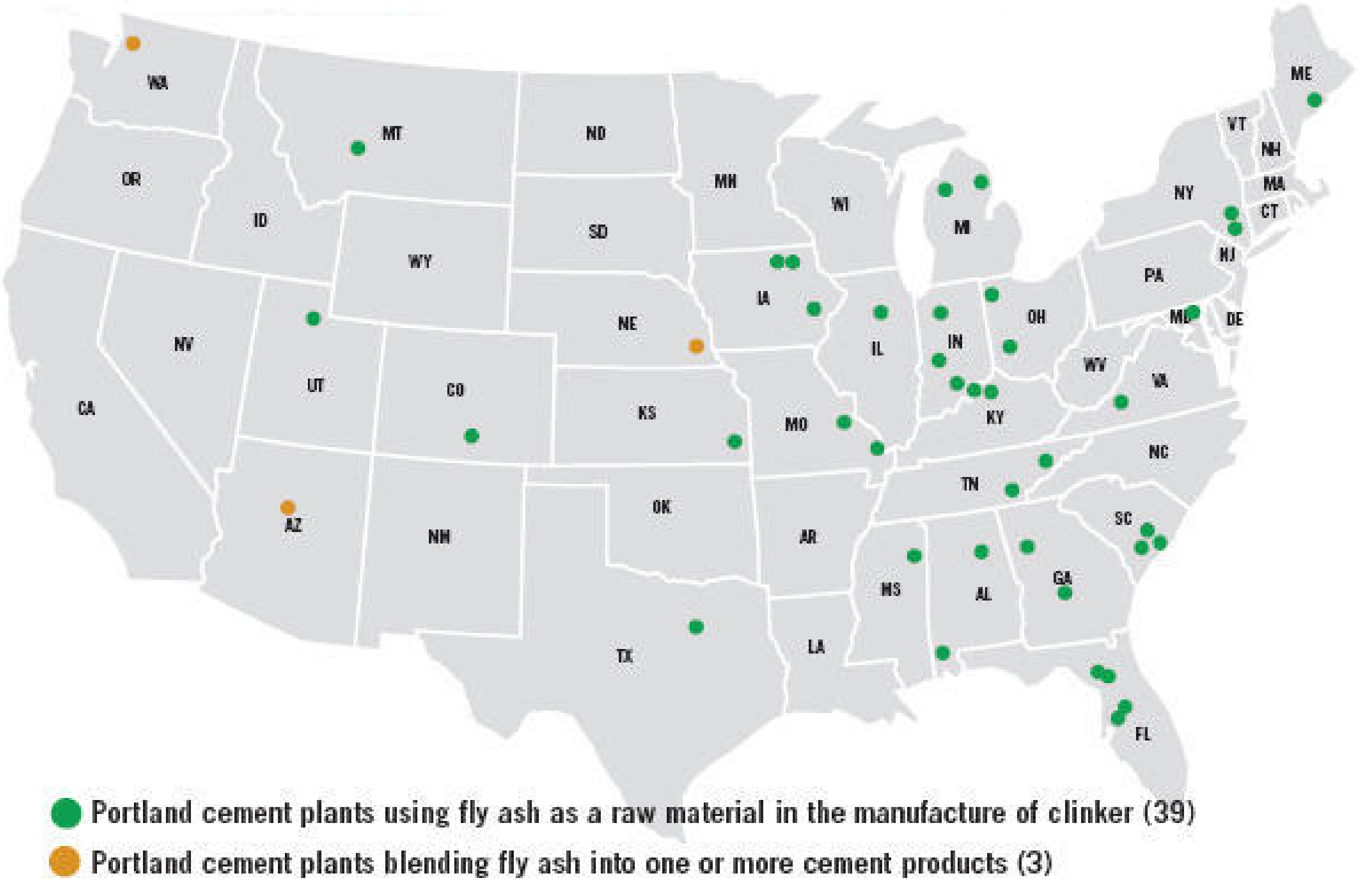
Table B-4 presents typical chemical compositions for coal fly ash produced from different coal types (FHWA, 1998)

Table B-4: Chemical Composition of Various Coal Fly Ash Types

Component	**Coal Type**		
	Bituminous	**Subbituminous**	**Lignite**
	---------------------------------*percent by weight*---------------------------		
SiO_2	20 - 60	40 - 60	15 - 45
Al_2O_3	5 - 35	20 - 30	10 - 25
Fe_2O_3	10 - 40	4 - 10	4 - 15
CaO	1 - 12	5 - 30	15 - 40
MgO	0 - 5	1 - 6	3 - 10
SO_3	0 - 4	0 - 2	0 - 10
Na_2O	0 - 4	0 - 2	0 - 6
K_2O	0 - 3	0 - 4	0 - 4
Loss on Ignition	0 - 15	0 - 3	0 - 5

Figure B-6 shows the locations of the 39 portland cement plants using coal fly ash as a raw feed in the manufacture of clinker and the 3 plants blending coal fly ash into finished cement products.

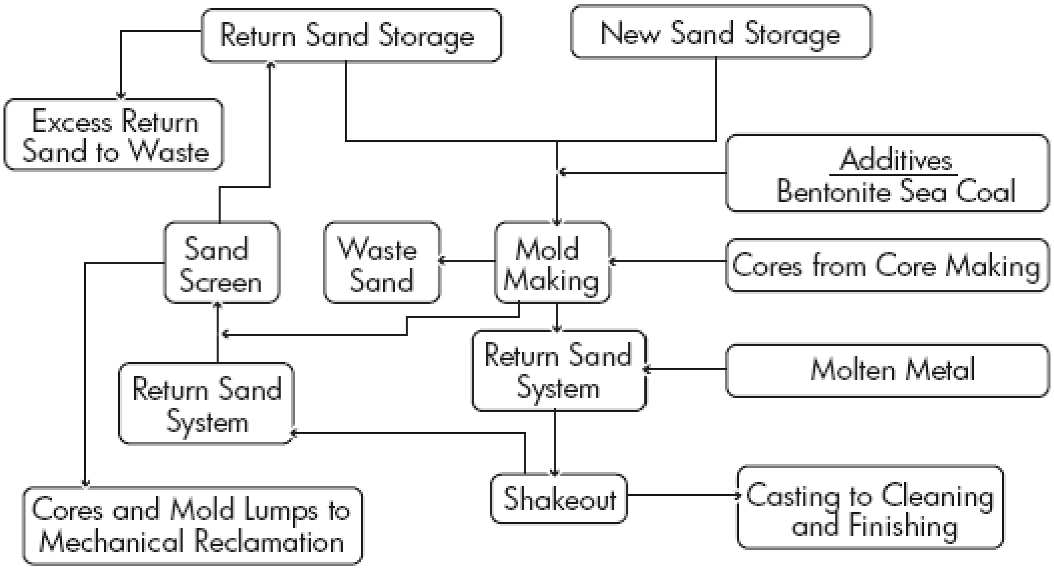
Figure B-6: U.S. Portland Cement Plants Utilizing Coal Fly Ash (PCA, 2005b)



B.5 Foundry Sand

Foundry sand is produced by five different foundry classes. The ferrous foundries (gray iron, ductile iron, and steel) produce the most sand in the United States, while aluminum, copper, brass, and bronze produce the rest. Foundries purchase high-quality, size-specific sand for use in their molding and casting operations. Foundry sand is used to form the outer shape of the mold cavity and relies upon a small amount of bentonite clay to act as the binder material. Depending on the geometry of the casting, sand cores are inserted into the mold cavity to form internal passages for the molten metal. Once the metal has solidified, the casting is separated from the molding and the core sand in the shakeout process. At that point, the old sand is displaced from the cycle as byproduct, new sand is introduced, and the cycle begins again (see Figure B-7) (FHWA, 2004).

Figure B-7: How sand is reused and becomes foundry sand



Two general types of binder systems are used in metalcasting: clay-bonded systems (green sand) and chemically-bonded systems. Both types of sand are suitable for beneficial use but they have different physical and environmental characteristics (FIRST, Undated):

- *Green Sand* molds are used to produce about 90% of casting volume in the United States. Green sand is composed of naturally occurring materials which are blended together: high quality silica sand (85% to 95%); bentonite clay (4% to10%) as a binder; a carbonaceous additive (2% to 10%) to improve the casting surface finish; and water (2% to 5%). Green sand is the most commonly used RFS for beneficial reuse.
- *Chemically bonded sand* are used both in coremaking, where high strengths are necessary to withstand the heat of the molten metal, and in mold making. Chemically bonded sand is generally light in color and coarser in texture than clay bonded sand.

Availability

Foundries are located throughout the United States in all 50 states. The top ten foundry production states are Alabama, California, Illinois, Indiana, Michigan, Ohio, Pennsylvania, Tennessee, Texas, and Wisconsin. There are approximately 12 cement kilns that are using foundry sand as a raw material, and there is an industry survey under way to obtain more complete data (FIRST, Undated). Cement kilns in New York, Texas, Wisconsin, Ohio, Missouri, Maryland, Illinois, and Iowa have used foundry sand as a source of silica.

B.6 Flue Gas Desulfurization Materials

Figure B-8 shows the locations of portland cement facilities grinding and blending flue gas desulfurization materials with clinker to produce finished cement products.

Figure B-8: U.S. Portland Cement Plants Utilizing FGD Materials (PCA, 2005b)

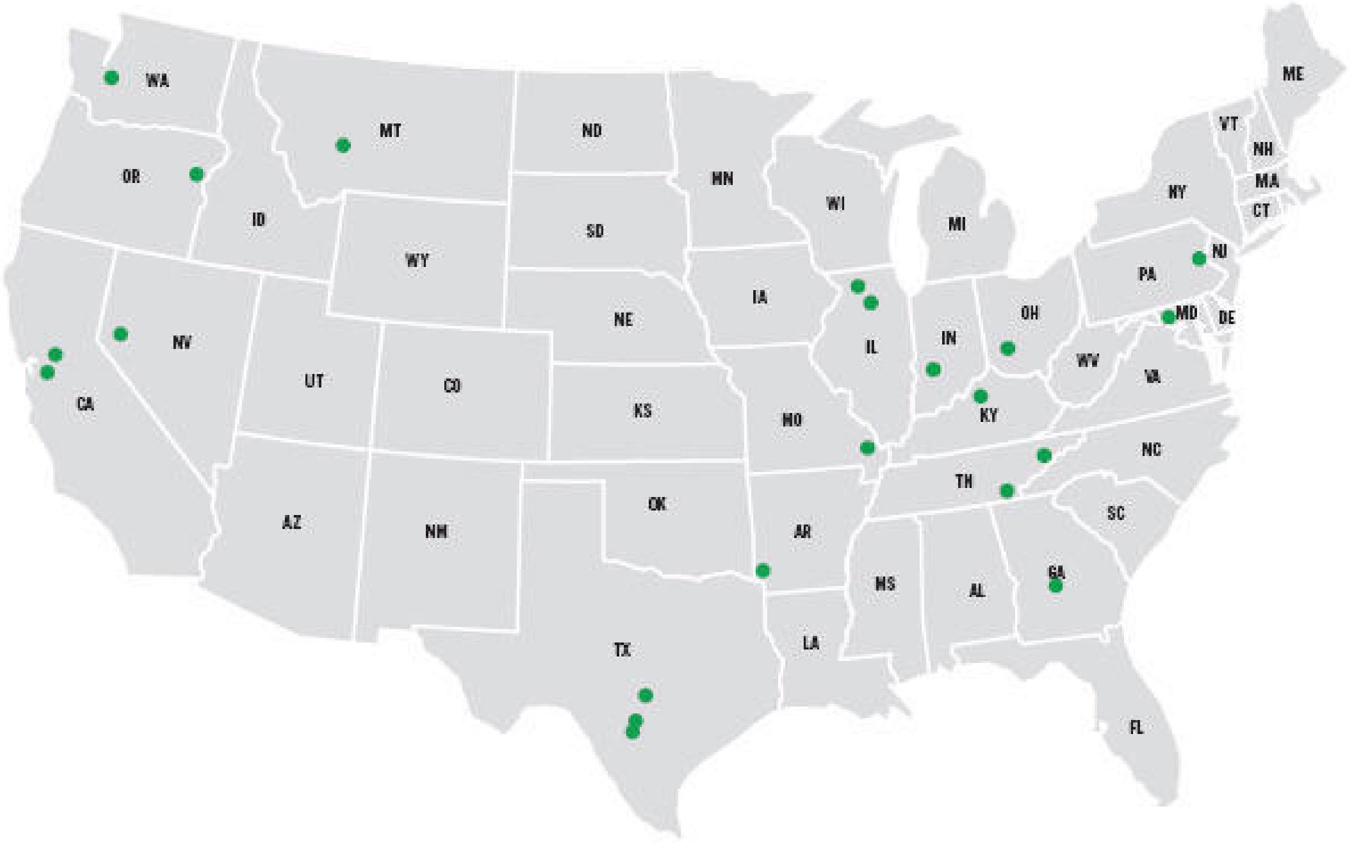


Table B-5 shows the FGD gypsum production and disposition in the United States by state in 2004.

Table B-5: FGD Gypsum Production and Disposition, by State (2004)

State	Number of Plants	Total FGD Gypsum Production	FGD Gypsum Landfilled	FGD Gypsum Ponded	FGD Gypsum Used or Stored On-Site	FGD Gypsum Sold	FGD Gypsum Disposed Off-Site
		----------*thousand metric tons*----------					
AL	2	452	--	405	--	47	--
FL	3	1,359	--	--	160	1,199	--
GA	1	29	--	--	--	29	--
IA	1	20	--	--	--	20	--
IL	1	160	6	--	--	154	--
IN	3	879	-	4	--	875	--
KY	5	1,738	--	466	--	1,272	--
NJ	1	39	--	--	--	39	--
NY	1	91	6	--	--	86	--
OH	2	576	--	--	--	576	--
PA	4	1,539	148	--	--	959	432
SC	1	242	--	--	101	141	--
TN	1	1,238	--	--	--	1,238	--
TX	4	329	59	197	--	73	--
WA	1	481	103	--	--	378	--
WV	1	222	--	--	--	222	--
Total	**32**	**9,394**	**322**	**1,072**	**261**	**7,307**	**432**

B.7 Bottom Ash

Physically, bottom ash is typically grey to black in color. Bottom ashes have angular particles with a very porous surface texture. The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times. Bottom ash is predominantly sand-sized, usually with 50% to 90% passing a 4.75 mm (No. 4) sieve, 10% to 60% passing a 0.42 mm (No. 40) sieve, 0% to 10% passing a 0.075 mm (No. 200) sieve. The top size usually ranges from 19 mm (3/4 in) to 38.1 mm (1-1/2 in) (FHWA, 1998).

The specific gravity of dry bottom ash is a function of chemical composition, with higher carbon content resulting in lower specific gravity, typically in the range of 2.1 to 2.7. The dry unit weight of bottom ash is typically in the range of 720 to 1,600 kg/m^3 (FHWA, 1998).

Bottom ash is composed primarily of silica, alumina and iron, with smaller percentages of calcium, magnesium, sulfates and other compounds. The composition is controlled primarily by the source of the coal and not by the type of furnace. Bottom ash derived from lignite or sub-bituminous coals has a higher percentage of calcium than the bottom ash from anthracite or bituminous coals. Sulfite content of bottom ash is typically very low (less than 1.0%). Table B-6 presents the chemical composition of several bottom ashes from different coal sources (FHWA, 1998).

Table B-6: Chemical Composition of Select Bottom Ash

Coal Type:	Bituminous			Sub-bituminous	Lignite
Location:	West Virginia		Ohio	Texas	
	percent by weight				
SiO_2	53.6	45.9	47.1	45.4	70.0
Al_2O_3	28.3	25.1	28.3	19.3	15.9
Fe_2O_3	5.8	14.3	10.7	9.7	2.0
CaO	0.4	1.4	0.4	15.3	6.0
MgO	4.2	5.2	5.2	3.1	1.9
Na_2O	1.0	0.7	0.8	1.0	0.6
K_2O	0.3	0.2	0.2	--	0.1

Table B-7 indicates production and disposition of bottom ash by state for 2004.

