

CEMENT SECTOR GREENHOUSE GAS EMISSIONS REDUCTION CASE STUDIES

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Abstract

The report describes five case studies of greenhouse gas (GHG) emissions reduction projects in the cement sector. Two of these are being implemented under the Clean Development Mechanism (CDM) program of the Kyoto Protocol. As such, they have been designed specifically to reduce GHG emissions, and are projects that would not have occurred in the absence of the program. These two case studies were selected based on their potential applicability to cement plants in California. They represent two different options for reducing emissions at cement plants by blending different pozzolanic materials (finely divided siliceous or siliceous and aluminous materials that react chemically with slaked lime at atmospheric temperatures and pressures in the presence of moisture to form cement), granulated blast furnace slag and fly ash, into Portland cement product. Being CDM projects, both are international. Three other case studies were selected based on their interest to staff of the California Air Resources Board which is developing regulations for the reduction of GHG emissions from California cement plants. These additional three studies evaluate the use of slag and fly ash blending in California cement, and the use of biofuels in California cement plants. All case studies discuss GHG emissions benefits and, as appropriate, other pollutant (criteria pollutants and air toxics) emissions benefits and project costs. Each case study provides insights that could prove useful for California's efforts to reduce GHG emissions.

Keywords: Greenhouse gas emissions, cement plants, Portland cement, slag blending, fly ash blending, biofuels in cement kilns

Executive Summary

This report describes five case studies of greenhouse gas emissions reduction projects in the cement sector. Two case studies were selected from an initial list developed in previous work under this contract. These two case studies are ones that are being implemented under the Clean Development Mechanism program of the Kyoto Protocol. They were selected because they represent two different options for reducing emissions at cement plants and their potential applicability to cement plants in California. Projects at plants of a similar vintage or technology type were selected.

Three other case studies were selected based on their interest to staff of the California Air Resources Board, which at the time of this work was developing regulations for the reduction of GHG emissions from California cement plants.

The five case studies are:

- Slag-Blended Cement Clean Development Mechanism Project: Mysore Cements Limited Portland Slag Cement Project, India. This case study describes the level of success of one plant in decreasing emissions from clinker production by displacing the ground clinker with ground, granulated blast furnace slag.
- Fly Ash-Blended Cement Clean Development Mechanism Project: Dalmia Cement Limited, India. This case study describes the plan of one cement plant to increase the proportion of fly ash used in blended cement (and reduce the amount of clinker) and its attempts to gain greater acceptance of its blended product in the marketplace.
- Slag-Blended Cement in California. This case study focuses on the availability and cost of obtaining granulated blast furnace slag in California. It considers where the slag might come from and the potential barriers to its greater use in blended cement.
- Fly Ash-Blended Cement in California. This case study considers the availability and cost of fly ash in California. The results of studies on the potential health concerns with mercury (and possibly other heavy metals) leaching are described. While mercury leaching does not appear to be a problem, other factors also affect the expanded use of fly ash-blended cement in the state.
- Biofuels in California Cement Plants. This case study describes availability and potential use of biomass combustion in California cement plants and associated emissions reduction benefits. The cost of biomass is expected to compare favorably with coal consumed by cement plants, although cement plants may face competition from electricity producers for biomass fuels, and thus increasing costs. It is suggested that biomass burning in cement plants be addressed in California's Bioenergy Action Plan.

All case studies discuss GHG emissions benefits and, as appropriate, other pollutant (criteria pollutants and air toxics) emissions benefits and project costs. Each case study provides insights that could prove useful for California's efforts to reduce greenhouse gas emissions.

CHAPTER 1: Introduction

This project acquired and developed data and information on the magnitude of emissions from various greenhouse gas (GHG) sources as well as emission reduction potential, costs, technical feasibility, and demonstrated effectiveness of methods for reducing greenhouse gas emissions from in-state sources. The data and information acquired and developed was intended to promote implementation of greenhouse gas emission reduction projects by state, regional and local agencies, utilities, businesses, industries, and other energy and economic sectors. For this work, a greenhouse gas emission reduction project (“project”) is defined as “a specific activity or set of activities intended to reduce GHG emissions, increase the storage of carbon, or enhance GHG removals from the atmosphere.”¹

For this project, four efforts were outlined as follows:

- Complete Report on Greenhouse Gas Emissions Data.
- Complete Report on Greenhouse Gas Emissions Reduction Market Assessment.
- Complete Report on Greenhouse Gas Emissions Reduction Projects.
- Conduct Feasibility Studies on Greenhouse Gas Emission Reduction Projects in Selected Industry Sectors.

The first of these efforts was completed, and the second initiated. However, while preparing the Greenhouse Gas Reduction Market Assessment Report, Energy Commission staff concluded that many of the efforts originally planned when the project was initiated, which occurred before adoption of the California Global Warming Solutions Act of 2006 (Assembly Bill 32 [AB 32]), were going to be incorporated into work the California Air Resources Board (ARB) would be completing in implementing AB 32 requirements. Accordingly, it was decided that efforts for the contract be redirected toward supporting ARB’s AB 32 work. Then, with the passage of the California Alternative and Renewable Fuel, Vehicle Technology, Clean Air, and Carbon Reduction Act of 2007 (Assembly Bill 118 [AB 118], Núñez, Chapter 750, Statutes of 2007), it was subsequently decided to focus contract efforts toward supporting Energy Commission staff in preparing and adopting the Investment Plan required by the legislation.

This report was prepared for the third bullet above. It describes five case studies of GHG emissions reduction projects in the cement sector. The Loreti Group prepared the report under subcontract to the Battelle Memorial Institute, which in turn served as a subcontractor to TIAX, LLC for the California Energy Commission on Contract #600-04-025. This report partially fulfills work required in Task 4 of Work Authorization 5.

