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.

[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

[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

[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.

[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,

[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