Table B-7: Bottom Ash Production and Disposition, by State (2004)*

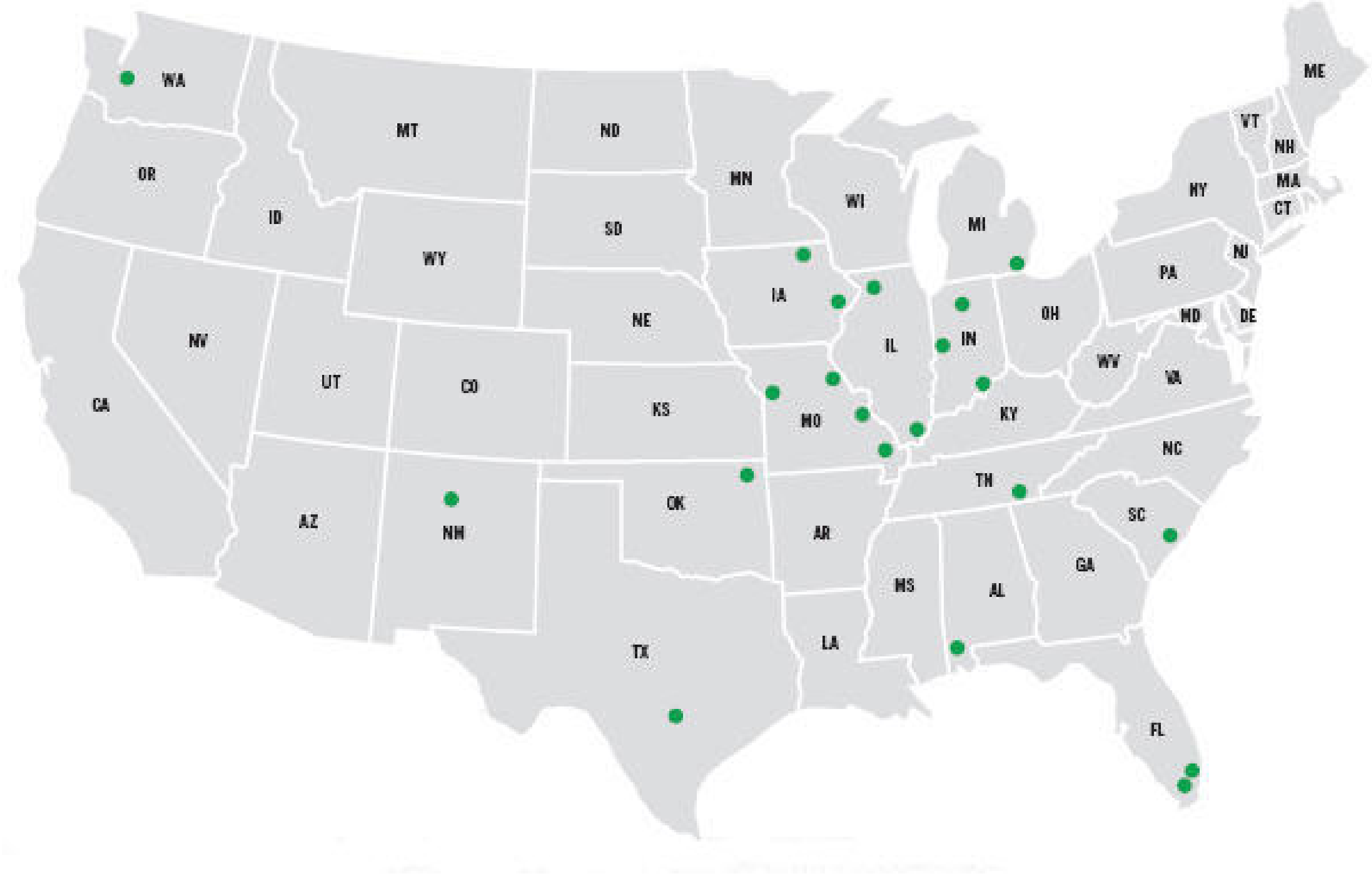
State	Number of Plants	Bottom Ash Total	Bottom Ash Landfilled	Bottom Ash Ponded	Bottom Ash Used or Stored On-site	Bottom Ash Sold	Bottom Ash Disposed Offsite
		thousand metric tons					
AL	9	548	136	252	106	53	1
AR	3	166	126	13	1	25	2
AZ	6	496	373	115	-	3	6
CO	11	237	85	3	28	18	103
CT	3	26	-	-	-	-	26
DE	2	53	-	-	43	8	2
FL	17	466	201	15	33	149	68
GA	10	451	69	205	11	166	-
HI	1	0	-	-	-	-	0
IA	12	245	16	73	6	110	39
IL	23	1,183	-	158	130	656	239
IN	20	1,379	33	564	302	428	51
KS	7	369	46	72	32	209	10
KY	18	760	124	379	70	42	145
LA	5	164	10	76	-	78	-
MA	4	49	-	-	3	36	10
MD	8	360	32	5	50	157	116
ME	3	149	149	-	-	-	0
MI	15	356	140	2	152	49	13
MN	10	256	17	58	131	48	1
MO	16	766	6	355	12	391	2
MS	5	228	131	0	44	53	-
MT	2	251	-	245	2	4	-
NC	16	395	31	165	37	98	64
ND	7	762	201	247	215	46	53
NE	6	104	51	-	2	47	5
NH	3	51	-	-	(10)	58	2
NJ	6	105	-	-	-	62	43
NM	3	598	-	-	247	-	351
NV	4	184	184	-	-	-	0

State	Number of Plants	Bottom Ash Total	Bottom Ash Landfilled	Bottom Ash Ponded	Bottom Ash Used or Stored On-site	Bottom Ash Sold	Bottom Ash Disposed Offsite
		----------------------------------*thousand metric tons*---					
NY	11	208	39	-	92	40	37
OH	22	1,213	18	399	266	360	169
OK	6	232	20	13	2	85	113
OR	1	22	13	-	-	9	-
PA	22	906	375	17	103	318	93
SC	14	277	41	138	-	65	33
SD	1	62	44	-	-	18	-
TN	7	350	-	110	198	39	3
TX	19	2,665	1,724	132	83	557	168
UT	6	403	292	111	-	-	-
VA	13	596	204	79	60	73	180
WA	1	1,129	301	-	332	496	-
WI	13	241	52	-	43	147	1
WV	14	566	126	98	128	201	13
WY	5	415	275	140	-	-	-
Total	**410**	**20,442**	**5,685**	**4,238**	**2,952**	**5,405**	**2,162**

* No bottom ash production was reported for Alaska, California, Idaho, Rhode Island and Vermont.

Figure B-9 presents the locations of portland cement facilities that use bottom ash and/or boiler slag as a raw feed in clinker production.

Figure B-9: U.S. Portland Cement Plants Utilizing Bottom Ash/Boiler Slag (PCA, 2005b)



B.8 Boiler Slag

Boiler slags are predominantly single-sized and within a range of 5.0 to 0.5 mm (No. 4 to No. 40 sieve). Ordinarily, boiler slags have a smooth surface texture, but if gases are trapped in the slag as it is tapped from the furnace, the quenched slag will become somewhat vesicular or porous. Boiler slag from the burning of lignite or subbituminous coal tends to be more porous than that of the eastern bituminous coals. Boiler slag is essentially the size of coarse to medium sand with 90% to 100% passing a 4.75 mm (No. 4) sieve, 40% to 60% passing a 2.0 mm (No. 10) sieve, 10% or less passing a 0.42 mm (No. 40) sieve, and 5% or less passing a 0.075 mm (No. 200) sieve (FHWA, 1998). The specific gravity of boiler slag is typically in the range of 2.3 to 2.9, and the dry unit weight is typically in the range of 960 to 1,440 kg/m^3 (FHWA, 1998).

Boiler slag is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. Like bottom ash, the composition of the boiler slag particles is controlled primarily by the source of the coal and not by the type of furnace. Boiler slag derived from lignite or sub-bituminous coals has a higher percentage of calcium than the boiler slag from anthracite or bituminous coals. Sulfate content is usually very low (less than 1.0%), unless pyrites have not been removed from the boiler slag. Table B-8 presents the chemical composition of select boiler slags (FHWA, 1998).

Table B-8: Chemical Composition of Select Boiler Slags

Coal Type:	**Bituminous**		**Lignite**
Location:	**West Virginia**		**North Dakota**
	----------*percent by weight*----------		
SiO_2	48.9	53.6	40.5
Al_2O_3	21.9	22.7	13.8
Fe_2O_3	14.3	10.3	14.2
CaO	1.4	1.4	22.4
MgO	5.2	5.2	5.6
Na_2O	0.7	1.2	1.7
K_2O	0.1	0.1	1.1

Figure B-9 above presents portland cement facilities using boiler slag and/or bottom ash as a raw feed in clinker production.

B.9 Steel Slag

Steel slag aggregates are highly angular in shape and have a rough surface texture. The cooling rate of steel slag is sufficiently low so that crystalline compounds are generally formed. The predominant compounds are dicalcium silicate, tricalcium silicate, dicalcium ferrite, merwinite, calcium aluminate, calcium-magnesium iron oxide, and some free lime and free magnesia. The relative proportions of these compounds depend on the steel-making practice and the steel slag cooling rate. Table B-9 presents the typical chemical composition of steel furnace slag. Steel slag typically has a high specific gravity ranging between 3.2 and 3.6, and a unit weight of 1,600 to 1,920 kg/m^3 (FHWA, 1998).

Table B-9: Typical Chemical Composition of Steel Furnace Slag

Constituent	**Range (percent by weight)**
CaO	40 - 52
SiO_2	10 - 19
Al_2O_3	1 - 3
MgO	5 - 10
FeO and Fe_2O_3	10 - 40
MnO	5 - 8
S	< 0.1
P_2O_5	0.5 - 1
Metallic Fe	0.5 - 10

B.10 Cement Kiln Dust (CKD)

CKD is a fine, dry, alkaline dust that readily absorbs water. It is composed of particles of unburned or partially burned feedstock materials, dehydrated clay, decarbonated (calcined) limestone, ash from combusted fuels, and various minerals formed during the different stages of the clinkering process. While composition varies from plant to plant, the primary constituents of CKD are calcium oxides, silicates, carbonates, potassium oxide, sulfates, chlorides, various metal oxides, and sodium oxide. CaO typically comprises the largest component of CKD, approaching as much as 50% by weight in some cases (U.S. EPA, 1993).

CKD is very fine grained with particle diameters ranging from near zero μm to greater than 50 μm. At least 55% of CKD measures less than 30 μm and nearly 82% is less than 50 μm (U.S. EPA, 1993). Because of its fine grained nature, CKD is readily entrained and transported in the continuous, rapidly flowing, and highly turbulent gas flow of cement kilns. To remove these entrained fine particles from kiln exhaust gas requires the use of complex air-pollution control devices such as electrostatic precipitators or fabric filters (i.e., bag houses). Wet scrubbers, common in other mineral processing industries, can not be used due to the chemically dehydrated nature and cementitious properties of CKD. Cement kiln dust collection systems are especially effective at removing CKD from exhaust gas, typically exhibiting 98% to nearly 100% removal efficiencies (U.S. EPA, 1993).

CKD's alkaline nature derives from its high concentrations of CaO and other alkaline compounds including K_2O, NaOH, Na_2CO_3, and $NaSO_4$. Even though CKD is a highly alkaline material, because it is a solid, it does not exhibit the RCRA Subtitle C hazardous waste characteristic of corrosivity. (This is because the RCRA hazardous identification regulations do not include a definition for corrosive solids.) When mixed with water, however, the resulting CKD and water mixtures often have pH levels greater than 12.5 and therefore do exhibit the corrosivity characteristic. Studies using the standard EPA leaching procedure (i.e., the Toxicity Characteristic Leaching Procedure or TCLP) show leachate pH levels falling in the 11 to 13 range (U.S. EPA, 1993).

Trace constituents commonly found in CKD include organic chemicals, metals, and radionuclides. Concentrations of heavy metals are of particular concern in the reuse of CKD either directly in the kiln or for other beneficial applications. Studies performed by EPA in preparation for its 1993 Report to Congress consistently found eight Toxicity Characteristic (TC) metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) and nine other metals (antimony, beryllium, copper, manganese, nickel, strontium, thallium, vanadium, and zinc) present in CKD samples. The predominant metals were antimony, barium, lead, manganese, strontium, thallium, and zinc. The others were found in lesser concentrations. While these metals were consistently present in the CKD samples, in general, their concentrations were well below the regulatory TCLP/Toxicity Characteristic levels (U.S. EPA, 1993). A few of the samples, however, did yield results above the regulatory limits for lead (4 of 244 samples), selenium (2 of 129 samples), barium (1 of 88 samples), and cadmium (1 of 88 samples) (U.S. EPA, 1993).

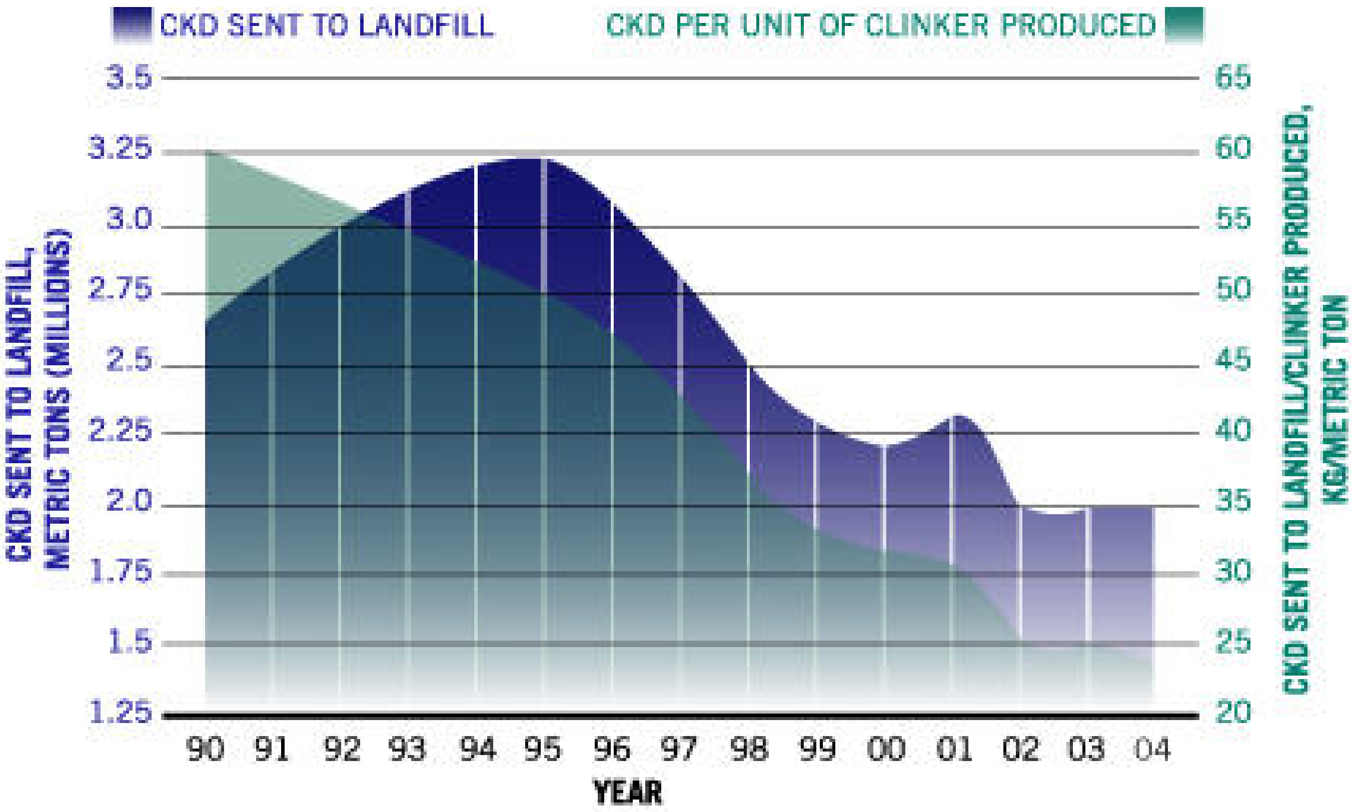
Table B-10 illustrates the typical chemical composition of CKD (FHWA, 1998).