Task 1 under Work Authorization 5 developed a list of GHG emission reduction projects that had been implemented or were planned for implementation at cement plants around the world. Task 2 profiled California cement plants, and Task 3 combined the information from the two previous tasks to screen for the potential for the emission reductions projects identified in the

¹ *Greenhouse Gas Protocol for Project Accounting*. World Business Council for Sustainable Development and World Resources Institute, 2005.

first task to be implemented at one or more California cement plants. Task 4 evaluated the applicability of this information to California and examined other strategies for reducing GHG emissions from the cement manufacturing sector.

In this report five case studies of GHG emission projects are described. Two case studies were selected from the initial list prepared in Task 1. These case studies are being implemented under the Clean Development Mechanism (CDM) program of the Kyoto Protocol. As such, they have been designed specifically to reduce GHG emissions and, under the rules of the CDM, they are projects that would not have occurred without the program.

These two case studies were selected because they represent two different options for reducing emissions at cement plants. They were also selected based on their potential applicability to cement plants in California. Projects at plants of a similar vintage or technology type were selected. The author did not consider projects at plants that used older or different technology for manufacturing cement, such as wet kilns, or vertical kilns (often used in China).

Three other case studies were selected based on their interest to staff of the California Air Resources Board, which at the time of this work was developing regulations for the reduction of GHG emissions from California cement plants.

The five case studies are:

- Slag-Blended Cement Clean Development Mechanism Project: Mysore Cements Limited Portland Slag Cement Project, India. This case study describes the level of success of one plant in decreasing emissions from clinker production by displacing the ground clinker with ground, granulated blast furnace slag.
- Fly Ash-Blended Cement Clean Development Mechanism Project: Dalmia Cement Limited, India. This case study describes the plan of one cement plant to increase the proportion of fly ash used in blended cement (and reduce the amount of clinker), and its attempts to gain greater acceptance of its blended product in the marketplace.
- Slag-Blended Cement in California. This case study focuses on the availability and cost of obtaining granulated blast furnace slag in California. It considers where the slag might come from and the potential barriers to its greater use in blended cement.
- Fly Ash-Blended Cement in California. This case study considers the availability and cost of fly ash in California. The results of studies on the potential health concerns with mercury (and possibly other heavy metals) leaching are described. While mercury leaching does not appear to be a problem, other factors also affect the expanded use of fly ash blended cement in the state.
- Biofuels in California Cement Plants. This case study describes availability and potential use of biomass combustion in California cement plants and associated emissions reduction benefits. The cost of biomass is expected to compare favorably with coal consumed by cement plants, although cement plants may face competition from electricity producers for biomass fuels, and thus increasing costs. It is suggested that biomass burning in cement plants be addressed in California's Bioenergy Action Plan.

This report often uses the term “tonne” when it refers to weights. This represents a “metric tonne,” and one metric tonne equals 1.1023 short tons.

This report also uses the terms “cement” and “concrete.” Cement is the binder used along with sand and rock to make the final product, called concrete. Normally, cement is combined with the other constituents at a concrete batch plant and then is mixed into the final product while it is transported to the end-use site using a truck called a “transit mix truck.”

CHAPTER 2: Case Study 1—Mysore Cements Limited Portland Slag Cement Project

Plant Location: Ammsandra, in the state of Karnataka, India

Key Stakeholders: Mysore Cements, Ltd. (part of the S.K. Birla Group): India (host country)

Implementation Process

The Mysore cement plant produces both ordinary Portland cement and Portland slag cement, which is a blend of Portland cement and ground granulated blast furnace slag². The production of Portland slag cement in India is governed by the Bureau of Indian Standards specification IS: 455: 1989, which specifies that slag shall be not less than 25 percent nor more than 65 percent of the cement. Implementation of this project increases the fraction of slag in the blended cement, thereby reducing the amount of clinker required to produce an equivalent amount of cement. If the project were not implemented, the slag would be dumped in designated landfill sites and the cement would be manufactured with a smaller fraction of slag in the blended cement. Instead, the project reduces the clinker percentage in the cement and the associated carbon dioxide (CO₂) emissions.

Implementation of this project has involved several activities. The existing blended cement operations required the installation of additional equipment, research and development on slag cement, and marketing and promotional activities to ensure acceptance of the cement in the marketplace. The expansion of the production of blended cement for this project required the following equipment additions/modifications:

- Storage, handling, and proportioning equipment for additive materials, such as hoppers, feeders, conveyors, and cement grinding aid.
- Additional and modified liners for the ball mills used to grind the clinker.

Because slag is abrasive and hard to grind, the operation and maintenance of ball mills in slag cement plants is more challenging than in ordinary Portland cement grinding plants. Increasing the percentage of slag in the cement increases the wear rate inside the ball mill used to grind the clinker, requiring the lining material of the ball mills to be replaced more frequently. Mysore Cement Limited installed modified high chrome boltless liner plates to reduce wear and improve grinding.

The company is also conducting activities to increase the acceptance of Portland slag cement with greater proportions of slag, as use of such cement is not common practice in the region. Ordinary Portland cement is reportedly perceived as being stronger than Portland slag cement. This is due to the lower early strength of Portland slag cement compared to ordinary Portland

² Information in this case study is summarized from the CDM Project Design Document for Mysore Cements Limited Portland Slag Cement Project, Version 3, September 25, 2006.

cement. The grey-white color of Portland slag cement also creates doubts in the marketplace due to the difference in color between ordinary and slag cement. It is expected that an increase in the slag content from 26-27 percent to 45-60 percent by weight will create even more doubt about the strength of the cement.

