Materials Characterization Paper
In Support of the
Advanced Notice of Proposed Rulemaking –
Identification of Nonhazardous Materials That Are Solid Waste

Blast Furnace Slag - Used as ingredient in clinker manufacture

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1. Definition of BFS

Blast furnace slag (BFS) is a nonmetallic byproduct of the manufacture of pig iron in a blast furnace. BFS consists primarily of silicates, aluminosilicates, and calcium-alumina-silicates. BFS forms when slagging agents (e.g., iron ore, coke ash, and limestone) are added to the iron ore to remove impurities. 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. Different forms of slag product are produced depending on the method used to cool the molten slag and subsequent processing: (1) granulated blast furnace slag (GBFS) is produced by quickly quenching (chilling) molten slag to produce a glassy, granular product; (2) GBFS can further be ground to a specified fineness, yielding ground granulated blast furnace slag (GGBFS); (3) blast furnace slag aggregate (BFSA) is produced by allowing the molten slag to cool and solidify slowly under ambient (atmospheric) conditions. BFSA and GBFS are used in clinker manufacture (EPA 2008).

2. Annual Quantities of BFS Generated and Used

(1) **Sectors that generate BFS:**
- Blast furnace slag is generated by NAICS industry sector 331111, Iron and Steel Mills.

(2) **Quantities and prices of BFS generated:**
- In 2004, between 13 and 15 million short tons of blast furnace slag were generated in the U.S (van Oss 2004).[1]
- In addition, approximately one million short tons of blast-furnace slag were imported into the United States in 2005.
- In 2004, average sales prices for GBFS were $55.79 per short ton, with a reported range of $20.00 per ton for un-ground GBFS to $64.99 per ton for GGBFS (EPA 2008).[2]
- In 2004, average sales prices of BFSA were $5.90 per short ton, with a range of $1.40 to $15.74 per short ton (EPA 2008).[3]

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[1] The USGS estimates that the quantity of blast-furnace slag produced is equivalent to 25 percent to 30 percent of crude iron (i.e., pig iron) production (EPA 2008).

[2] This range does not include old, weathered GBFS from existing stockpiles that is sold as fine aggregate for a few dollars per metric ton (EPA 2008). Prices were converted from a metric ton to short ton basis.

[3] Prices were converted from a metric ton to short ton basis.

(3) **Trends in generation of BFS:**

- The generally declining trend in the U.S. output of iron and steel implies future overall supply constraints from domestic sources, especially as existing stockpiles get drawn down. This is especially true for the long-term availability of air-cooled slag, given the continuing decline in the number of operating blast furnaces (van Oss 2006).
- The supply of GBFS from domestic blast furnaces is constrained by the fact that granulation cooling is currently installed at only five blast furnaces in the United States, and one of these has been idle since mid-2005, with no assurance of restarting. Retrofitting other blast furnaces with granulators is possible and a handful of new slag grinders are being constructed in the U.S., which will likely increase GGBFS supply in coming years (EPA 2008).

3. Uses of BFS

(1) **Ingredient uses of BFS:**

- Both BFSA and GBFS can be added to the raw material feed in clinker manufacturing to contribute specific required elements, such as silica, alumina, calcium, and magnesium in the final cement composition. The primary virgin material used in clinker manufacture is limestone, with smaller quantities of sand, clay, and shale to achieve the correct mineral composition. Thus, BFS partially offsets these virgin raw feed materials.
- Cement kilns are represented by NAICS industry sector 327310, Cement Manufacturing, which included 247 facilities in 2002 (U.S. Census Bureau, 2002). EPA reports that this sector included 144 facilities in 2006 (EPA 2006).

(2) **Non-combustion uses of BFS:**

- Blast furnace slag aggregate is used as a substitute for virgin aggregate in road base, concrete, asphalt concrete, rail ballast, roofing, shingles, mineral wool, and glass making.
- GGBFS can be used as a supplementary cementitious material either by premixing the slag with portland cement or hydrated lime to produce a blended cement (during the cement production process) or by adding the slag to portland cement concrete as a mineral admixture.

(3) **Quantities of BFS landfilled:**

- No data exist on the disposal or landfilling of blast-furnace slag, but it is likely that the utilization of blast furnace slag is nearly 100 percent of U.S. production, reflecting the high value of these materials as cementitious materials, aggregates, or components of blended cements (EPA 2008).

(4) **Quantities of BFS stockpiled/stored:**

- A preliminary sampling of three blast furnace slag processors in the U.S. has identified approximately 100 million metric tons of stockpiled slag as of 2006 (Connor, Martin, and Wolanske 2006). The total quantity of stockpiled slag in the U.S. is likely significantly higher, but additional slag processors have not been surveyed to obtain an estimate.
- It is unclear what percentage of the known 100 million metric tons of stockpiled slag is suitable for use in clinker manufacture.

Exhibit 1: Overview of Generation and Use of BFS in 2004

Commodity	Annual Quantity Generated	Annual Quantity Used as Ingredient		Annual Quantity Landfilled	Annual Quantity in Other Uses	Total Quantity Stockpiled as of 2006
		Cement Kilns	Other			
	-------------------- *Short Tons* --------------------					
Blast Furnace Slag	12.0-14.0 million	0.25 million	0	0	11.58 million	>100 million[a]

Sources:
Unless otherwise noted, data is from U.S. EPA, April 28, 2008, *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*.
Notes:
a. Personal communication with Jamie Connor, Tube City IMS Corporation, Chuck Martin, Beaver Valley Slag, Inc., and Max Wolanske, Lafarge NA, December 5, 2006 and December 6, 2006.

4. Management and Combustion processes for BFS

(1) **Types of units using BFS**
- Blast furnace slag is added to cement kilns during the clinker manufacturing process.

(2) **Sourcing of BFS**
- Cement manufacturing facilities purchase blast furnace slag directly from iron mills or from a slag processing/grinding facility.

(3) **Processing of BFS:**
- Once molten slag has been cooled into either BFSA or GBFS, no further processing is required for use as a raw material in clinker manufacture.

(4) **State status of BFS use as ingredient:**
- At this stage, we have not identified any states that have specifically granted beneficial use designation to the use of blast furnace slag in clinker manufacture, but we have not performed an exhaustive investigation of state activities and regulations.

5. BFS Composition and Impacts

(1) **Composition of BFS:**
- The chemical composition of BFS includes: calcium oxide (CaO), silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), magnesium oxide (MgO), iron (FeO or Fe_2O_3), manganese oxide (MnO), and sulfur (S) (Turner-Fairbank Highway Research Center).
- When heated to high temperatures (1450 degrees Celsius) in a cement kiln, some of the chemical constituents of slag may be volatized.

(2) **Impacts of BFS use:**

- In clinker manufacture, blast furnace slag partially offsets the need for virgin materials such as limestone, sand, clay, and shale. Substitution of slags for natural raw materials to make clinker can reduce the unit consumption of fuel and limestone in the kiln, which may then reduce the emissions of certain pollutants (van Oss 2006).
- The specific lifecycle impacts of BFS use as a raw material in clinker production are not evaluated here because of uncertainties in lifecycle scenario development. For example, it is difficult to determine the replacement ratio between BFS and other raw feed materials in clinker production. Thus, the correct quantity of material to be modeled is unclear. In addition, BFS may substitute for a variety of virgin raw materials as well as other secondary materials (e.g., cement kiln dust, CCPs, foundry sand, etc.); the choice of material often depends on location-specific factors such as the proximity of material sources to the cement kiln and relative availability of different materials. Avoided upstream impacts depend heavily on the specific material being displaced in the lifecycle scenario.

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