Table B-10: Typical Chemical Composition of CKD

Parameter	**Fresh**	**Stockpiled**	
		Sample 1	**Sample 2**
	------*percent by weight*------		
CaO	40.5	31.4	44.2
Free Lime	4.4	0.0	0.0
SiO_2	14.5	11.7	11.9
Al_2O_3	4.1	3.18	3.24
MgO	1.55	0.97	1.73
Na_2O_3	0.44	0.13	0.27
K_2O	4.66	1.65	2.92
Fe_2O_3	2.00	2.16	1.45
SO_3	6.50	8.24	2.40
Loss on Ignition, 105°C	22.9	40.4	30.2

Figure B-10 below shows the amount of CKD disposed in landfills from 1990 through 2004 and compares the amount of CKD disposed in landfills to clinker production during this same time period. The graph below represents CKD recovered from CKD scrubbers and does not reflect any CKD automatically re-ducted back into the kiln.

Figure B-10 CKD Landfilled; CKD Landfilled versus Clinker Produced



APPENDIX C:

CEMENT AND RMC PRODUCERS

Table C-1: U.S. Cement Plants (PCA, 2006)

Company	City	State
CEMEX	Demopolis	AL
Holcim (US) Inc.	Theodore	AL
Lafarge North America, Inc.	Calera	AL
Lehigh SE Cement Company	Roberta	AL
National Cement Company Of Alabama	Ragland	AL
California Portland Cement Company	Rillito	AZ
Phoenix Cement Company (a.k.a., Salt River Materials)	Clarkdale	AZ
Ash Grove Cement Company	Foreman	AR
California Portland Cement Company	Colton	CA
California Portland Cement Company	Mojave	CA
CEMEX	Victorville	CA
Texas Industries, Inc.	Riverside	CA
Hanson Permanente Cement (recently purchased by Lehigh)	Cupertino	CA
Lehigh Southwest Cement Company	Tehachapi	CA
Lehigh Southwest Cement Company	Redding	CA
Mitsubishi Cement Corporation	Lucerne Valley	CA
National Cement Company Of California	Lebec	CA
RMC Pacific Materials, Inc. (now part of CEMEX)	Davenport	CA
Texas Industries, Inc. (TXI Riverside Cement)	Oro Grande and Crestmore	CA
CEMEX	Lyons	CO
Holcim (US) Inc. (facility is closed)	LaPorte	CO
Holcim (US) Inc.	Florence	CO
CEMEX	Brooksville	FL
Florida Rock Industries, Inc.	Newberry	FL
Lafarge North America, Inc. (owned by Florida Rock Industries)	Palmetto	FL
Lafarge North America, Inc. (owned by Florida Rock Industries)	Tampa	FL
Rinker Materials (owned by CEMEX)	Brooksville	FL
Rinker Materials (owned by CEMEX)	Miami	FL
Tarmac America, Inc.	Medley	FL
CEMEX	Clinchfield	GA
Lafarge North America, Inc.	Atlanta	GA
Ash Grove Cement Company	Inkom	ID
Centex Construction Products, Inc. (Eagle Materials)	La Salle	IL
Dixon-Marquette Cement Company (St Mary's Cement)	Dixon	IL
Lafarge North America, Inc.	Grand Chain	IL
Lone Star Industries, Inc. (Buzzi Unicem)	Oglesby	IL
Essroc Cement Corp.	Speed	IN
Essroc Cement Corp.	Logansport	IN
Lehigh Cement Company	Mitchell	IN
Lone Star Industries, Inc. (Buzzi Unicem)	Greencastle	IN

Company	**City**	**State**
Holcim (US) Inc.	Mason City	IA
Lafarge North America, Inc.	Buffalo	IA
Lehigh Cement Company	Mason City	IA
Ash Grove Cement Company	Chanute	KS
Lafarge North America, Inc.	Fredonia	KS
Monarch Cement Company	Humboldt	KS
RC Cement Company, Inc.	Independence	KS
Kosmos Cement Company (operated by CEMEX)	Louisville	KY
Lone Star Industries, Inc. (Buzzi Unicem)	New Orleans	LA
Dragon Products Company	Thomaston	ME
Essroc Cement Corp.	Frederick	MD
Lehigh Cement Company	Union Bridge	MD
St. Lawrence Cement Company	Hagerstown	MD
CEMEX	Charlevoix	MI
Essroc Cement Corp.	Essexville	MI
Holcim (US) Inc.	Dundee	MI
Lafarge North America, Inc.	Alpena	MI
St. Marys Cement, Inc. (U.S.)	Detroit	MI
Holcim (US) Inc.	Artesia	MS
Continental Cement Company, Inc.	Hannibal	MO
Holcim (US) Inc.	Clarksville	MO
Lafarge North America, Inc.	Sugar Creek	MO
Lone Star Industries, Inc. (Buzzi Unicem)	Cape Girardeau	MO
RC Cement Company, Inc. (Buzzi Unicem)	Fustus	MO
Ash Grove Cement Company	Montana City	MT
Holcim (US) Inc.	Three Forks	MT
Ash Grove Cement Company	Louisville	NE
Centex Construction Products, Inc.	Fernley	NV
Royal Cement Company, Inc. (facility closed)	Logandale	NV
GCC Rio Grande	Tijeras	NM
Lehigh Cement Company	Glens Falls	NY
Lehigh Cement Company	Cementon	NY
Lafarge North America, Inc.	Ravena	NY
St. Lawrence Cement Company	Catskill	NY
CEMEX	Fairborn	OH
Lafarge North America, Inc.	Paulding	OH
Holcim (US) Inc.	Ada	OK
Lafarge North America, Inc.	Tulsa	OK
Lone Star Industries, Inc. (Buzzi Unicem)	Pryor	OK
Ash Grove Cement Company	Durkee	OR
Armstrong Cement & Sup. Corp.	Cabot	PA
CEMEX	Wampum	PA
Essroc Cement Corp.	Nazareth	PA
Essroc Cement Corp.	Bessemer	PA
Giant Cement Holding, Inc.	Bath	PA
Lafarge North America, Inc.	Whitehall	PA
Lehigh Cement Company	Evansville	PA

Company	**City**	**State**
Lehigh Cement Company	York	PA
RC Cement Company, Inc. (Buzzi Unicem)	Stockertown	PA
Giant Cement Holding, Inc.	Harleyville	SC
Holcim (US) Inc.	Holly Hill	SC
Lafarge North America, Inc.	Harleyville	SC
GCC Dacotah	Rapid City	SD
CEMEX	Knoxville	TN
RC Cement Company, Inc. (Buzzi Unicem)	Chattanooga	TN
Alamo Cement Company	San Antonio	TX
Capitol Aggregates, Ltd.	San Antonio	TX
CEMEX	Odessa	TX
CEMEX	New Braunfels	TX
Texas Industries Inc.	New Braunfels	TX
Texas Industries Inc.	Midlothian	TX
Texas-Lehigh Cement Company	Buda	TX
Holcim (US) Inc.	Midlothian	TX
Lehigh Cement Company	Waco	TX
Lone Star Industries, Inc. (Buzzi Unicem)	Maryneal	TX
North Texas Cement Company, L.P. (Ash Grove Texas LP)	Midlothian	TX
Ash Grove Cement Company	Leamington	UT
Holcim (US) Inc.	Morgan	UT
Roanoke Cement Company	Cloverdale	VA
Ash Grove Cement Company	Seattle	WA
Lafarge North America, Inc.	Seattle	WA
Lehigh Northwest Cement Company	Bellingham	WA
Essroc Cement Corp.	Martinsburg	WV
Centex Construction Products, Inc.	Laramie	WY

Table C-2: U.S. Blast Furnace Slag Processors (van Oss, 2004b)

Company	City	State
Fritz Enterprises, Inc.	Fairfield	AL
Holcim (US) Inc.	Birmingham (Fairfield)	AL
Civil & Marine, Inc. (Hanson Slag Cement)	Cape Canaveral	FL
Florida Rock Industries, Inc.	Tampa	FL
Rinker Materials Corp.	Miami	FL
Titan Florida, Inc.	Medley	FL
Lafarge North America, Inc.	Chicago	IL
Lafarge North America, Inc.	Joppa	IL
Holcim (US) Inc.	Gary	IN
Lafarge North America, Inc.	East Chicago	IN
Levy Co., Inc., The	Burns Harbor	IN
Levy Co., Inc., The	East Chicago	IN
Levy Co., Inc., The	Gary	IN
Mountain Enterprises, Inc.	Ashland	KY
Stein, Inc.	Ashland	KY
Buzzi Unicem USA, Inc.	New Orleans	LA
Lafarge North America, Inc.	Sparrows Point	MD
MultiServ	Sparrows Point	MD
Edward C. Levy Co.	Detroit	MI
Edward C. Levy Co.	Detroit	MI
St. Marys Cement, Inc.	Detroit	MI
St. Lawrence Cement, Inc.	Camden	NJ
Buffalo Crushed Stone, Inc.	Woodlawn	NY
Glens Falls-Lehigh Cement Co.	Cementon	NY
Essroc Corp.	Middlebranch	OH
Lafarge North America, Inc.	Cleveland (Cuyahoga Co.)	OH
Lafarge North America, Inc.	Lordstown	OH
Lafarge North America, Inc.	McDonald	OH
Lafarge North America, Inc.	Salt Springs (Youngstown)	OH
Lafarge North America, Inc.	Warren	OH
Stein, Inc.	Cleveland	OH
Stein, Inc.	Lorain	OH
Tube City IMS Corporation	Middletown	OH
Tube City IMS Corporation	Mingo Junction	OH
Beaver Valley Slag	Aliquippa	PA
Lafarge North America, Inc.	West Mifflin	PA
Lafarge North America, Inc.	West Mifflin (Brown Reserve)	PA
Lafarge North America, Inc.	Whitehall	PA
Lehigh Cement	Evansville	PA
Tube City-IMS, IMS Division	Bethlehem	PA
MultiServ	Geneva (Provo)	UT
Lafarge North America, Inc.	Seattle	WA
Holcim (US) Inc.	Weirton	WV
Lafarge North America, Inc.	Weirton	WV

Table C-3: U.S. Steel Slag Processors (van Oss, 2004b)

Company	City	State
AMSI	Holsopple	PA
Barfield Enterprises, Inc.	La Place	LA
Barfield Enterprises, Inc.	Lone Star	TX
Beaver Valley Slag	Aliquippa	PA
Beaver Valley Slag (Thor Mill Services)	Roanoke	VA
Blackheart Slag Company	Muscatine (Montpelier)	IA
Border Steel, Inc.	El Paso	TX
Edward C. Levy Company	Decatur (Trinity)	AL
Edward C. Levy Company	Butler	IN
Edward C. Levy Company	Columbia City	IN
Edward C. Levy Company	Crawfordsville	IN
Edward C. Levy Company	Detroit	MI
Edward C. Levy Company	Detroit	MI
Edward C. Levy Company	Canton	OH
Edward C. Levy Company	Delta	OH
Edward C. Levy Company	Huger	SC
Fritz Enterprises, Inc.	Fairfield	AL
Gerdau Ameristeel Corporation	Jacksonville	FL
Gerdau Ameristeel Corporation	Charlotte	NC
Levy Company, Inc., The	Burns Harbor	IN
MultiServ	Birmingham	AL
MultiServ	Tuscaloosa	AL
MultiServ	Blytheville	AR
MultiServ	Blytheville (Armorel)	AR
MultiServ	Pueblo	CO
MultiServ	Wilton (Muscatine)	IA
MultiServ	East Chicago	IN
MultiServ	Indiana Harbor	IN
MultiServ	Ghent	KY
MultiServ	Sparrows Point	MD
MultiServ	Ahoskie (Cofield)	NC
MultiServ	Canton	OH
MultiServ	Mansfield	OH
MultiServ	Warren	OH
MultiServ	Braddock (Mon Valley)	PA
MultiServ	Butler	PA
MultiServ	Coatesville	PA
MultiServ	Koppel	PA
MultiServ	Steelton	PA
MultiServ	Midlothian	TX
MultiServ	Geneva (Provo)	UT
MultiServ	Seattle	WA
Stein, Inc.	Sterling	IL
Stein, Inc.	Ashland	KY
Stein, Inc.	Cleveland	OH

Company	**City**	**State**
Stein, Inc.	Loraine	OH
Tube City IMS Corporation	Birmingham	AL
Tube City IMS Corporation	Newport	AR
Tube City IMS Corporation	Rancho Cucamonga	CA
Tube City IMS Corporation	Portage	IN
Tube City IMS Corporation	Norfolk	NE
Tube City IMS Corporation	Perth Amboy	NJ
Tube City IMS Corporation	Sayreville	NJ
Tube City IMS Corporation	Middletown	OH
Tube City IMS Corporation	Mingo Junction	OH
Tube City IMS Corporation	Youngstown	OH
Tube City IMS Corporation	Sand Springs	OK
Tube City IMS Corporation	Cayce	SC
Tube City IMS Corporation	Knoxville	TN
Tube City IMS Corporation	Seguin	TX
Tube City IMS Corporation	Petersburg	VA
Tube City-IMS, IMS Division	Axis	AL
Tube City-IMS, IMS Division	Fort Smith	AR
Tube City-IMS, IMS Division	Newport	AR
Tube City-IMS, IMS Division	Kingman	AZ
Tube City-IMS, IMS Division	Claymont	DE
Tube City-IMS, IMS Division	Cartersville	GA
Tube City-IMS, IMS Division	Wilton (Muscatine)	IA
Tube City-IMS, IMS Division	Kankakee	IL
Tube City-IMS, IMS Division	Peoria	IL
Tube City-IMS, IMS Division	Laplace	LA
Tube City-IMS, IMS Division	Jackson	MI
Tube City-IMS, IMS Division	Monroe	MI
Tube City-IMS, IMS Division	St. Paul	MN
Tube City-IMS, IMS Division	Jackson	MS
Tube City-IMS, IMS Division	Charlotte	NC
Tube City-IMS, IMS Division	Perth Amboy	NJ
Tube City-IMS, IMS Division	Sayreville	NJ
Tube City-IMS, IMS Division	Auburn	NY
Tube City-IMS, IMS Division	Marion	OH
Tube City-IMS, IMS Division	McMinnville	OR
Tube City-IMS, IMS Division	Portland	OR
Tube City-IMS, IMS Division	Bethlehem	PA
Tube City-IMS, IMS Division	Bridgeville	PA
Tube City-IMS, IMS Division	Midland	PA
Tube City-IMS, IMS Division	Monroeville	PA
Tube City-IMS, IMS Division	New Castle	PA
Tube City-IMS, IMS Division	Park Hill (Johnstown)	PA
Tube City-IMS, IMS Division	Pricedale	PA
Tube City-IMS, IMS Division	Reading	PA
Tube City-IMS, IMS Division	Darlington	SC
Tube City-IMS, IMS Division	Georgetown	SC

Company	**City**	**State**
Tube City-IMS, IMS Division	Jackson	TN
Tube City-IMS, IMS Division	Beaumont	TX
Tube City-IMS, IMS Division	Jewett	TX
Tube City-IMS, IMS Division	Longview	TX
Tube City-IMS, IMS Division	Plymouth	UT
Tube City-IMS, IMS Division	Saukville	WI
Tube City-IMS, IMS Division	Weirton	WV

Table C-4: U.S. Facilities Producing Coal Fly Ash (U.S. DOE, 2004b)