Doubt about use of Portland slag cement is evident in the marketplace, as some government departments specify that only ordinary Portland cement be used in major construction projects, even when Portland slag cement would be appropriate. Therefore, the company is conducting a marketing and education program to increase acceptance of Portland slag cement.

The change in the composition of the Portland slag cement produced by the plant and the change in GHG emissions intensity is shown in Table 1, along with monitored emission reductions. This table provides information from both the Project Design Document³ and the project's first monitoring report⁴. While the additional amount of slag used varies (and associated reduction in clinker use varies), the clinker content of the cement was expected to be reduced – and was reduced – by up to about 10 percentage points relative to the baseline.

The figures in Table 1 vary slightly between the Project Design Document and the monitoring report for all but the project clinker fraction in the blended cement. It is not clear why the baseline clinker fraction and emissions intensity are different, as the monitoring report does not include the detailed data used in the calculations. The project emissions may be different due to differences between the actual leakage rates in emissions and those expected when the Project Design Document was prepared. In any case, the differences are small. (Since the monitoring report data are more recent and based on actual performance, they should be relied upon in preference to the data from the Project Design Document.)

At present, the project continues to operate. While emission reductions have been reported as shown in Table 1, the verification of these monitored emission reductions and the subsequent issuance of Certified Emission Reductions, which may be sold under the CDM program, have not yet occurred.

³ Ibid.

⁴ Monitoring Report of Mysore Cements Limited Portland Slag Cement project for the period January 1, 2001, to December 31, 2006, UNFCCC Reference No: 0711, Version 1, April 2007.

Table 1: Change in Clinker Fraction, GHG Emissions Intensity, and GHG Emissions for the Mysore Cements Limited Portland Slag Cement Project

Production Parameter	2001	2002	2003	2004	2005	2006
<i>From Project Design Document (Source 1):</i>						
Baseline clinker fraction in blended cement	0.602	0.594	0.586	0.579	ND	ND
Project clinker fraction in blended cement	0.513	0.498	0.519	0.500	ND	ND
Baseline Emissions, tonne CO ₂ /tonne blended cement	0.640	0.633	0.625	0.617	0.610	0.602
Project Emissions, tonne CO ₂ /tonne blended cement	0.588	0.535	0.540	0.537	0.527	0.517
<i>From First Monitoring Report (Source 2):</i>						
Baseline clinker fraction in blended cement	0.598	0.590	0.582	0.575	0.567	0.559
Project clinker fraction in blended cement	0.513	0.498	0.519	0.500	0.514	0.506
Baseline Emissions, tonne CO ₂ /tonne blended cement	0.639	0.632	0.624	0.616	0.602	0.619
Project Emissions, tonne CO ₂ /tonne blended cement	0.589	0.535	0.543	0.539	0.551	0.566
Emission Reductions, tonne CO ₂ -e	12,406	34,366	30,294	29,227	17,151	17,983

Source 1: *Mysore Cements Limited Portland Slag Cement Project*. Clean Development Mechanism, Project Design Document Form (CDM PDD), Version 02, CDM Executive Board, United Nations Framework Convention on Climate Change (UNFCCC).

Source 2: *Monitoring Report of Mysore Cements Limited Portland Slag Cement Project, for the period January 1, 2001 to December 31, 2006*, UNFCCC Reference No: 0711, prepared by CARE Sustainability, Sector 9, Nerul, Navi Mumbai-400 706, India, April 2007.

Reduction in Greenhouse Gas Emissions

Reductions in GHG emissions from this project result from less clinker needed to produce a given quantity of cement. Process CO₂ emissions are reduced as a result of reduced limestone calcination, and thermal and electrical energy used in the production of clinker is also reduced, resulting in lower emissions. Changes in methane and nitrous oxide emissions from combustion processes were considered to be negligible and excluded from the calculations because the differences in the baseline and project activity are not substantial.

The estimated total reduction of GHG emissions over a 10-year period is 358,064 tonnes carbon dioxide equivalent (CO₂e). This amounts to approximately 35,800 tonnes per year on average. As shown in Table 1, actual emission reductions have been lower than the predicted average,

sometimes substantially so between 2001 and 2006. This has occurred because less of the blended cement has been produced in some years (for example, 2001) and the emissions intensity of the blended cement has also been greater than expected in some years (for example, 2005 and 2006).

Reduction in Criteria Pollutant Emissions

The project proponents did not calculate the criteria pollutant emission reductions associated with this project. Since the increase in the proportion of slag in the cement results in a decrease in the amount of clinker, the criteria pollutant emissions reductions should be in roughly direct proportion to the reduction in the amount of clinker produced. Based on the figures in Table 1, this reduction would be about 14 percent.

Other Benefits

The reduction in clinker production and increase in slag consumption reduces the environmental impacts associated with slag disposal and conserves natural resources such as limestone and coal. Portland slag cement has excellent resistance to sulfate and chloride and is thus highly suitable for construction in coastal areas. It also gives higher long term strength and durability to concrete compared to ordinary Portland cement. Due to its lower heat of hydration, Portland slag cement is highly suitable for mass concrete projects like dams and bridges to reduce thermal cracking.

Conclusions

Decreasing the quantity of clinker in cement through blending with ground, granulated blast furnace slag can be an effective means of reducing GHG emissions of the Mysore Cements plant. Market acceptance of the blended cement product is key to expanding its use. This is particularly true in countries outside the United States, such as India, where blended cements are already used, and the clinker fraction in the cement is already lower.