Utility Name	**Plant Name**	**City**	**State**
Alabama Electric Coop, Inc.	Charles R Lowman	Leroy	AL
Alabama Power Co.	Barry	Bucks	AL
Alabama Power Co.	Gadsden	East Gadsden	AL
Alabama Power Co.	Gorgas	Parrish	AL
Alabama Power Co.	Greene County	Demopolis	AL
Alabama Power Co.	E C Gaston	Wilsonville	AL
Alabama Power Co.	James H Miller Jr	Quinton	AL
International Paper Co.-Courtland	International Paper Courtland Mill	Courtland	AL
Tennessee Valley Authority	Colbert	Tuscumbia	AL
Tennessee Valley Authority	Widows Creek	Stevenson	AL
Entergy Arkansas, Inc.	White Bluff	Redfield	AR
Entergy Arkansas, Inc.	Independence	Newark	AR
Southwestern Electric Power Co.	Flint Creek	Gentry	AR
Arizona Electric Pwr Coop, Inc.	Apache Station	Cochise	AZ
Arizona Public Service Co.	Cholla	Joseph City	AZ
Salt River Proj Ag I & P Dist	Navajo	Page	AZ
Salt River Proj Ag I & P Dist	Coronado	St Johns	AZ
UNS Electric, Inc.	H Wilson Sundt Generating Station	Cherry Bell Station	AZ
UNS Electric, Inc.	Springerville	Springerville	AZ
ACE Cogeneration Co.	ACE Cogeneration Facility	Trona	CA
Colorado Springs, City of	Martin Drake	Colorado Springs	CO
Colorado Springs, City of	Ray D Nixon	Fountain	CO
Platte River Power Authority	Rawhide	Wellington	CO
Public Service Co. of Colorado	Arapahoe	Denver	CO
Public Service Co. of Colorado	Cherokee	Denver	CO
Public Service Co. of Colorado	Comanche	Pueblo	CO
Public Service Co. of Colorado	Valmont	Boulder	CO
Public Service Co. of Colorado	Hayden	Hayden	CO
Public Service Co. of Colorado	Pawnee	Brush	CO
Tri-State G & T Assn, Inc.	Nucla	Nucla	CO
Tri-State G & T Assn, Inc.	Craig	Craig	CO
AES Thames LLC	AES Thames	Uncasville	CT
NRG Devon Operations, Inc.	Devon Station	Devon	CT
NRG Norwalk Harbor Operations	NRG Norwalk Harbor	South Norwalk	CT
PSEG Power Connecticut LLC	Bridgeport Station	Bridgeport	CT
Conectiv Energy Supply, Inc.	Edge Moor	Edgemoor	DE
Indian River Operations, Inc.	Indian River Operations	Millsboro	DE
Central Power & Lime, Inc.	Central Power & Lime	Brooksville	FL
Florida Power & Light Co.	Cape Canaveral	Cocoa	FL
Florida Power & Light Co.	Riviera	Riviera Beach	FL
Florida Power & Light Co.	Sanford	Lake Monroe	FL
Florida Power & Light Co.	Manatee	Parrish	FL
Gainesville Regional Utilities	Deerhaven Generating Station	Alachua	FL
Gulf Power Co.	Crist	Pensacola	FL
Gulf Power Co.	Lansing Smith	Southport FL	FL

Utility Name	**Plant Name**	**City**	**State**
Indiantown Cogeneration LP	Indiantown Cogen Facility	Indiantown	FL
JEA	St Johns River Power Park	Oceanway	FL
JEA	Northside Generating Station	Oceanway	FL
Orlando Utilities Comm	Stanton Energy Center	Alafaya Branch	FL
PG&E Operating Service Co.	Cedar Bay Generating LP	Jacksonville	FL
Progress Energy Florida, Inc.	Crystal River	Crystal River	FL
Progress Energy Florida, Inc.	P L Bartow	St Petersburg	FL
Seminole Electric Coop Inc.	Seminole	Bostwick	FL
Tampa Electric Co.	Big Bend	Ruskin	FL
Georgia Power Co.	Bowen	Taylorsville	GA
Georgia Power Co.	Hammond	Coosa	GA
Georgia Power Co.	Harllee Branch	Milledgeville	GA
Georgia Power Co.	Jack McDonough	Smyrna	GA
Georgia Power Co.	Mitchell	Putney	GA
Georgia Power Co.	Yates	Sargent	GA
Georgia Power Co.	Wansley	Roopville	GA
Georgia Power Co.	Scherer	Juliette	GA
International Paper Co.	International Paper Savanna Mill	Savannah	GA
Savannah Electric & Power Co.	Kraft	Port Wentworth	GA
Savannah Electric & Power Co.	McIntosh	Rincon	GA
AES Corp	AES Hawaii	Kapolei	HI
Archer Daniels Midland Co.	Archer Daniels Midland Cedar Rapids	Cedar Rapids	IA
Interstate Power & Light Co.	Milton L Kapp	Clinton	IA
Interstate Power & Light Co.	Prairie Creek	Cedar Rapids	IA
Interstate Power & Light Co.	Sutherland	Marshalltown	IA
Interstate Power & Light Co.	Burlington	Burlington	IA
Interstate Power and Light	Ottumwa	Ottumwa	IA
MidAmerican Energy Co.	Riverside	Bettendorf	IA
MidAmerican Energy Co.	Council Bluffs	Council Bluffs	IA
MidAmerican Energy Co.	George Neal North	Salix	IA
MidAmerican Energy Co.	Louisa	Muscatine	IA
MidAmerican Energy Co.	George Neal South	Salix	IA
Muscatine, City of	Muscatine Plant #1	Muscatine	IA
Ameren Energy Generating Co.	Coffeen	Coffeen	IL
Ameren Energy Generating Co.	Hutsonville	Hutsonville	IL
Ameren Energy Generating Co.	Meredosia	Meredosia	IL
Ameren Energy Generating Co.	Newton	Newton	IL
Ameren Energy Resources Generating	E D Edwards	Bartonville	IL
Ameren Energy Resources Generating	Duck Creek	Canton	IL
Archer Daniels Midland Co.	Archer Daniels Midland Decatur	Decatur	IL
Dominion Energy Services Co.	Kincaid Generation LLC	Kincaid	IL
Dynegy Midwest Generation, Inc.	Baldwin Energy Complex	Baldwin	IL
Dynegy Midwest Generation, Inc.	Havana	Havana	IL
Dynegy Midwest Generation, Inc.	Hennepin Power Station	Hennepin	IL
Dynegy Midwest Generation, Inc.	Vermilion	Oakwood	IL

Utility Name	**Plant Name**	**City**	**State**
Dynegy Midwest Generation, Inc.	Wood River	East Alton	IL
Electric Energy, Inc.	Joppa Steam	Joppa	IL
Midwest Generations EME LLC	Joliet 29	Joliet	IL
Midwest Generations EME LLC	Crawford	Chicago	IL
Midwest Generations EME LLC	Joliet 9	Joliet	IL
Midwest Generations EME LLC	Powerton	Pekin	IL
Midwest Generations EME LLC	Waukegan	Waukegan	IL
Midwest Generations EME LLC	Will County	Romeoville	IL
Midwest Generations EME LLC	Fisk Street	Chicago	IL
Southern Illinois Power Coop	Marion	Marion	IL
Springfield, City of	Dallman	Springfield	IL
Alcoa Power Generating, Inc.	Warrick	Newburgh	IN
Hoosier Energy R E C, Inc.	Frank E Ratts	Petersburg	IN
Hoosier Energy R E C, Inc.	Merom	Sullivan	IN
Indiana Michigan Power Co.	Tanners Creek	Lawrenceburg	IN
Indiana Michigan Power Co.	Rockport	Rockport	IN
Indiana-Kentucky Electric Corp	Clifty Creek	Madison	IN
Indianapolis Power & Light Co.	Harding Street	Indianapolis	IN
Indianapolis Power & Light Co.	Eagle Valley	Martinsville	IN
Indianapolis Power & Light Co.	AES Petersburg	Petersburg	IN
Northern Indiana Pub Serv Co.	Bailly	Chesterton	IN
Northern Indiana Pub Serv Co.	Michigan City	Michigan City	IN
Northern Indiana Pub Serv Co.	R M Schahfer	Wheatfield	IN
PSI Energy, Inc.	Cayuga	Cayuga	IN
PSI Energy, Inc.	Edwardsport	Edwardsport	IN
PSI Energy, Inc.	R Gallagher	New Albany	IN
PSI Energy, Inc.	Wabash River	Terre Haute	IN
PSI Energy, Inc.	Gibson	Mt Carmel	IN
Southern Indiana Gas & Elec Co.	F B Culley	Newburgh	IN
Southern Indiana Gas & Elec Co.	A B Brown	Mount Vernon	IN
State Line Energy LLC	State Line Energy	Hammond	IN
Kansas City, City of	Quindaro	Fairfax Station	KS
Kansas City, City of	Nearman Creek	Robert L Roberts STA	KS
Kansas City Power & Light Co.	La Cygne	La Cygne	KS
Sunflower Electric Power Corp	Holcomb	Holcomb	KS
Westar Energy	Lawrence Energy Center	Lawrence, Kansas	KS
Westar Energy	Tecumseh Energy Center	Tecumseh	KS
Westar Energy	Jeffrey Energy Center	Belvue	KS
Cincinnati Gas & Electric Co.	East Bend	Rabbit Hash	KY
East Kentucky Power Coop, Inc.	Cooper	Burnside	KY
East Kentucky Power Coop, Inc.	Dale	Winchester	KY
East Kentucky Power Coop, Inc.	H L Spurlock	Maysville	KY
Kentucky Power Co.	Big Sandy	Louisa	KY
Kentucky Utilities Co.	E W Brown	Burgin	KY
Kentucky Utilities Co.	Ghent	Ghent	KY
Kentucky Utilities Co.	Green River	Central City	KY
Kentucky Utilities Co.	Tyrone	Versailles	KY

Utility Name	**Plant Name**	**City**	**State**
Louisville Gas & Electric Co.	Cane Run	Louisville	KY
Louisville Gas & Electric Co.	Mill Creek	Louisville	KY
Louisville Gas & Electric Co.	Trimble County	Bedford	KY
Owensboro, City of	Elmer Smith	Daviess	KY
Tennessee Valley Authority	Paradise	Drakesboro	KY
Tennessee Valley Authority	Shawnee	West Paducah	KY
Western Kentucky Energy Corp	Kenneth C Coleman	Hawesville	KY
Western Kentucky Energy Corp	HMP&L Station Two Henderson	Sebree	KY
Western Kentucky Energy Corp	R D Green	Sebree	KY
Western Kentucky Energy Corp	D B Wilson	Centertown	KY
Cleco Power LLC	Dolet Hills	Mansfield	LA
Cleco Power LLC	Rodemacher	Lena	LA
Entergy Gulf States, Inc.	R S Nelson	Lake Charles	LA
Louisiana Generating LLC	Big Cajun 2	New Roads	LA
Consolidated Edison E MA, Inc.	West Springfield	West Springfield	MA
Dominion Energy New England	Brayton Point	Somerset	MA
Mirant Canal LLC	Canal	Sandwich	MA
Northeast Generation Services Co.	Mount Tom	Holyoke	MA
Somerset Power LLC	Somerset Station	Somerset	MA
U S Gen New England, Inc.	Salem Harbor	Salem	MA
AES WR Ltd Partnership	AES Warrior Run Cogeneration Facility	Cumberland	MD
Allegheny Energy Supply Co. LLC	R Paul Smith Power Station	Williamsport	MD
Constellation Power Source Gen	Brandon Shores	Baltimore	MD
Constellation Power Source Gen	C P Crane	Baltimore	MD
Constellation Power Source Gen	Herbert A Wagner	Baltimore	MD
Mirant Mid-Atlantic LLC	Chalk Point LLC	Aquasco	MD
Mirant Mid-Atlantic LLC	Dickerson	Dickerson	MD
Mirant Mid-Atlantic LLC	Morgantown Generating Plant	Newburg MD	MD
Vienna Operations, Inc.	Vienna Operations	Vienna	MD
FPL Energy Wyman LLC	William F Wyman	Yarmouth	ME
MeadWestvaco Corp	Rumford Cogeneration	Rumford	ME
S D Warren Co.	Somerset Plant	Skowhegan	ME
Consumers Energy Co.	B C Cobb	Muskegon	MI
Consumers Energy Co.	Dan E Karn	Essexville	MI
Consumers Energy Co.	J H Campbell	West Olive	MI
Consumers Energy Co.	J C Weadock	Essexville	MI
Consumers Energy Co.	J R Whiting	Erie	MI
Detroit Edison Co.	Harbor Beach	Harbor Beach	MI
Detroit Edison Co.	Monroe	Monroe	MI
Detroit Edison Co.	River Rouge	River Rouge	MI
Detroit Edison Co.	St Clair	East China	MI
Detroit Edison Co.	Trenton Channel	Trenton	MI
Detroit Edison Co.	Belle River	Belle River	MI
Lansing, City of	Eckert Station	Lansing	MI
Lansing, City of	Erickson Station	Lansing	MI
MeadWestvaco Corp	Escanaba Paper Company	Escanaba	MI
Wisconsin Electric Power Co.	Presque Isle	Marquette	MI

Utility Name	Plant Name	City	State
Allete, Inc.	Syl Laskin	Aurora	MN
Allete, Inc.	Clay Boswell	Cohasset	MN
Allete, Inc.	Taconite Harbor Energy Center	Schroeder	MN
Cleveland Cliffs, Inc.	Silver Bay Power	Silver Bay	MN
Northern States Power Co.	Black Dog	Burnsville	MN
Northern States Power Co.	High Bridge	St. Paul	MN
Northern States Power Co.	Allen S King	Bayport	MN
Northern States Power Co.	Riverside	Minneapolis	MN
Northern States Power Co.	Sherburne County	Becker	MN
Otter Tail Power Co.	Hoot Lake	Fergus Falls	MN
Ameren UE	Labadie	Labadie	MO
Ameren UE	Meramec	St Louis	MO
Ameren UE	Sioux	West Alton	MO
Ameren UE	Rush Island	Festus	MO
Aquila, Inc.	Sibley	Sibley	MO
Aquila, Inc.	Lake Road	St Joseph	MO
Associated Electric Coop, Inc.	New Madrid	Marston	MO
Associated Electric Coop, Inc.	Thomas Hill	Moberly	MO
Empire District Electric Co.	Asbury	Asbury	MO
Independence, City of	Blue Valley	Independence	MO
Kansas City Power & Light Co.	Montrose	Clinton	MO
Kansas City Power & Light Co.	Iatan	Weston	MO
Sikeston, City of	Sikeston Power Station	Sikeston	MO
Springfield, City of	James River Power Station	Springfield	MO
Springfield, City of	Southwest Power Station	Springfield	MO
Entergy Mississippi, Inc.	Gerald Andrus	Greenville	MS
Mississippi Power Co.	Jack Watson	Gulfport	MS
Mississippi Power Co.	Victor J Daniel Jr	Escatawpa	MS
South Mississippi El Pwr Assn	R D Morrow	Purvis	MS
Tractebel Power, Inc.	Red Hills Generating Facility	Ackerman	MS
Weyerhaeuser Co.	Weyerhaeuser Columbus MS	Columbus	MS
PPL Montana LLC	J E Corette Plant	Billings	MT
PPL Montana LLC	Colstrip	Colstrip	MT
Carolina Power & Light Co.	Asheville	Arden	NC
Carolina Power & Light Co.	Cape Fear	Moncure	NC
Carolina Power & Light Co.	Lee	Goldsboro	NC
Carolina Power & Light Co.	Roxboro	Semora	NC
Carolina Power & Light Co.	L V Sutton	Wilmington	NC
Carolina Power & Light Co.	W H Weatherspoon	Lumberton	NC
Carolina Power & Light Co.	Mayo	Roxboro	NC
Cogentrix of N Carolina, Inc.	Cogentrix Southport	Southport	NC
Cogentrix of Rocky Mount, Inc.	Cogentrix Dwayne Collier Battle Cogen	Battleboro	NC
Duke Energy Corp	G G Allen	Belmont	NC
Duke Energy Corp	Buck	Spencer	NC
Duke Energy Corp	Cliffside	Cliffside	NC
Duke Energy Corp	Dan River	Eden	NC
Duke Energy Corp	Marshall	Terrell	NC