This case study provides a couple of lessons that are relevant to the expanded use of slag blended cement in California. One is that the product can be economically produced by cement manufacturers. The other is that unless the product gains acceptance in the marketplace, the expected emission reduction benefits may not be fully realized. Additional considerations related to use of ground granulated blast furnace slag in California are presented in Case Study 3.

CHAPTER 3: Case Study 2—Dalmia Cement Limited, India Fly Ash-Blended Cement Project

Plant Location: Dalmiapuram, Tamilnadu, a state in southern India

Key Stakeholders: Dalmia Cement (Bharat) Ltd (DCBL); India (host country)

Implementation Process

Dalmia Cement Limited produces both ordinary Portland cement (OPC) and Portland pozzolanic cement (PPC), which is a blend of Portland cement and other pozzolanic materials⁵. In this case, the other pozzolan is fly ash. The project increases the proportion of fly ash from 23.6 percent to 25.9 percent, which is higher than the blending practices of cement plants in the region. If the project were not implemented, the fly ash would be landfilled, and the cement would be manufactured with a greater proportion of Portland cement. By reducing the clinker percentage in the cement, the associated CO₂ emissions are reduced.

The project involves the following activities:

- Transportation of fly ash from a power plant to the cement plant.
- Transfer of fly ash from tanker trucks to fly ash silo.
- Fly ash handling and feeding system delivery to the cement mill.
- Fly ash mixing and transfer of Portland pozzolanic cement (PPC) to storage silo.

Transportation of fly ash from power plant to DCBL facility. Fly ash is transported from power plants to the DCBL cement manufacturing facility by truck. DCBL is using fly ash from Mettur Thermal Power Station and Neyveli Lignite Power Station, which are located at distances of 220 km and 130 km respectively from the cement plant.

Transfer of fly ash from tanker to fly ash silo. The transported fly ash delivered by the tanker trucks is stored in a fly ash silo and storage yard. Pneumatic conveyors transfer fly ash from the tanker trucks to a fly ash storage yard.

Fly ash handling and feeding system delivery to the cement mill. Based on production requirements, dry fly ash from the fly ash storage yard is transported to a fly ash/slag hopper by pneumatic conveyor. The fly ash hopper is directly connected to the cement mill and fly ash flows by gravity from the hopper to the cement mills.

⁵ Pozzolanic materials are finely divided siliceous or siliceous and aluminous materials that react chemically with slaked lime at atmospheric temperatures and pressures in the presence of moisture to form cement.

⁶ Information in this case study is summarized from the CDM Project Design Document for the “Optimal Utilization of Clinker” Project at Dalmia Cement (Bharat) Limited (DCBL), Dalmiapuram, Tamilnadu, Version 2, July 31, 2006.

Fly ash mixing and transfer of PPC to storage silo. Mixing of fly ash, clinker, and gypsum takes place simultaneously during the grinding process, and PPC is transported to a bag filter after the cement mill and eventually transferred to the storage silo.

Baghouses are provided at the top of the fly ash silo to vent transport air during unloading of fly ash from tanker trucks and aeration air, which is provided at the bottom of the silo. This is standard emissions control technology in India.

While the technological aspects of blending fly ash with cement are relatively straightforward, this project has also involved a marketing and education program. Some of the activities have included:

- Conducting regular training and educational programs for engineers, architects, contractors, builders, masons, retailers, dealers, and end users to discuss merits of PPC.
- Publishing a separate magazine for masons that highlights benefits of PPC, good operational practices of PPC usage and answers questions from masons.
- Inviting masons to contact a cement dealer to receive briefings about use of PPC with higher additive percentages.
- Organizing visits for consumers, architects, engineers, contractors, builders, and dealers to the cement plant to show them the process of manufacturing PPC and laboratory testing of the cement to enhance confidence in PPC use.
- Mass distribution of handbills, leaflets, and brochures among different segments of consumers.
- Advertisements in the media, including newspapers, magazines, and television.

Reduction in GHG Emissions

Reductions in GHG emissions from this project result from less clinker being needed to produce a given quantity of cement. Process CO₂ emissions are reduced as a result of reduced limestone calcinations. Thermal and electrical energy used in the production of clinker is also reduced, resulting in lower emissions. Changes in methane and nitrous oxide emissions from combustion processes were not calculated because they were considered to be negligible.

Table 2 illustrates the change in the clinker content of the cement over a 10-year period beginning in 2000. The increased use of fly ash leads to a lower fraction of clinker in the cement and a corresponding reduction in GHG emissions.

Transportation-related emissions for the delivery of additional fly ash to the cement plant were included in the emissions reduction calculations as leakage. (The leakage is added to the difference between the baseline and project emissions.) As a conservative simplification, however, emissions reductions from reduced transport of raw materials for clinker production

were not taken into account. In any case, the transportation-related emissions have very little effect on the calculated emission reductions as shown in Table 2.

Table 2: Change in Clinker Fraction and Total Emissions, Leakage, and Emission Reductions for the Dalmia Cements Limited Fly Ash-Blended Cement Project

Year	Baseline Emissions		Project Emissions			
	Tonnes CO ₂ /Tonne Cement	Total, tonnes	Tonnes CO ₂ /Tonne Cement	Total, tonnes	Leakage	Emission Reductions
2000-2001	0.621	324,254	0.608	317,678	225	6,351
2001-2002	0.615	316,890	0.593	305,221	345	11,324
2002-2003	0.602	333,604	0.581	321,653	319	11,632
2003-2004	0.594	338,893	0.580	330,706	193	7,994
2004-2005	0.598	431,257	0.601	433,163	-36	-1,870
2005-2006	0.625	639,053	0.646	659,768	-177	-20,538
2006-2007	0.621	1,084,296	0.597	1,041,823	934	41,539
2007-2008	0.617	1,334,120	0.579	1,251,855	1625	80,640
2008-2009	0.613	1,568,169	0.579	1,481,623	1752	84,794
2009-2010	0.608	1,685,710	0.570	1,578,895	2104	104,711
Total		8,056,246		7,722,385	7,284	326,577

Source: *Dalmia Cement Limited, India Fly Ash-Blended Cement Project*. Clean Development Mechanism, Project Design Document Form (CDM PDD), Version 02, CDM Executive Board, United Nations Framework Convention on Climate Change (UNFCCC).

By implementing the project activity, DCBL plans to reduce 326,577 tons of CO₂ emissions, or approximately 32,700 tonnes per year on average, over 10 years.

At present, the project continues to operate. No monitoring reports of emission reductions could be located for this project, and the verification of emission reductions and subsequent issuance of Certified Emission Reductions by the CDM Executive Board have not yet occurred.

Reduction in Criteria Pollutant Emissions

The project proponents did not calculate the criteria pollutant emission reductions associated with this project. Since the increase in the proportion of fly ash in the cement results in a decrease in the amount of clinker, the criteria pollutant emissions reductions should be in roughly direct proportion to the reduction in the amount of clinker produced. Based on the figures in Table 2, this reduction would be about 4-5 percent but varies from year to year.

In addition, the use of the fly ash by the project is expected to reduce the amount of fugitive particulate matter emitted at landfills near the power plants.

Other Benefits

The project conserves natural resources such as limestone and coal and reduces the environmental impacts associated with coal mining. The project also reduces the potential for water pollution resulting from runoff of leachate from fly ash dumping.

Conclusions

Blending cement with fly ash can be an effective way of reducing GHG emissions from the Dalmia Cement Limited plant. Fly ash has the advantage that it does not require additional grinding, as granulated blast furnace slag does, thereby eliminating the cost, energy, and emissions associated with such grinding.

The actual emission reduction benefits that will result from this project depend upon the amount of fly ash that can be sold in the blended cement. Market acceptance is key to expanding the use of fly ash blended cement. Neither monitoring nor verification reports on the actual emission reductions from this project has been published, and therefore it is not clear how much additional fly ash has been consumed by the project. Additional considerations related to the use of fly ash blended cement in California are presented in Case Study 4.

CHAPTER 4: Case Study 3—Ground Granulated Blast Furnace Slag As A Cement Substitute

Background

In the production of iron in blast furnaces, molten slag is produced as a by-product. This slag may be treated by cooling with air or water to solidify the slag for further processing and use. Granulated blast furnace slag (GBFS) is formed by quenching molten slag in water to form sand-sized particles of glass⁷. When very finely ground, “ground, granulated blast furnace slag” (GGBFS) has moderate hydraulic cementitious properties. If it can access free lime during hydration, GGBFS’s cementitious properties become strong⁸. For this reason, GGBFS is blended with Portland cement to produce Portland slag cement. Substituting GGBFS for ground clinker reduces the amount of clinker in the finished cement and the corresponding emissions associated with producing the clinker.

The use of GGBFS in cement blends is common practice for both environmental and economic reasons. The Slag Cement Association reports annual compound growth in U.S. slag cement shipments of 12.7 percent between 1996 and 2006 (compared to 3.4 percent for Portland cement), with total shipments for its member companies of 3.62 million metric tons in 2006⁹. (These figures include blended cements and slag cement shipped as a separate product.)

Slag Cement in California

Increasing the use of GGBFS could result in significant reductions in greenhouse gas emissions associated with cement production, as described in the Task 3 report under this work authorization. Reducing the clinker content of cement by 10 percent in California would result in the reduction in the California cement industry’s GHG emissions by more than a million tonnes per year. The ability to use GGBFS in blended cement to achieve such reductions is largely dependent on the demand for such cement, as well as the cost and availability of GGBFS in the state.

U.S. processors of GGBFS are listed in Table 3. This table lists the name and location of the processor as well as the name of the steel company that is the source of the slag. When the company is designated as “foreign,” the facility imports unground granulated blast furnace slag from various steel companies and grinds it onsite. When the source is described as “domestic,” the unground slag comes from the domestic market but is not from a service contract with a particular steel mill.

⁷ 2006 Minerals Yearbook: Slag—Iron and Steel, U.S. Geological Survey, December 2007.

⁸ Ibid.

⁹ *U.S. Slag Cement Shipments: Continued Expansion of Blended Cement Fuels Record Year for Slag Cement Shipments in 2006*, Slag Cement Association, Woodstock Georgia, Web page accessed May 10, 2008.

Table 3. Processors of Granulated Blast Furnace Slag in the United States

Slag Processing Company	Processing Plant Location	Steel Company Serviced
Buzzi Unicem USA, Inc.	New Orleans, LA	Foreign, some domestic.
Dragon Products Co., Inc.	Thomaston, ME	Miscellaneous domestic and foreign
Essroc Corp.	Middlebranch, OH	Miscellaneous domestic and foreign
Hanson Slag Cement, Inc.	Cape Canaveral, FL	Foreign
Florida Rock Industries, Inc.	Tampa, FL	Foreign
Fritz Enterprises, Inc.	Fairfield, AL*	U.S. Steel LLC
Holcim (US) Inc.	Birmingham (Fairfield), AL*	U.S. Steel LLC
	Gary, IN	U.S. Steel LLC
Lafarge North America Inc.	Joppa, IL	Mittal Steel USA
	South Chicago, IL	Mittal Steel USA
	East Chicago, IN	Mittal Steel USA
	Sparrows Point, MD	Mittal Steel USA
	Lordstown, OH	Old slag pile site
	Seattle, WA	Foreign
Lehigh Cement Co.	Evansville, PA	Foreign
Lehigh Northeast Cement Co. ⁶	Cementon, NY	Foreign
	Gary, IN	U.S. Steel LLC
Rinker Materials Corp.	Miami, FL	Foreign
St. Lawrence Cement, Inc.	Camden, NJ	Foreign
St. Marys Cement, Inc.	Detroit, MI	Foreign
	Milwaukee, WI	Foreign, some domestic.