Utility Name	Plant Name	City	State
Duke Energy Corp	Riverbend	Mount Holly	NC
Duke Energy Corp	Belews Creek	Walnut Cove	NC
Westmoreland-LG&E Partners	Westmoreland-LG&E Roanoke Valley I	Weldon	NC
Basin Electric Power Coop	Leland Olds	Stanton	ND
Basin Electric Power Coop	Antelope Valley	Beulah	ND
Great River Energy	Stanton	Stanton	ND
Great River Energy	Coal Creek	Underwood	ND
MDU Resources Group, Inc.	R M Heskett	Mandan	ND
Minnkota Power Coop, Inc.	Milton R Young	Center	ND
Otter Tail Power Co.	Coyote	Beulah	ND
Fremont, City of	Lon Wright	Fremont	NE
Grand Island, City of	Platte	Grand Island	NE
Nebraska Public Power District	Sheldon	Hallam	NE
Nebraska Public Power District	Gerald Gentleman	Sutherland	NE
Omaha Public Power District	North Omaha	Florence	NE
Omaha Public Power District	Nebraska City	Nebraska City	NE
Public Service Co. of NH	Merrimack	Concord	NH
Public Service Co. of NH	Schiller	Portsmouth	NH
Public Service Co. of NH	Newington	Portsmouth	NH
Atlantic City Electric Co.	B L England	Marmora	NJ
Atlantic City Electric Co.	Deepwater	Penns Grove	NJ
Chambers Cogeneration LP	Chambers Cogeneration LP	Carneys Point	NJ
Logan Generating Co. LP	Logan Generating Plant	Swedesboro	NJ
PSEG Fossil LLC	PSEG Hudson Generating Station	Jersey City	NJ
PSEG Fossil LLC	PSEG Mercer Generating Station	Trenton	NJ
Arizona Public Service Co.	Four Corners	Fruitland	NM
Public Service Co. of NM	San Juan	Waterflow	NM
Tri-State G & T Assn, Inc.	Escalante	Prewitt	NM
Nevada Power Co.	Reid Gardner	Moapa	NV
Sierra Pacific Power Co.	North Valmy	Valmy	NV
Southern California Edison Co.	Mohave	Laughlin	NV
AES Cayuga LLC	AES Cayuga	Lansing	NY
AES Greenidge LLC	AES Greenidge LLC	Dresden	NY
AES Somerset LLC	AES Somerset LLC	Barker	NY
AES Westover LLC	AES Westover	Johnson City	NY
Astoria Generating Co. LP	Astoria Generating Station	Woolsey	NY
Dunkirk Power LLC	Dunkirk Generating Station	Central Avenue	NY
Dynegy Northeast Gen, Inc.	Danskammer Generating Station	Newburgh	NY
Dynegy Northeast Gen, Inc.	Roseton Generating Station	Newburgh	NY
Eastman Kodak Co.	Kodak Park Site	Rochester	NY
Mirant New York, Inc.	Lovett	Tomkins Cove	NY
NRG Huntley Operations, Inc.	C R Huntley Generating Station	Tonawanda	NY
Rochester Gas & Electric Corp	Rochester 7	Rochester	NY
American Mun Power-Ohio, Inc.	Richard Gorsuch	Marietta	OH
Cardinal Operating Co.	Cardinal	Brilliant	OH
Cincinnati Gas & Electric Co.	Walter C Beckjord	New Richmond	OH
Cincinnati Gas & Electric Co.	Miami Fort	North Bend	OH

Utility Name	**Plant Name**	**City**	**State**
Cincinnati Gas & Electric Co.	W H Zimmer	Cincinnati	OH
Cleveland Electric Illum Co.	Ashtabula	Ashtabula	OH
Cleveland Electric Illum Co.	Eastlake	Eastlake	OH
Cleveland Electric Illum Co.	Lake Shore	Cleveland	OH
Columbus Southern Power Co.	Conesville	Conesville	OH
Columbus Southern Power Co.	Picway	Lockbourne	OH
Dayton Power & Light Co.	O H Hutchings	Miamisburg	OH
Dayton Power & Light Co.	J M Stuart	Aberdeen	OH
Dayton Power & Light Co.	Killen Station	Manchester	OH
Hamilton, City of	Hamilton	Hamilton	OH
Ohio Edison Co.	R E Burger	Shadyside	OH
Ohio Edison Co.	W H Sammis	Stratton	OH
Ohio Power Co.	Muskingum River	Beverly	OH
Ohio Power Co.	General James M Gavin	Cheshire	OH
Ohio Valley Electric Corp	Kyger Creek	Cheshire	OH
Orion Power Midwest LP	Avon Lake	Avon Lake	OH
Orion Power Midwest LP	Niles	Niles	OH
Toledo Edison Co.	Bay Shore	Oregon	OH
AES Shady Point, LLC	AES Shady Point	Panama	OK
Fort James Operating Co.	Muskogee Mill	Muskogee	OK
Grand River Dam Authority	GRDA	Chouteau	OK
Oklahoma Gas & Electric Co.	Muskogee	Ft Gibson	OK
Oklahoma Gas & Electric Co.	Sooner	Morrison	OK
Public Service Co. of Oklahoma	Northeastern	Oologah	OK
Western Farmers Elec Coop, Inc.	Hugo	Fort Towson	OK
Portland General Electric Co.	Boardman	Boardman	OR
AES Beaver Valley	AES Beaver Valley Partners Beaver Valley	Monaca	PA
Allegheny Energy Supply Co. LLC	Armstrong Power Station	Kittaning	PA
Allegheny Energy Supply Co. LLC	Hatfields Ferry Power Station	Masontown	PA
Allegheny Energy Supply Co. LLC	Mitchell Power Station	Courtney	PA
Exelon Generation Co. LLC	Cromby Generating Station	Phoenixville	PA
Exelon Generation Co. LLC	Delaware Generating Station	Philadelphia	PA
Exelon Generation Co. LLC	Eddystone Generating Station	Chester	PA
Exelon Generation Co. LLC	Schuylkill Generating Station	Philadelphia	PA
Midwest Generation	Homer City Station	Homer City	PA
Orion Power Midwest LP	New Castle Plant	West Pittsburg	PA
Orion Power Midwest LP	Cheswick Power Plant	Cheswick	PA
P H Glatfelter Co.	P H Glatfelter	Spring Grove	PA
Pennsylvania Power Co.	Bruce Mansfield	Shippingport	PA
PG&E National Energy Group	Northhampton Generating LP	Northampton	PA
PPL Corp	PPL Brunner Island	York Haven	PA
PPL Corp	PPL Martins Creek	Martins Creek	PA
PPL Corp	PPL Montour	Washingtonville	PA
Reliant Energy Mid-Atlantic PH	Portland	Portland	PA
Reliant Energy Mid-Atlantic PH	Titus	Birdboro	PA
Reliant Energy Mid-Atlantic PH	Shawville	Clearfield	PA
Reliant Energy NE Mgt Co.	Conemaugh	New Florence	PA

Utility Name	**Plant Name**	**City**	**State**
Reliant Energy NE Mgt Co.	Keystone	Shelocta	PA
Sunbury Generation LLC	WPS Energy Servs Sunbury Gen	Shamokin Dam	PA
TIFD VIII-W, Inc.	Colver Power Project	Colver	PA
Zinc Corp of America	G F Weaton Power Station	Monaca	PA
Carolina Power & Light Co.	H B Robinson	Hartsville	SC
Duke Energy Corp	W S Lee	Pelzer	SC
International Paper Co.-Eastovr	International Paper Eastover Facility	Eastover	SC
South Carolina Electric&Gas Co.	Canadys Steam	Canadys	SC
South Carolina Electric&Gas Co.	McMeekin	Irmo	SC
South Carolina Electric&Gas Co.	Urquhart	Urquhart	SC
South Carolina Electric&Gas Co.	Wateree	Eastover	SC
South Carolina Genertg Co., Inc.	Williams	Goose Creek	SC
South Carolina Pub Serv Auth	Cross	Cross	SC
South Carolina Pub Serv Auth	Dolphus M Grainger	Conway	SC
South Carolina Pub Serv Auth	Jefferies	Moncks Corner	SC
South Carolina Pub Serv Auth	Winyah	Georgetown	SC
Stone Container Corp	Stone Container Florence Mill	Florence	SC
Otter Tail Power Co.	Big Stone	Big Stone City	SD
Eastman Chemical Co.-TN Ops	Tennessee Eastman Operations	Kingsport	TN
Tennessee Valley Authority	Allen Steam Plant	Memphis	TN
Tennessee Valley Authority	Bull Run	Clinton	TN
Tennessee Valley Authority	Cumberland	Cumberland City	TN
Tennessee Valley Authority	Gallatin	Gallatin	TN
Tennessee Valley Authority	John Sevier	Rogersville	TN
Tennessee Valley Authority	Johnsonville	New Johnsonville	TN
Tennessee Valley Authority	Kingston	Kingston	TN
AEP Texas North Co.	Oklaunion	Vernon	TX
AES Corp	AES Deepwater	Pasadena	TX
Alcoa, Inc.	Sandow Station	Rockdale	TX
Lower Colorado River Authority	Fayette Power Project	La Grange	TX
San Antonio Public Service Bd	J T Deely	Downtown Station	TX
San Antonio Public Service Bd	J K Spruce	Downtown Station	TX
San Miguel Electric Coop, Inc.	San Miguel	Christine	TX
Sempra Energy Resources	Twin Oaks Power One	Bremond	TX
Southwestern Electric Power Co.	Welsh	Pittsburg	TX
Southwestern Electric Power Co.	Pirkey	Hallsville	TX
Southwestern Public Service Co.	Harrington	Amarillo	TX
Southwestern Public Service Co.	Tolk	Muleshoe	TX
Texas Genco	Limestone	Jewett	TX
Texas Genco	W A Parish	Thompsons	TX
Texas Municipal Power Agency	Gibbons Creek	Anderson	TX
Topaz Power Group LLC	Coleto Creek	Fannin	TX
TXU Electric Co.	Big Brown	Fairfield	TX
TXU Electric Co.	Martin Lake	Tatum	TX
TXU Electric Co.	Monticello	Mt. Pleasant	TX
TXU Electric Co.	Sandow No 4	Rockdale	TX
Deseret Generation & Tran Coop	Bonanza	Vernal	UT

Utility Name	**Plant Name**	**City**	**State**
Kennecott Utah Copper Corporation	KUCC	Magna Post Office	UT
Los Angeles, City of	Intermountain Power Project	Delta	UT
PacifiCorp	Carbon	Helper	UT
PacifiCorp	Hunter	Castledale	UT
PacifiCorp	Huntington	Huntington	UT
Appalachian Power Co.	Clinch River	Cleveland	VA
Appalachian Power Co.	Glen Lyn	Glen Lyn	VA
Birchwood Power Partners LP	Birchwood Power	King George	VA
Cogentrix of Richmond, Inc.	Cogentrix of Richmond	Richmond	VA
Cogentrix-Virginia Leas'g Corp	Cogentrix Portsmouth	Portsmouth	VA
Covanta Fairfax, Inc.	Covanta Fairfax Energy	Lorton	VA
DPS Mecklenburg LLC	Mecklenburg Power Station	Clarksville	VA
James River Cogeneration Co.	Cogentrix Hopewell	Hopewell	VA
Mirant Mid-Atlantic LLC	Potomac River	George Washington	VA
St Laurent Paper Products Co.	West Point Mill	West Point	VA
Virginia Electric & Power Co.	Bremo Bluff	Bremo Bluff	VA
Virginia Electric & Power Co.	Chesterfield	Chester	VA
Virginia Electric & Power Co.	Chesapeake	Chesapeake	VA
Virginia Electric & Power Co.	Yorktown	Yorktown	VA
Virginia Electric & Power Co.	Clover	Clover	VA
TransAlta Centralia Gen LLC	Transalta Centralia Generation	Centralia	WA
Dairyland Power Coop	Alma	Alma	WI
Dairyland Power Coop	Genoa	Genoa	WI
Dairyland Power Coop	John P Madgett	Alma	WI
Fort James Operating Co.	Green Bay West Mill	Green Bay	WI
Madison Gas & Electric Co.	Blount Street	Madison	WI
Wisconsin Electric Power Co.	Port Washington Generating Station	Port Washington	WI
Wisconsin Electric Power Co.	South Oak Creek	Oak Creek	WI
Wisconsin Electric Power Co.	Valley	Milwaukee	WI
Wisconsin Electric Power Co.	Pleasant Prairie	Kenosha	WI
Wisconsin Power & Light Co.	Edgewater	Sheboygan	WI
Wisconsin Power & Light Co.	Nelson Dewey	Cassville	WI
Wisconsin Power & Light Co.	Columbia	Pardeeville	WI
Wisconsin Public Service Corp	Pulliam	Green Bay	WI
Wisconsin Public Service Corp	Weston	Rothschild	WI
Appalachian Power Co.	John E Amos	St Albans	WV
Appalachian Power Co.	Kanawha River	Glasgow	WV
Appalachian Power Co.	Mountaineer	New Haven	WV
Central Operating Co.	Philip Sporn	New Haven	WV
Monongahela Power Co.	Albright	Albright	WV
Monongahela Power Co.	Fort Martin Power Station	Maidsville	WV
Monongahela Power Co.	Harrison Power Station	Haywood	WV
Monongahela Power Co.	Rivesville	Rivesville	WV
Monongahela Power Co.	Willow Island	Williow Island	WV
Monongahela Power Co.	Pleasants Power Station	Willow Island	WV
Ohio Power Co.	Kammer	Moundsville	WV
Ohio Power Co.	Mitchell	Moundsville	WV

Utility Name	Plant Name	City	State
PPG Industries, Inc.	PPG Natrium Plant	New Martinsville	WV
Virginia Electric & Power Co.	Mt Storm	Mt Storm	WV
Basin Electric Power Coop	Laramie River Station	Wheatland	WY
PacifiCorp	Dave Johnston	Casper	WY
PacifiCorp	Naughton	Kemmerer	WY
PacifiCorp	Wyodak	Gillette	WY
PacifiCorp	Jim Bridger	Rock Springs	WY

Table C-5: U.S. Silica Fume Producers (Corathers, 2004)

Company	City	State
Elkem Materials, Inc.	Alloy	WV
Norchem, Inc.	Waterford	OH
Norchem, Inc.	Selma	AL
Norchem, Inc.	Niagara Falls*	NY
Oxbow Carbon and Minerals LLC	Bridgeport	AL
Simcala, Inc.	Mount Meigs	AL
CC Metals and Alloys, Inc.	Calvert City	KY

*Note - Globe's plant in Niagara Falls was idle in 2004

Table C-6: U.S. Facilities Producing Flue Gas Desulfurization (FGD) Gypsum (U.S. DOE, 2004b)

Utility Name	Plant Name	City	State
Alabama Electric Coop, Inc.	Charles R Lowman	Leroy	AL
Tennessee Valley Authority	Widows Creek	Stevenson	AL
JEA	St Johns River Power Park	Oceanway	FL
Tampa Electric Company	Big Bend	Ruskin	FL
Seminole Electric Coop, Inc.	Seminole	Bostwick	FL
Georgia Power Co.	Yates	Sargent	GA
Muscatine, City of	Muscatine Plant #1	Muscatine	IA
Springfield, City of	Dallman	Springfield	IL
Indianapolis Power & Light Co.	AES Petersburg	Petersburg	IN
Northern Indiana Pub. Service Co.	R M Schahfer	Wheatfield	IN
Southern Indiana Gas & Electric Co.	F B Culley	Newburgh	IN
Kentucky Utilities Co.	Ghent	Ghent	KY
Louisville Gas & Electric Co.	Mill Creek	Louisville	KY
Louisville Gas & Electric Co.	Trimble County	Bedford	KY
Owensboro, City of	Elmer Smith	Daviess	KY
Tennessee Valley Authority	Paradise	Drakesboro	KY
Atlantic City Electric Co.	B L England	Marmora	NJ
AES Cayuga LLC	AES Cayuga	Lansing	NY
Cincinnati Gas & Electric Co.	W H Zimmer	Cincinnati	OH
Orion Power Midwest LP	Niles	Niles	OH
AES Beaver Valley	AES Beaver Valley Partners Beaver Valley	Monaca	PA
Midwest Generation	Homer City Station	Homer City	PA
Pennsylvania Power Co.	Bruce Mansfield	Shippingport	PA
Reliant Energy NE Mgt Co.	Conemaugh	New Florence	PA
South Carolina Pub Service Authority	Cross	Cross	SC
Tennessee Valley Authority	Cumberland	Cumberland City	TN
AES Corp.	AES Deepwater	Pasadena	TX
San Antonio Public Service Bd.	J K Spruce	Downtown Station	TX
TXU Electric Co.	Monticello	Mt. Pleasant	TX
TXU Electric Co.	Sandow No 4	Rockdale	TX
TransAlta Centralia Gen LLC	Transalta Centralia Generation	Centralia	WA
Monongahela Power Co.	Pleasants Power Station	Willow Island	WV

Table C-7: U.S. Facilities Producing Bottom Ash (U.S. DOE, 2004b)

Utility Name	Plant Name	City	State
Alabama Electric Coop, Inc.	Charles R Lowman	Leroy	AL
Alabama Power Co.	Barry	Bucks	AL
Alabama Power Co.	Gadsden	East Gadsden	AL
Alabama Power Co.	Gorgas	Parrish	AL
Alabama Power Co.	Greene County	Demopolis	AL
Alabama Power Co.	E C Gaston	Wilsonville	AL
Alabama Power Co.	James H Miller Jr	Quinton	AL
Tennessee Valley Authority	Colbert	Tuscumbia	AL
Tennessee Valley Authority	Widows Creek	Stevenson	AL
Entergy Arkansas, Inc.	White Bluff	Redfield	AR
Entergy Arkansas, Inc.	Independence	Newark	AR
Southwestern Electric Power Co.	Flint Creek	Gentry	AR
Arizona Electric Pwr Coop, Inc.	Apache Station	Cochise	AZ
Arizona Public Service Co.	Cholla	Joseph City	AZ
Salt River Proj Ag I & P Dist	Navajo	Page	AZ
Salt River Proj Ag I & P Dist	Coronado	St Johns	AZ
UNS Electric, Inc.	H Wilson Sundt Generating Station	Cherry Bell Station	AZ
UNS Electric, Inc.	Springerville	Springerville	AZ
Colorado Springs, City of	Martin Drake	Colorado Springs	CO
Colorado Springs, City of	Ray D Nixon	Fountain	CO
Platte River Power Authority	Rawhide	Wellington	CO
Public Service Co. of Colorado	Arapahoe	Denver	CO
Public Service Co. of Colorado	Cherokee	Denver	CO
Public Service Co. of Colorado	Comanche	Pueblo	CO
Public Service Co. of Colorado	Valmont	Boulder	CO
Public Service Co. of Colorado	Hayden	Hayden	CO
Public Service Co. of Colorado	Pawnee	Brush	CO
Tri-State G & T Assn, Inc.	Nucla	Nucla	CO
Tri-State G & T Assn, Inc.	Craig	Craig	CO
AES Thames LLC	AES Thames	Uncasville	CT
NRG Norwalk Harbor Operations	NRG Norwalk Harbor	South Norwalk	CT
PSEG Power Connecticut LLC	Bridgeport Station	Bridgeport	CT
Conectiv Energy Supply, Inc.	Edge Moor	Edgemoor	DE
Indian River Operations, Inc.	Indian River Operations	Millsboro	DE
Central Power & Lime, Inc.	Central Power & Lime	Brooksville	FL
Florida Power & Light Co.	Cape Canaveral	Cocoa	FL
Florida Power & Light Co.	Turkey Point	Homestead	FL
Progress Energy Florida, Inc.	Crystal River	Crystal River	FL
Progress Energy Florida, Inc.	P L Bartow	St Petersburg	FL
Progress Energy Florida, Inc.	Suwannee River	Live Oak	FL
Progress Energy Florida, Inc.	Anclote	Tarpon Springs	FL
Gainesville Regional Utilities	Deerhaven Generating Station	Alachua	FL
Gulf Power Co.	Crist	Pensacola	FL
Gulf Power Co.	Lansing Smith	Southport FL	FL
Indiantown Cogeneration LP	Indiantown Cogen Facility	Indiantown	FL

Utility Name	**Plant Name**	**City**	**State**
JEA	St Johns River Power Park	Oceanway	FL
JEA	Northside Generating Station	Oceanway	FL
Orlando Utilities Comm	Stanton Energy Center	Alafaya Branch	FL
PG&E Operating Service Co.	Cedar Bay Generating LP	Jacksonville	FL
Tampa Electric Co.	Big Bend	Ruskin	FL
Seminole Electric Coop, Inc.	Seminole	Bostwick	FL
Georgia Power Co.	Bowen	Taylorsville	GA
Georgia Power Co.	Hammond	Coosa	GA
Georgia Power Co.	Harllee Branch	Milledgeville	GA
Georgia Power Co.	Jack McDonough	Smyrna	GA
Georgia Power Co.	Mitchell	Putney	GA
Georgia Power Co.	Yates	Sargent	GA
Georgia Power Co.	Wansley	Roopville	GA
Georgia Power Co.	Scherer	Juliette	GA
Savannah Electric & Power Co.	Kraft	Port Wentworth	GA
Savannah Electric & Power Co.	McIntosh	Rincon	GA
AES Corp	AES Hawaii	Kapolei	HI
Archer Daniels Midland Co.	Archer Daniels Midland Cedar Rapids	Cedar Rapids	IA
Interstate Power and Light	Ottumwa	Ottumwa	IA
Interstate Power & Light Co.	Milton L Kapp	Clinton	IA
Interstate Power & Light Co.	Prairie Creek	Cedar Rapids	IA
Interstate Power & Light Co.	Sutherland	Marshalltown	IA
Interstate Power & Light Co.	Burlington	Burlington	IA
MidAmerican Energy Co.	Riverside	Bettendorf	IA
MidAmerican Energy Co.	Council Bluffs	Council Bluffs	IA
MidAmerican Energy Co.	George Neal North	Salix	IA
MidAmerican Energy Co.	Louisa	Muscatine	IA
MidAmerican Energy Co.	George Neal South	Salix	IA
Muscatine, City of	Muscatine Plant #1	Muscatine	IA
Ameren Energy Generating Co.	Coffeen	Coffeen	IL
Ameren Energy Generating Co.	Hutsonville	Hutsonville	IL
Ameren Energy Generating Co.	Meredosia	Meredosia	IL
Ameren Energy Generating Co.	Newton	Newton	IL
Archer Daniels Midland Co.	Archer Daniels Midland Decatur	Decatur	IL
Dominion Energy Services Co.	Kincaid Generation LLC	Kincaid	IL
Dynegy Midwest Generation, Inc.	Baldwin Energy Complex	Baldwin	IL
Dynegy Midwest Generation, Inc.	Havana	Havana	IL
Dynegy Midwest Generation, Inc.	Hennepin Power Station	Hennepin	IL
Dynegy Midwest Generation, Inc.	Vermilion	Oakwood	IL
Dynegy Midwest Generation, Inc.	Wood River	East Alton	IL
Electric Energy, Inc.	Joppa Steam	Joppa	IL
Midwest Generations EME LLC	Joliet 29	Joliet	IL
Midwest Generations EME LLC	Crawford	Chicago	IL
Midwest Generations EME LLC	Joliet 9	Joliet	IL
Midwest Generations EME LLC	Powerton	Pekin	IL
Midwest Generations EME LLC	Waukegan	Waukegan	IL
Midwest Generations EME LLC	Will County	Romeoville	IL

Utility Name	**Plant Name**	**City**	**State**
Midwest Generations EME LLC	Fisk Street	Chicago	IL
Southern Illinois Power Coop	Marion	Marion	IL
Springfield, City of	Dallman	Springfield	IL
Ameren Energy Resources Generating	E D Edwards	Bartonville	IL
Ameren Energy Resources Generating	Duck Creek	Canton	IL
Alcoa Power Generating, Inc.	Warrick	Newburgh	IN
Hoosier Energy R E C, Inc.	Frank E Ratts	Petersburg	IN
Hoosier Energy R E C, Inc.	Merom	Sullivan	IN
Indiana-Kentucky Electric Corp	Clifty Creek	Madison	IN
Indianapolis Power & Light Co.	Harding Street	Indianapolis	IN
Indianapolis Power & Light Co.	Eagle Valley	Martinsville	IN
Indianapolis Power & Light Co.	AES Petersburg	Petersburg	IN
Indiana Michigan Power Co.	Tanners Creek	Lawrenceburg	IN
Indiana Michigan Power Co.	Rockport	Rockport	IN
Northern Indiana Pub Serv Co.	Bailly	Chesterton	IN
Northern Indiana Pub Serv Co.	Michigan City	Michigan City	IN
Northern Indiana Pub Serv Co.	R M Schahfer	Wheatfield	IN
PSI Energy, Inc.	Cayuga	Cayuga	IN
PSI Energy, Inc.	Edwardsport	Edwardsport	IN
PSI Energy, Inc.	R Gallagher	New Albany	IN
PSI Energy, Inc.	Wabash River	Terre Haute	IN
PSI Energy, Inc.	Gibson	Mt Carmel	IN
Southern Indiana Gas & Elec Co.	F B Culley	Newburgh	IN
Southern Indiana Gas & Elec Co.	A B Brown	Mount Vernon	IN
State Line Energy LLC	State Line Energy	Hammond	IN
Kansas City, City of	Quindaro	Fairfax Station	KS
Kansas City, City of	Nearman Creek	Robert L Roberts STA	KS
Kansas City Power & Light Co.	La Cygne	La Cygne	KS
Sunflower Electric Power Corp	Holcomb	Holcomb	KS
Westar Energy	Lawrence Energy Center	Lawrence, Kansas	KS
Westar Energy	Tecumseh Energy Center	Tecumseh	KS
Westar Energy	Jeffrey Energy Center	Belvue	KS
Cincinnati Gas & Electric Co.	East Bend	Rabbit Hash	KY
East Kentucky Power Coop, Inc.	Cooper	Burnside	KY
East Kentucky Power Coop, Inc.	Dale	Winchester	KY
East Kentucky Power Coop, Inc.	H L Spurlock	Maysville	KY
Kentucky Utilities Co.	E W Brown	Burgin	KY
Kentucky Utilities Co.	Ghent	Ghent	KY
Kentucky Utilities Co.	Green River	Central City	KY
Kentucky Utilities Co.	Tyrone	Versailles	KY
Louisville Gas & Electric Co.	Cane Run	Louisville	KY
Louisville Gas & Electric Co.	Mill Creek	Louisville	KY
Louisville Gas & Electric Co.	Trimble County	Bedford	KY
Owensboro, City of	Elmer Smith	Daviess	KY
Tennessee Valley Authority	Shawnee	West Paducah	KY
Western Kentucky Energy Corp	Kenneth C Coleman	Hawesville	KY
Western Kentucky Energy Corp	HMP&L Station Two Henderson	Sebree	KY

Utility Name	**Plant Name**	**City**	**State**
Western Kentucky Energy Corp	R D Green	Sebree	KY
Western Kentucky Energy Corp	D B Wilson	Centertown	KY
Kentucky Power Co.	Big Sandy	Louisa	KY
Cleco Power LLC	Dolet Hills	Mansfield	LA
Cleco Power LLC	Rodemacher	Lena	LA
Entergy Gulf States, Inc.	R S Nelson	Lake Charles	LA
International Paper Co.	Mansfield Mill	Mansfield	LA
Louisiana Generating LLC	Big Cajun 2	New Roads	LA
Dominion Energy New England	Brayton Point	Somerset	MA
U S Gen New England, Inc.	Salem Harbor	Salem	MA
Northeast Generation Services Co.	Mount Tom	Holyoke	MA
Somerset Power LLC	Somerset Station	Somerset	MA
AES WR Ltd Partnership	AES Warrior Run Cogeneration Facility	Cumberland	MD
Constellation Power Source Gen	Brandon Shores	Baltimore	MD
Constellation Power Source Gen	C P Crane	Baltimore	MD
Constellation Power Source Gen	Herbert A Wagner	Baltimore	MD
Mirant Mid-Atlantic LLC	Chalk Point LLC	Aquasco	MD
Mirant Mid-Atlantic LLC	Dickerson	Dickerson	MD
Mirant Mid-Atlantic LLC	Morgantown Generating Plant	Newburg MD	MD
Allegheny Energy Supply Co. LLC	R Paul Smith Power Station	Williamsport	MD
MeadWestvaco Corp	Rumford Cogeneration	Rumford	ME
S D Warren Co.	Somerset Plant	Skowhegan	ME
FPL Energy Wyman LLC	William F Wyman	Yarmouth	ME
Consumers Energy Co.	B C Cobb	Muskegon	MI
Consumers Energy Co.	Dan E Karn	Essexville	MI
Consumers Energy Co.	J H Campbell	West Olive	MI
Consumers Energy Co.	J C Weadock	Essexville	MI
Consumers Energy Co.	J R Whiting	Erie	MI
Detroit Edison Co.	Harbor Beach	Harbor Beach	MI
Detroit Edison Co.	Monroe	Monroe	MI
Detroit Edison Co.	River Rouge	River Rouge	MI
Detroit Edison Co.	St Clair	East China	MI
Detroit Edison Co.	Trenton Channel	Trenton	MI
Detroit Edison Co.	Belle River	Belle River	MI
Lansing, City of	Eckert Station	Lansing	MI
Lansing, City of	Erickson Station	Lansing	MI
MeadWestvaco Corp	Escanaba Paper Company	Escanaba	MI
Wisconsin Electric Power Co.	Presque Isle	Marquette	MI
Allete, Inc.	Syl Laskin	Aurora	MN
Allete, Inc.	Clay Boswell	Cohasset	MN
Allete, Inc.	Taconite Harbor Energy Center	Schroeder	MN
Cleveland Cliffs, Inc.	Silver Bay Power	Silver Bay	MN
Northern States Power Co.	Black Dog	Burnsville	MN
Northern States Power Co.	High Bridge	St. Paul	MN
Northern States Power Co.	Allen S King	Bayport	MN
Northern States Power Co.	Riverside	Minneapolis	MN
Northern States Power Co.	Sherburne County	Becker	MN

Utility Name	**Plant Name**	**City**	**State**
Otter Tail Power Co.	Hoot Lake	Fergus Falls	MN
Aquila, Inc.	Sibley	Sibley	MO
Aquila, Inc.	Lake Road	St Joseph	MO
Associated Electric Coop, Inc.	New Madrid	Marston	MO
Associated Electric Coop, Inc.	Thomas Hill	Moberly	MO
Empire District Electric Co.	Asbury	Asbury	MO
Independence, City of	Blue Valley	Independence	MO
Kansas City Power & Light Co.	Hawthorn	Kansas City	MO
Kansas City Power & Light Co.	Montrose	Clinton	MO
Kansas City Power & Light Co.	Iatan	Weston	MO
Sikeston, City of	Sikeston Power Station	Sikeston	MO
Springfield, City of	James River Power Station	Springfield	MO
Springfield, City of	Southwest Power Station	Springfield	MO
Ameren UE	Labadie	Labadie	MO
Ameren UE	Meramec	St Louis	MO
Ameren UE	Sioux	West Alton	MO
Ameren UE	Rush Island	Festus	MO
Mississippi Power Co.	Jack Watson	Gulfport	MS
Mississippi Power Co.	Victor J Daniel Jr	Escatawpa	MS
South Mississippi El Pwr Assn	R D Morrow	Purvis	MS
Tractebel Power, Inc.	Red Hills Generating Facility	Ackerman	MS
Weyerhaeuser Co.	Weyerhaeuser Columbus MS	Columbus	MS
PPL Montana LLC	J E Corette Plant	Billings	MT
PPL Montana LLC	Colstrip	Colstrip	MT
Carolina Power & Light Co.	Asheville	Arden	NC
Carolina Power & Light Co.	Cape Fear	Moncure	NC
Carolina Power & Light Co.	Lee	Goldsboro	NC
Carolina Power & Light Co.	Roxboro	Semora	NC
Carolina Power & Light Co.	L V Sutton	Wilmington	NC
Carolina Power & Light Co.	W H Weatherspoon	Lumberton	NC
Carolina Power & Light Co.	Mayo	Roxboro	NC
Cogentrix of Rocky Mount, Inc.	Cogentrix Dwayne Collier Battle Cogen	Battleboro	NC
Duke Energy Corp	G G Allen	Belmont	NC
Duke Energy Corp	Buck	Spencer	NC
Duke Energy Corp	Cliffside	Cliffside	NC
Duke Energy Corp	Dan River	Eden	NC
Duke Energy Corp	Marshall	Terrell	NC
Duke Energy Corp	Riverbend	Mount Holly	NC
Duke Energy Corp	Belews Creek	Walnut Cove	NC
Weyerhaeuser Co.	Weyerhaeuser Plymouth NC	Plymouth	NC
Basin Electric Power Coop	Leland Olds	Stanton	ND
Basin Electric Power Coop	Antelope Valley	Beulah	ND
Great River Energy	Stanton	Stanton	ND
Great River Energy	Coal Creek	Underwood	ND
MDU Resources Group, Inc.	R M Heskett	Mandan	ND
Minnkota Power Coop, Inc.	Milton R Young	Center	ND
Otter Tail Power Co.	Coyote	Beulah	ND