* Fritz Enterprises operates the granulator, but Holcim owns the apparatus and markets the slag.

Source: 2006 Minerals Yearbook: Slag-Iron and Steel

All but one of the slag processors in the United States are located from the Mississippi River eastward. This should not be surprising since all of the blast furnaces in the United States are located east of the Mississippi. Only four blast furnaces in the United States produce granulated blast furnace slag that may be ground¹⁰, as the blast furnace at Mittal Steel's Weirton plant has been permanently shut down¹¹. Therefore, the use of domestically produced granulated blast furnace slag in blended cement in California would require shipping the slag considerable distances, most likely by rail. As in the shipment of coal and other mineral commodities, the shipment of slag long distances would add considerably to the cost.

Table 3 does list one processor of slag on the West Coast. Lafarge operates a facility using foreign-sources slag in Seattle, Washington. According to a company representative¹², this facility has the capacity to grind 500,000 tonnes of slag or cement clinker per year. Since it is located at a cement plant, it is used for both purposes. The facility has excess grinding capacity for slag, as it is currently grinding about 200,000 tonnes per year. While some of the remaining capacity is used for cement grinding, if demand for slag grinding were sufficient, the company could use the plant solely for slag grinding and produce cement at its other facilities.

Most of the ground slag produced by the Lafarge facility is used in the Oregon and Washington markets, although it has begun to supply ground granulated blast furnace slag to suppliers of the ready-mix concrete market in California. All of the unground slag processed at the facility is imported from Japan, as rail transport of slag from the eastern United States is not considered economical. The slag imported from Japan serves as return cargo for ships used to export lumber from the United States to Japan.

The U.S. Geological Survey (USGS) reports that imports of granulated blast furnace slag (most of it unground) amounted to 1.1 million tonnes in 2005 and 2006 (based on U.S. Census Data)¹³. The leading sources of imported granulated slag were Canada (35%), Italy (28%), Japan (24%), and France (4%). The agency notes that Commerce Department data indicate substantially more imports – about 3.0 million tonnes per year, and its own canvass survey data indicate that imported slag accounts for a total of 1.7 million tonnes out of total U.S. sales of 4.2 million tonnes in 2006. The report also suggests that sales of granulated slag in the United States may have been closer to 5.5 million tonnes in 2006 instead of the 4.2 million tonnes because importers are not included in the USGS canvass data.

Mexico is not listed among the countries from which granulated blast furnace slag is imported. One blast furnace there is located closer to California than any other. Mittal Steel's Lazaro Cardenas plant on the Pacific coast of Mexico produces approximately 400,000 tonnes of granulated blast furnace slag per year. While at least some of this is currently committed to customers, it is not believed that longer term contracts are in place for most of it¹⁴. Thus, this steel mill represents a potential source of unground granulated blast furnace slag in the state.

¹⁰ Ibid.

¹¹ Osborn, Jonathan, Business Analyst, ArcelorMittal USA, personal communication, April 17, 2008.

¹² Cleary, Patrick, Lafarge North America, personal communication, May 28, 2008.

¹³ Ibid.

¹⁴ Osborne, Jonathan, 2008.

Unfortunately, during the course of this study, the company was unable to provide additional details on the potential availability of this slag for export to California.

Slag Cost

Granulated blast furnace slag is the most valuable form of slag produced by the iron and steel industry, particularly when it is ground. The USGS reports a price range of \$19.29 - \$94.80 per ton for 2006, with the low end for unground slag and the high end for GGBFS, and the same price at the high end was reported in a January 2008 USGS¹⁵.

Due to their location, cement plants in California would be expected to pay much more for unground, granulated blast furnace slag than the low end of the range indicated above. Since all blast furnace slag on the West Coast is imported, the cost of imported slag is more relevant than national average costs. The USGS reports that the average cost of imported, granulated slag was \$54.24 per ton in 2006 (and \$47.90 per ton in 2005), including insurance and freight¹⁶. Since most of the imported slag is unground, this figure may be taken as a rough indication of the cost of unground, granulated blast furnace slag imported into California.

The price of ground granulated blast furnace slag approaches that of Portland cement. According to a Lafarge representative¹⁷, it sells for 90 to 95 percent of the cost of Type 1 or Type 2 Portland cement, or roughly \$115 per ton at today's prices in California and close to \$90 per ton in the state of Washington.

To produce GGBFS as a substitute for cement, the unground granulated blast furnace slag has to be ground to sufficient fineness. There are two approaches to doing this: Constructing a stand-alone grinding facility specifically for the process, or grinding the slag in the finish mill of a cement plant, either in conjunction with or separately from the grinding of the cement clinker.

The cost of separately grinding granulated blast furnace slag has been estimated to be \$15 per ton¹⁸. According to the USGS, a stand-alone slag grinding facility does not currently exist in California. If one were constructed and could grind the slag at a cost of \$15 per ton, based on the cost of imported, unground, granulated blast furnace cited above, the total cost of GGBFS in California would be \$69.24 per ton. The USGS reports that GGBFS sells at a 20 to 25 percent discount to Portland cement¹⁹ (somewhat less than what Lafarge reports). Using a cement price of \$102 per ton²⁰, this means the price of slag would be expected to fall into the range of \$76.50 to \$81.60 per ton, suggesting that the importation and grinding of granulated blast furnace slag in California could be economically competitive even based on the lower price of GGBFS reported by the USGS.