Utility Name	**Plant Name**	**City**	**State**
Fremont, City of	Lon Wright	Fremont	NE
Nebraska Public Power District	Sheldon	Hallam	NE
Nebraska Public Power District	Gerald Gentleman	Sutherland	NE
Omaha Public Power District	North Omaha	Florence	NE
Omaha Public Power District	Nebraska City	Nebraska City	NE
Grand Island, City of	Platte	Grand Island	NE
Public Service Co. of NH	Merrimack	Concord	NH
Public Service Co. of NH	Schiller	Portsmouth	NH
Public Service Co. of NH	Newington	Portsmouth	NH
Atlantic City Electric Co.	B L England	Marmora	NJ
Atlantic City Electric Co.	Deepwater	Penns Grove	NJ
Chambers Cogeneration LP	Chambers Cogeneration LP	Carneys Point	NJ
Logan Generating Co. LP	Logan Generating Plant	Swedesboro	NJ
PSEG Fossil LLC	PSEG Hudson Generating Station	Jersey City	NJ
PSEG Fossil LLC	PSEG Mercer Generating Station	Trenton	NJ
Arizona Public Service Co.	Four Corners	Fruitland	NM
Public Service Co. of NM	San Juan	Waterflow	NM
Tri-State G & T Assn, Inc.	Escalante	Prewitt	NM
Nevada Power Co.	Reid Gardner	Moapa	NV
Sierra Pacific Power Co.	Fort Churchill	Yerington	NV
Sierra Pacific Power Co.	North Valmy	Valmy	NV
Southern California Edison Co.	Mohave	Laughlin	NV
AES Greenidge LLC	AES Greenidge LLC	Dresden	NY
Dynegy Northeast Gen, Inc.	Danskammer Generating Station	Newburgh	NY
Dynegy Northeast Gen, Inc.	Roseton Generating Station	Newburgh	NY
Eastman Kodak Co.	Kodak Park Site	Rochester	NY
Mirant New York, Inc.	Lovett	Tomkins Cove	NY
NRG Huntley Operations, Inc.	C R Huntley Generating Station	Tonawanda	NY
Dunkirk Power LLC	Dunkirk Generating Station	Central Avenue	NY
Rochester Gas & Electric Corp	Rochester 7	Rochester	NY
AES Cayuga LLC	AES Cayuga	Lansing	NY
AES Somerset LLC	AES Somerset LLC	Barker	NY
AES Westover LLC	AES Westover	Johnson City	NY
Cardinal Operating Co.	Cardinal	Brilliant	OH
Cincinnati Gas & Electric Co.	Walter C Beckjord	New Richmond	OH
Cincinnati Gas & Electric Co.	Miami Fort	North Bend	OH
Cincinnati Gas & Electric Co.	W H Zimmer	Cincinnati	OH
Cleveland Electric Illum Co.	Ashtabula	Ashtabula	OH
Cleveland Electric Illum Co.	Eastlake	Eastlake	OH
Cleveland Electric Illum Co.	Lake Shore	Cleveland	OH
Columbus Southern Power Co.	Conesville	Conesville	OH
Columbus Southern Power Co.	Picway	Lockbourne	OH
Dayton Power & Light Co.	O H Hutchings	Miamisburg	OH
Dayton Power & Light Co.	J M Stuart	Aberdeen	OH
Dayton Power & Light Co.	Killen Station	Manchester	OH
Hamilton, City of	Hamilton	Hamilton	OH
Ohio Edison Co.	R E Burger	Shadyside	OH

Utility Name	**Plant Name**	**City**	**State**
Ohio Edison Co.	W H Sammis	Stratton	OH
Ohio Power Co.	Muskingum River	Beverly	OH
Ohio Power Co.	General James M Gavin	Cheshire	OH
Ohio Valley Electric Corp	Kyger Creek	Cheshire	OH
Orion Power Midwest LP	Avon Lake	Avon Lake	OH
Orion Power Midwest LP	Niles	Niles	OH
Toledo Edison Co.	Bay Shore	Oregon	OH
American Mun Power-Ohio, Inc.	Richard Gorsuch	Marietta	OH
AES Shady Point, LLC	AES Shady Point	Panama	OK
Fort James Operating Co.	Muskogee Mill	Muskogee	OK
Grand River Dam Authority	GRDA	Chouteau	OK
Oklahoma Gas & Electric Co.	Muskogee	Ft Gibson	OK
Public Service Co. of Oklahoma	Northeastern	Oologah	OK
Western Farmers Elec Coop, Inc.	Hugo	Fort Towson	OK
Portland General Electric Co.	Boardman	Boardman	OR
AES Beaver Valley	AES Beaver Valley Partners Beaver Valley	Monaca	PA
Exelon Generation Co. LLC	Cromby Generating Station	Phoenixville	PA
Exelon Generation Co. LLC	Eddystone Generating Station	Chester	PA
Midwest Generation	Homer City Station	Homer City	PA
Orion Power Midwest LP	Elrama Power Plant	Elrama	PA
Orion Power Midwest LP	Cheswick Power Plant	Cheswick	PA
Orion Power Midwest LP	New Castle Plant	West Pittsburg	PA
Pennsylvania Power Co.	Bruce Mansfield	Shippingport	PA
PPL Corp	PPL Brunner Island	York Haven	PA
PPL Corp	PPL Martins Creek	Martins Creek	PA
PPL Corp	PPL Montour	Washingtonville	PA
Reliant Energy NE Mgt Co.	Conemaugh	New Florence	PA
Reliant Energy NE Mgt Co.	Keystone	Shelocta	PA
Reliant Energy Mid-Atlantic PH	Portland	Portland	PA
Reliant Energy Mid-Atlantic PH	Titus	Birdboro	PA
Reliant Energy Mid-Atlantic PH	Shawville	Clearfield	PA
TIFD VIII-W, Inc.	Colver Power Project	Colver	PA
Sunbury Generation LLC	WPS Energy Servs Sunbury Gen	Shamokin Dam	PA
PG&E National Energy Group	Northhampton Generating LP	Northampton	PA
Allegheny Energy Supply Co. LLC	Armstrong Power Station	Kittaning	PA
Allegheny Energy Supply Co. LLC	Hatfields Ferry Power Station	Masontown	PA
Allegheny Energy Supply Co. LLC	Mitchell Power Station	Courtney	PA
Carolina Power & Light Co.	H B Robinson	Hartsville	SC
Duke Energy Corp	W S Lee	Pelzer	SC
International Paper Co.-Eastovr	International Paper Eastover Facility	Eastover	SC
South Carolina Electric & Gas Co.	Canadys Steam	Canadys	SC
South Carolina Electric & Gas Co.	McMeekin	Irmo	SC
South Carolina Electric & Gas Co.	Urquhart	Urquhart	SC
South Carolina Electric & Gas Co.	Wateree	Eastover	SC
South Carolina Electric & Gas Co.	Cope	Cope	SC
South Carolina Pub Serv Auth	Cross	Cross	SC
South Carolina Pub Serv Auth	Dolphus M Grainger	Conway	SC

Utility Name	Plant Name	City	State
South Carolina Pub Serv Auth	Jefferies	Moncks Corner	SC
South Carolina Pub Serv Auth	Winyah	Georgetown	SC
South Carolina Genertg Co., Inc.	Williams	Goose Creek	SC
Stone Container Corp	Stone Container Florence Mill	Florence	SC
Otter Tail Power Co.	Big Stone	Big Stone City	SD
Eastman Chemical Co.-TN Ops	Tennessee Eastman Operations	Kingsport	TN
Tennessee Valley Authority	Bull Run	Clinton	TN
Tennessee Valley Authority	Cumberland	Cumberland City	TN
Tennessee Valley Authority	Gallatin	Gallatin	TN
Tennessee Valley Authority	John Sevier	Rogersville	TN
Tennessee Valley Authority	Johnsonville	New Johnsonville	TN
Tennessee Valley Authority	Kingston	Kingston	TN
Alcoa, Inc.	Sandow Station	Rockdale	TX
Topaz Power Group LLC	Coleto Creek	Fannin	TX
Lower Colorado River Authority	Fayette Power Project	La Grange	TX
San Antonio Public Service Bd	J T Deely	Downtown Station	TX
San Antonio Public Service Bd	J K Spruce	Downtown Station	TX
San Miguel Electric Coop, Inc.	San Miguel	Christine	TX
Sempra Energy Resources	Twin Oaks Power One	Bremond	TX
Southwestern Electric Power Co.	Welsh	Pittsburg	TX
Southwestern Electric Power Co.	Pirkey	Hallsville	TX
Southwestern Public Service Co.	Harrington	Amarillo	TX
Southwestern Public Service Co.	Tolk	Muleshoe	TX
Texas Municipal Power Agency	Gibbons Creek	Anderson	TX
Texas Genco	Limestone	Jewett	TX
Texas Genco	W A Parish	Thompsons	TX
AEP Texas North Co.	Oklaunion	Vernon	TX
TXU Electric Co.	Big Brown	Fairfield	TX
TXU Electric Co.	Martin Lake	Tatum	TX
TXU Electric Co.	Monticello	Mt. Pleasant	TX
TXU Electric Co.	Sandow No 4	Rockdale	TX
Los Angeles, City of	Intermountain Power Project	Delta	UT
PacifiCorp	Carbon	Helper	UT
PacifiCorp	Hunter	Castledale	UT
PacifiCorp	Huntington	Huntington	UT
Deseret Generation & Tran Coop	Bonanza	Vernal	UT
Kennecott Utah Copper Corporation	KUCC	Magna Post Office	UT
Appalachian Power Co.	Clinch River	Cleveland	VA
Appalachian Power Co.	Glen Lyn	Glen Lyn	VA
Birchwood Power Partners LP	Birchwood Power	King George	VA
St Laurent Paper Products Co.	West Point Mill	West Point	VA
Cogentrix of Richmond, Inc.	Cogentrix of Richmond	Richmond	VA
Covanta Fairfax, Inc.	Covanta Fairfax Energy	Lorton	VA
Mirant Mid-Atlantic LLC	Potomac River	George Washington	VA
Virginia Electric & Power Co.	Bremo Bluff	Bremo Bluff	VA
Virginia Electric & Power Co.	Chesterfield	Chester	VA
Virginia Electric & Power Co.	Chesapeake	Chesapeake	VA

Utility Name	**Plant Name**	**City**	**State**
Virginia Electric & Power Co.	Yorktown	Yorktown	VA
Virginia Electric & Power Co.	Clover	Clover	VA
DPS Mecklenburg LLC	Mecklenburg Power Station	Clarksville	VA
TransAlta Centralia Gen LLC	Transalta Centralia Generation	Centralia	WA
Dairyland Power Coop	Alma	Alma	WI
Dairyland Power Coop	Genoa	Genoa	WI
Dairyland Power Coop	John P Madgett	Alma	WI
Fort James Operating Co.	Green Bay West Mill	Green Bay	WI
Madison Gas & Electric Co.	Blount Street	Madison	WI
Wisconsin Electric Power Co.	Port Washington Generating Station	Port Washington	WI
Wisconsin Electric Power Co.	South Oak Creek	Oak Creek	WI
Wisconsin Electric Power Co.	Valley	Milwaukee	WI
Wisconsin Electric Power Co.	Pleasant Prairie	Kenosha	WI
Wisconsin Power & Light Co.	Edgewater	Sheboygan	WI
Wisconsin Power & Light Co.	Columbia	Pardeeville	WI
Wisconsin Public Service Corp	Pulliam	Green Bay	WI
Wisconsin Public Service Corp	Weston	Rothschild	WI
Appalachian Power Co.	John E Amos	St Albans	WV
Appalachian Power Co.	Kanawha River	Glasgow	WV
Appalachian Power Co.	Mountaineer	New Haven	WV
Central Operating Co.	Philip Sporn	New Haven	WV
Monongahela Power Co.	Albright	Albright	WV
Monongahela Power Co.	Fort Martin Power Station	Maidsville	WV
Monongahela Power Co.	Harrison Power Station	Haywood	WV
Monongahela Power Co.	Rivesville	Rivesville	WV
Monongahela Power Co.	Willow Island	Williow Island	WV
Monongahela Power Co.	Pleasants Power Station	Willow Island	WV
Ohio Power Co.	Kammer	Moundsville	WV
Ohio Power Co.	Mitchell	Moundsville	WV
PPG Industries, Inc.	PPG Natrium Plant	New Martinsville	WV
Virginia Electric & Power Co.	Mt Storm	Mt Storm	WV
Basin Electric Power Coop	Laramie River Station	Wheatland	WY
PacifiCorp	Dave Johnston	Casper	WY
PacifiCorp	Naughton	Kemmerer	WY
PacifiCorp	Wyodak	Gillette	WY
PacifiCorp	Jim Bridger	Rock Springs	WY

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.

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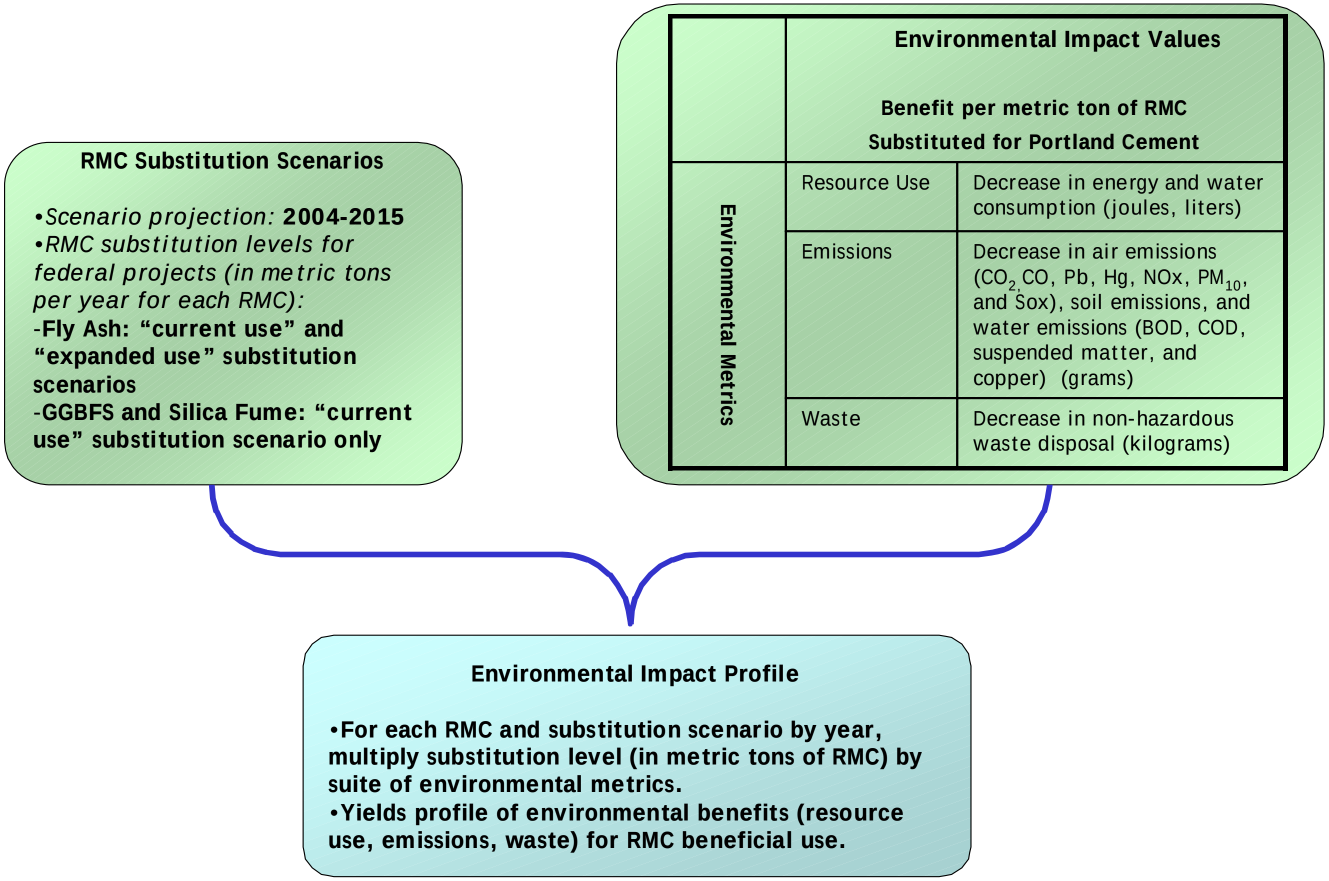
[3] The Agency recognizes that these environmental benefits may represent the reduced need for new or expanded portland cement producing capacity in future years. With the use of RMCs, the same amount of portland cement/clinker will likely be produced, but will result in more concrete production than 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



RMC Substitution Scenarios

- *Scenario projection:* **2004-2015**
- *RMC substitution levels for federal projects (in metric tons per year for each RMC):*

-Fly Ash: “current use” and “expanded use” substitution scenarios

-GGBFS and Silica Fume: “current use” substitution scenario only

	Environmental Impact Values **Benefit per metric ton of RMC Substituted for Portland Cement**	
Environmental Metrics	Resource Use	Decrease in energy and water consumption (joules, liters)
	Emissions	Decrease in air emissions (CO_2, CO, Pb, Hg, NOx, PM_{10}, and Sox), soil emissions, and water emissions (BOD, COD, suspended matter, and copper) (grams)
	Waste	Decrease in non-hazardous waste disposal (kilograms)

Environmental Impact Profile

- **For each RMC and substitution scenario by year, multiply substitution level (in metric tons of RMC) by suite of environmental metrics.**
- **Yields profile of environmental benefits (resource use, emissions, waste) for RMC beneficial use.**

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,

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[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^{2}P^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^{2}P^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^{2}P^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^{2}P^2 (C^{2}P^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.