¹⁵ U.S. Geological Survey, Mineral Commodity Summaries: Iron and Steel Slag, January 2008.

¹⁶ *2006 Minerals Yearbook: Slag – Iron and Steel*.

¹⁷ Cleary, Patrick, 2008.

¹⁸ Osborne, Jonathan, 2008.

¹⁹ *2006 Minerals Yearbook: Slag – Iron and Steel*.

²⁰ U.S. Geological Survey, Mineral Commodity Summaries: Cement, January 2008.

The grinding of blast furnace slag at cement plants California would eliminate the need for a stand-alone grinding facility for unground, imported slag. It would, however, entail added costs for process modifications at the plants. Because slag is harder than clinker and must be ground finer, it requires more grinding energy and leads to greater wear on grinding equipment. The moisture content of the unground slag also has to be considered, since depending on the plant configuration and the amount of slag to be mixed with the clinker, the slag may need to be pre-dried before being ground.

The two principal costs associated with slag grinding in cement plants are the increased cost of maintenance to the grinding systems due to the greater wear, and the increased electricity consumption for the slag grinding. Both of these factors depend on the type of grinding mill used. Fortsch reports that a slag of average hardness typically requires 65-69 kilowatt hours (kWh)/ton to grind to 5500 cm²/g Blaine, (a measure of fineness) as compared to 36 kWh/ton to grind clinker of average hardness to 3800 Blaine²¹. At 8 cents per kWh, this translates into an additional electricity cost of approximately \$2.50 per ton of GGBFS. Because ball mills are less efficient than roller presses or vertical roller mills, this figure should be considered to be at the high end of the electricity cost differential.

Increased costs will also result from hardening the grinding surfaces to handle the slag or from more frequent replacement of surfaces that are not modified. There will also be increased costs for storage and delivery systems for the ground slag (unless such equipment is already in place). According to Worrell and Galitsky²², an investment cost of \$0.65 per ton of cement capacity can be expected for delivery and storage systems needed to produce blended cement, while other costs would be expected to vary from plant to plant and would need to be assessed on the basis of individual plants.

Emissions Benefits

The emission reductions that result from displacing cement with GGBFS are directly proportional to the amount of cement displaced. The GHG emissions intensity of cement production in California, reported by the ARB to be 0.87 tonnes of CO₂ per tonne of cement²³. This figure would be reduced by the emissions associated with the additional electricity needed for slag grinding, which, according to the figures given above for grinding in ball mills, would amount to 31 kwh * 385 g/kWh²⁴ = 12 kg CO₂ per ton. This would have only a slight effect on the emissions benefit, reducing it to 0.86 tonnes of CO₂ per tonne of cement displaced.

²¹ Fortsch, David, 2005. "Modern Slag Grinding," *World Cement*, September 2005.

²² Worrell, Ernst, and Christina Galitsky, *Energy Efficiency Improvement Opportunities for Cement Making: An Energy Star Guide for Energy and Plant Managers*. Lawrence Berkeley National Laboratory, January, 2004. LBNL-55036.

²³ Pyle, Tom, CAT Cement Sub-Group Leader, Industry Background and Overview, Presentation at the ARB Cement Working Group meeting, April 10, 2008, Sacramento, California.

²⁴ Schwyzer, Diana, California Energy Commission, personal communication January 18, 2008.

The calculations above do not consider emissions associated with the transport of the slag. Without knowing the distances the slag might travel and the mode of transportation, it is not possible to include such differences in the calculation. Based on the analysis for fly ash, which is presented in Case Study 4, differences in transportation-related emissions are not expected to significantly affect the results.

Conclusions

California has the potential to significantly increase its consumption of cement blended with ground, granulated blast furnace slag resulting in reduced GHG emissions. The Lafarge slag grinding facility in Seattle has unused capacity of approximately 300,000 tons per year, which could be used to meet demand in California. Cement plants in California could also provide additional grinding capacity, but this would require the shipment of the imported slag to them and its subsequent distribution to ready-mix suppliers. In either case, use of blended cement requires additional storage silos for the ground granulated slag prior to its use to make concrete.

Key to increasing the use of slag-blended cement in California is greater acceptance in the marketplace. While slag-blended cement has been used for years in the eastern United States where blast furnaces are located, it is not as well-known on the West Coast²⁵. Slag-blended cement is beginning to be used within California, however, as cement purchasers who recognize its environmental benefits specify its use in their contracts.

Slag-blended cement is a cost-effective way to reduce GHG emissions as the ground granulated blast furnace slag is priced at less than the Portland cement it displaces. Therefore, the end-user need not experience any price increase for using it and the cost of emission reductions would be zero or less per tonne of emission reduction.

²⁵ Cleary, Patrick, 2008.

CHAPTER 5: Case Study 4—Fly Ash-Blended Cement

Background

Fly ash is the non-combustible residue that is contained in the flue gas from combustion processes. Most fly ash in the United States is produced by coal-fired power plants. Because fly ash is cementitious, it may be used in place of Portland cement in the production of concrete.

According to the American Coal Ash Association, 72.4 million tons of fly ash were produced in the United States in 2006²⁶, of which approximately 45 percent were used in various applications. The single largest use category is “concrete/concrete products/grout,” which accounted for 15.0 million tons, just less than 21 percent of the total fly ash produced. An additional 4.15 million tons, or 5.7 percent of the total produced, were used as raw material in the production of cement clinker.