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[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.

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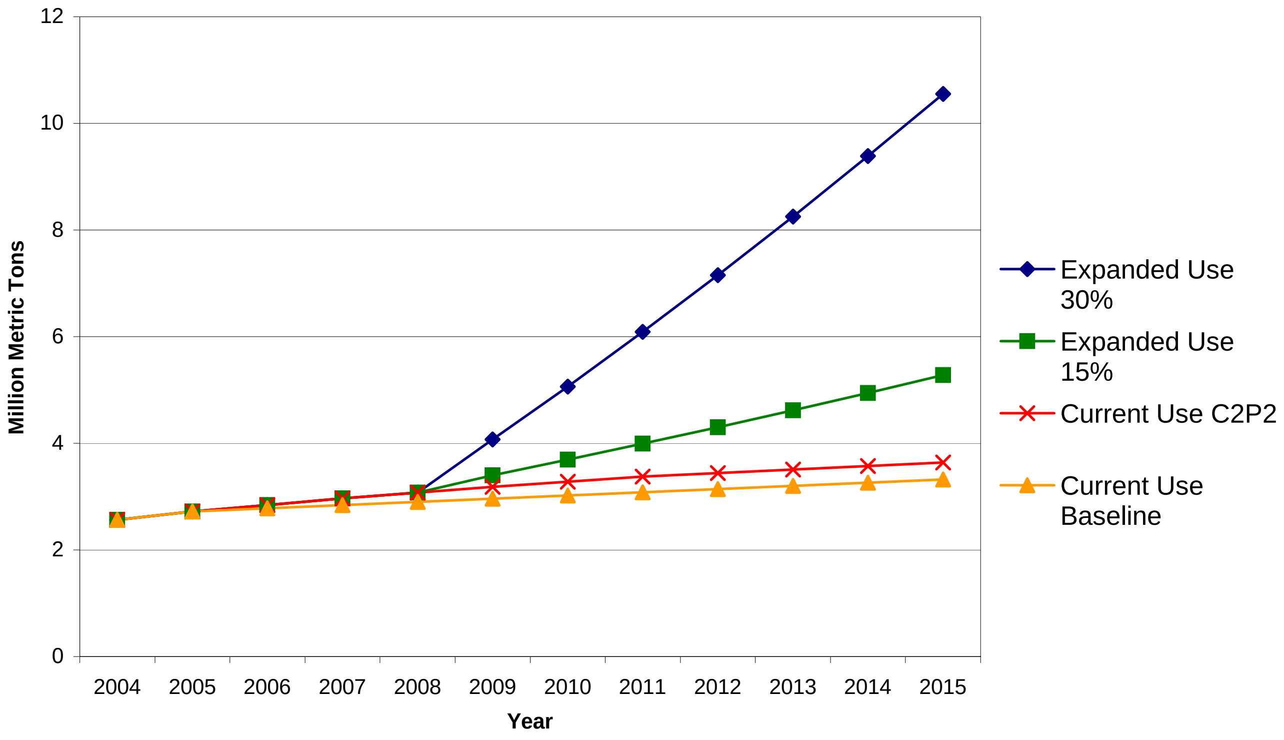
[8] The Bill language instructs all agency heads to implement recommendations of the 30 month study with regard to procurement guidelines no later than one year after the release of the study, or approximately early to mid 2009

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

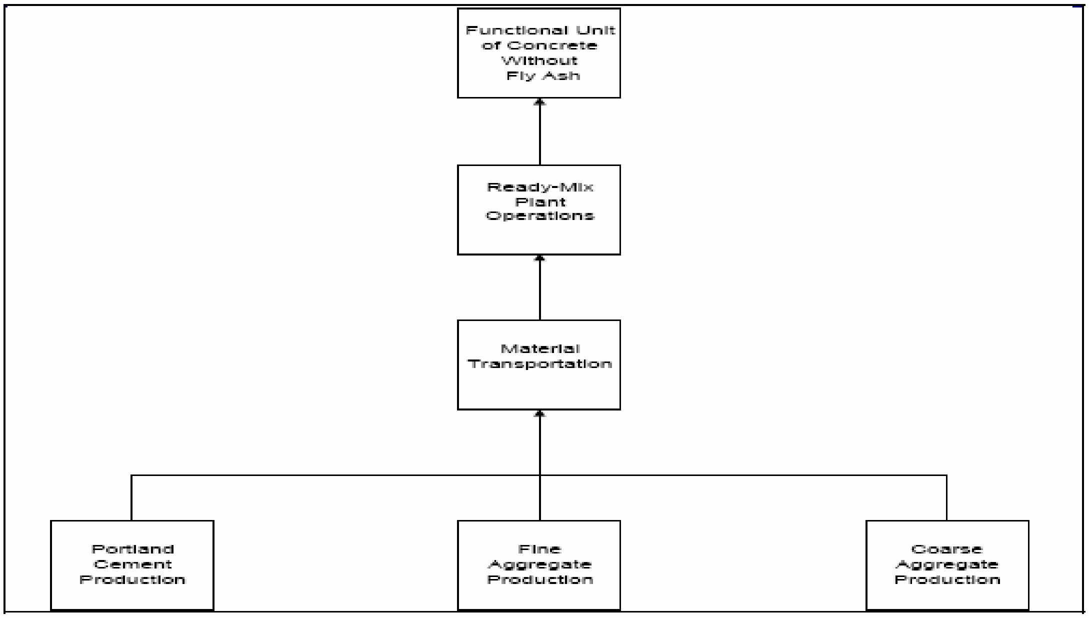
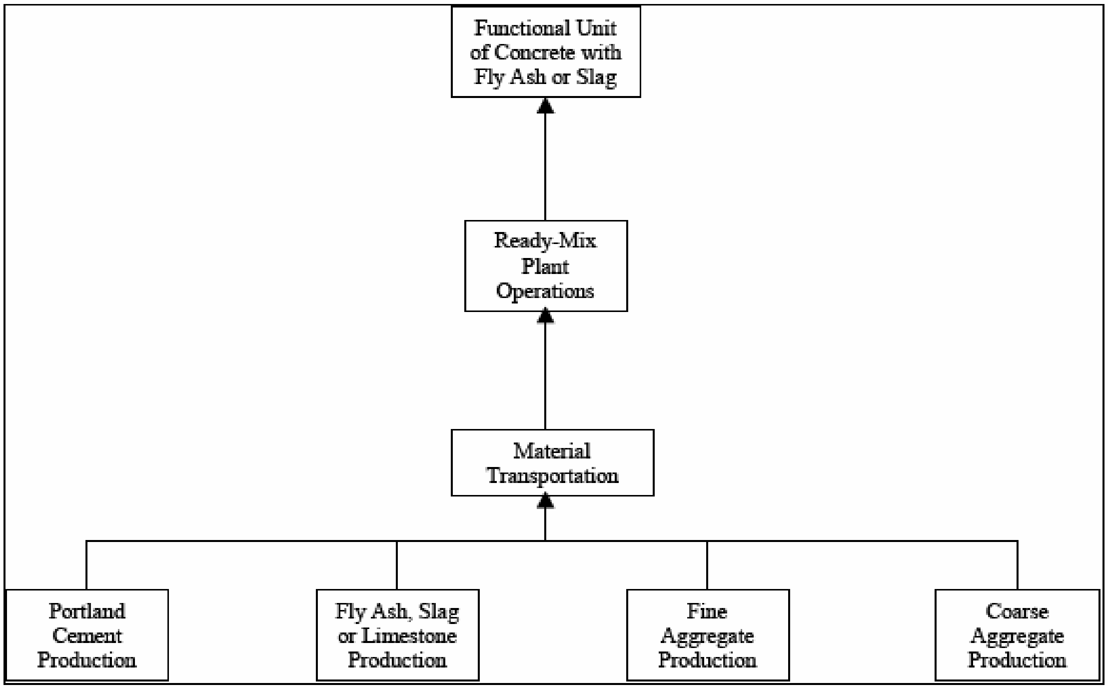


Figure D-4 shows the assumed life cycle system boundaries for a 4 KSI concrete beam in BEES made with blended cement (i.e., incorporating an RMC).

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]

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[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.

<table>
<tr><th rowspan="2">Metric</th><th colspan="3">----------------------Material ---------------------</th></tr>
<tr><th>Coal Fly Ash[a]</th><th>GGBFS</th><th>Silica Fume[b]</th></tr>
<tr><td colspan="4">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.</td></tr>
</table>

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.

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[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^{2}P^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$_2$0	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*42.0*	*43.2*	*44.5*	*45.4*	*46.2*	*47.1*	*48.0*	503.3
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	6.1
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	5.0
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.1	11.8
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	6.8	7.0	7.2	7.3	7.5	7.6	7.7	81.3
Avoided PM$_{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^2[a]		**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$_2$0	*metric tons*	*0.0*	*0.0*	*0.8*	*1.6*	*2.3*	*2.9*	*3.4*	*3.9*	*4.0*	*4.0*	*4.1*	*4.2*	31.4
Passenger cars not driven for one year	million passenger cars	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Avoided gasoline consumption	billion liters	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.7
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avoided NOx (air)	thousand metric tons	0.0	0.0	0.1	0.3	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.7	5.1
Avoided PM$_{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$_2$0	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*44.8*	*48.7*	*52.7*	*56.7*	*60.9*	*65.2*	*69.6*	*585.4*
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	7.1
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.6	0.6	0.7	5.8
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.3	1.4	1.5	1.6	13.8
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	7.2	7.9	8.5	9.2	9.8	10.5	11.2	94.6
Avoided PM$_{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$_2$0	*metric tons*	*33.8*	*35.9*	*37.5*	*39.1*	*40.6*	*53.7*	*66.8*	*80.4*	*94.3*	*108.8*	*123.8*	*139.2*	*853.7*
Passenger cars not driven for one year	million passenger cars	0.4	0.4	0.5	0.5	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.7	10.4
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.3	0.4	0.4	0.4	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.4	8.4
Avoided gasoline consumption	billion liters	0.8	0.8	0.9	0.9	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.3	20.1
Avoided oil consumption	billion barrels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Avoided NOx (air)	thousand metric tons	5.5	5.8	6.1	6.3	6.6	8.7	10.8	13.0	15.2	17.6	20.0	22.5	137.9
Avoided PM$_{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.

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[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).

APPENDIX E:

SUMMARY OF INDUSTRY REPRESENTATIVE COMMENTS ON MECHANISMS TO INCREASE RMC SUBSTITUTION

Table E-1 below summarizes suggestions from six key industry stakeholders on potential mechanisms to address barriers and increase use of coal fly ash, foundry sand, and other RMCs.

Table E-1: Summary of Suggestions from Industry on Potential Mechanisms

Industry Member	Suggestions
National Ready Mixed Concrete Association (NRMCA)	• Mandates for use of RMCs, including requiring specific minimum quantities, should be avoided. All mechanisms for increased use should ensure that the resulting concrete meets quality standards that will not compromise its service life. • Government should implement education efforts aimed at harmonizing policy by ensuring that state transportation agencies (on Federally supported projects) do not restrict the beneficial use unless there are technically valid reasons locally. • Government should provide financial (economic) and other incentives to the industry to increase the beneficial use of RMCs.
Headwaters, Inc.	The U.S. government should: • Continue on-going activities aimed at removing informational barriers including, but not be limited to: o Education through various media regarding the safety and performance- enhancing capabilities of RMCs. o Elimination of use restrictions not supported by technical considerations. o Support for performance-based specifications for concrete and RMCs used in concrete. • Substantially increase efforts to overcome logistical barriers. This may include creation of infrastructure incentives. Financial (economic) incentives, such as tax credits or accelerated depreciation of capital expenditures could assist companies that invest in the construction of infrastructure to store, process, transport or improve the quality of RMCs.
American Coal Ash Association (ACAA)	In Federal projects, current requirements that contractors use recovered mineral resources do not have adequate "teeth." A number of caveats make it easy for a contractor to opt-out of beneficial use material options. If the procurement process directed contractors to use RMC materials whenever the design specification allows it, RMCs would be more likely be used. Furthermore, other CCPs including FGD gypsum, boiler slag, bottom ash, and cenospheres could also be included.

Industry Member	Suggestions
Holcim, Ltd.	*General Comments:* • Create greater transparency about the use of RMCs • Create a centralized reporting system that tallies the amount and type of recycled cement/concrete products used in Federally funded projects. *State Agencies:* • Where Federal funds are involved, include requirements in state and local contracts requiring contractors to use cement/concrete containing RMCs (unless cost, availability or technical specifications prohibit such use). *Federal Agencies:* • Review and update Federal procurement rules to require that contractors bidding on Federal construction projects use cement/concrete containing RMCs (unless cost, availability or technical specifications prohibit such use). • On an annual basis, each Federal agency should provide EPA with copies of their procurement plans and rules, grant regulations, and information submitted to them by Federal contractors and state and local governments as to the amount and type of recycled cement/concrete being used, or reasons it is not being used, in Federally funded projects. • Require states to adopt specifications including RMCs in order to in order to receive Federal funds.
Silica Fume Association (SFA)	• Since cement production is a pound for pound contributor of CO_2 emissions, SFA suggests a strong program that requires elimination of cement-only concretes or requiring the use of SCMs in Federal projects using concrete. Give weighted financial credit (economic incentive) for using CPG materials to produce concrete on Federal projects. • Any program of this sort must include a technology transfer element, as most concrete producers in the US are not well versed in cement and cement replacement technology. To help provide this education or technology transfer, we recommend the Federal agencies using concrete join with the concrete industry organizations, and together provide this education to the industry.

Industry Member	**Suggestions**
Slag Cement Association (SCA)	• The CPGs can be much more effective if they had more explicit requirements regarding replacement rates, use of ternary mixtures, and had actual "teeth" so that non-compliance would have negative project impacts. Create minimum upper limits on slag cement (and fly ash) percentages in concrete based on application. • Require that specifications allow the use of ternary mixtures. • Establish a review protocol to allow a technical evaluation by an outside party if a project stakeholder challenges compliance of a specification to the CPGs. This "outside party" could be an appropriate functional agency for the project (e.g. FHWA for transportation, DOD for military, GSA for general facilities), or the EPA or a combination thereof. • Add "teeth" to the CPGs so that if the review protocol recommends specification changes, 1) reissue specifications if there is a reasonable amount of time prior to the project bid date (if time frame is too short before the bid date, then the bid date would need to be delayed); 2) if the project has already been bid, then re-bidding would be required; 3) if the project specifications are not changed then Federal funding should be withheld. • Provide incentives that encourage more domestic granulation capacity, such as tax incentives for new granulator installation (such as accelerated depreciation or tax credits), and provide funding for training programs on the proper use of GGBF slag (and other RMCs). • Provide funding for the nascent Green Highways Partnership, which is attempting to incorporate sustainable design concepts into highway design.