Fly Ash in Cement

Fly ash may be blended with cement at the cement manufacturing plant or at the place where the concrete is produced, most commonly a ready-mix concrete batch plant where cement is mixed with water and other constituents to make concrete. This wet concrete is typically transported to the place where the concrete is to be used using a truck called a “transit mix truck”.

This case study focuses on the use of fly ash to produce blended cement. Although fly ash can and is used as a raw material in the production of cement clinker, its principal benefit in reducing greenhouse gas emissions from the production of concrete comes from its direct use as a component of blended cement. This is so because using the fly ash directly in blended cement does not require heating to high temperature in the cement kiln. Indeed, the largest distributor of fly ash in the state was unaware of any California cement plants that used fly ash as a raw material, stating that concrete and concrete product manufacturers were responsible for all of the fly ash used in the production of concrete in the state²⁷.

Except for cement that is bagged, blending at a ready-mix plant rather than the cement plant is the preferred option because it provides more flexibility on the proportion of fly ash in the blend, which may range up to 40 percent depending on the application. If a cement plant produces a bulk cement product with a specific fraction of fly ash in it, specifications and codes will often prohibit the introduction of additional cementitious material at the ready-mix plant,²⁸ thus limiting the market for the blended cement. For this reason, the discussion below focuses

26 American Coal Ash Association, *2006 CCP Production and Use Survey*. Aurora, Colorado, August 2007.

27 DeCarlo, Drew K., Headwaters Resources, Riverside, CA, personal communication, May 7, 2008.

28 Ibid.

on the use of fly ash as a cement substitute to produce concrete at ready-mix concrete batch plants.

Emissions Benefits

The emission reductions that result from displacing cement with fly ash are directly proportional to the amount of cement displaced. The U.S. EPA reports a figure of 0.87 metric tons of CO₂ emission reductions per short ton (2000 lbs) of fly ash consumed²⁹. This figure takes into account the transportation-related emissions of moving fly ash and cement to the concrete mixing plant. In the EPA analysis, however, the transportation-related emissions for fly ash and cement are calculated to be the same. Therefore, the emission reductions are due solely to reductions in the emissions associated with the production of the cement that is displaced.

The EPA emission reduction figure of 0.87 tonnes of CO₂ per ton of fly ash is the same on a per-ton-of-cement-displaced basis, since fly ash is taken to replace cement on a one-to-one basis³⁰. This figure is equivalent to 0.96 tonnes of CO₂ per tonne of fly ash used (or cement displaced) when the emission reductions and fly ash consumption are both expressed in terms of metric tons. This figure is somewhat greater than the average GHG emissions intensity of cement production in California, which is reported by the ARB to be 0.87 tonnes of CO₂ per tonne of cement³¹. Because this figure is more representative of cement manufacture in California than the average used in the EPA report, it would also more accurately represent the emissions benefits from displacing cement with fly ash during the production of concrete in California.

Mercury and Other Heavy Metals in Fly Ash

Coal combustion results in the volatilization of the mercury contained in it. The mercury may be emitted as vapor or as part of the fly ash. One of the means of reducing emissions from coal combustion at power plants is to inject powdered activated carbon to adsorb the mercury and subsequently remove the carbon with the plant's particulate control system, which also removes the fly ash from the flue gas. The result of using this technique is that more carbon and more mercury end up with the fly ash.

Concerns have been raised about the fate of mercury that is introduced into concrete made with fly ash-blended cement. The literature reviewed for this case study indicates that it has little environmental significance because it is retained in the concrete.

²⁹ Background Document for Life-Cycle Greenhouse Gas Emission Factors for Fly Ash Used as a Cement Replacement in Concrete. U.S. Environmental Protection Agency, EPA530-R-03-016, November 7, 2003.

³⁰ Ibid.

³¹ Pyle, Tom, 2008.

The Portland Cement Association has reported on the mercury and lead content of raw materials used in cement manufacture, including fly ash³². While these results are for fly ash introduced into cement kilns, the author expects they would be the same for fly ash used in blended cement. Table 4 lists the results for 16 samples tested.

To put the figures in Table 4 in perspective, the median mercury concentration in fly ash was greater than in any of the other cement raw materials, and twice the median concentration in recycled cement kiln dust, the raw material having the second highest median concentration of mercury. The mean concentration of mercury in fly ash was lower than the mean concentration in the recycled cement kiln dust, due mainly to some outliers in the cement kiln dust data, but even when they were removed, the mean mercury concentration in the cement kiln dust was somewhat greater than in the fly ash (253 versus 205 ppb).

Table 4. Mercury and Lead Concentrations in Fly Ash

Metal	Number of Samples	Mean Concentration, ppb	Median Concentration, ppb
Mercury	16	205	136
Lead	16	33.3	28.2

Source: PCA, 2006³³

In contrast, the lead concentrations in fly ash tend to be in the middle of the raw materials used in the manufacture of cement. While most natural products such as limestone, sand, and clay were shown to have lower lead concentrations, most of the residues from manufactured products, such as mill scale, recycled cement kiln dust, and silica, as well as iron ore, had concentrations that were greater.

Mercury Volatilization and Leaching From Concrete Made With Fly Ash

A number of studies have been performed on the behavior of mercury in fly ash as well as concrete manufactured with fly-ash blended cements. For concrete that is exposed to aqueous environments, the potential for mercury to leach out of the concrete into the water has been studied. For concrete exposed to air, the potential for volatilization has been assessed.

Liu (2007)³⁴ reported on the results of mercury vapor emissions from bricks made almost entirely of fly ash having mercury concentrations less than 100 ppb. His results indicated that

³² Hills, Linda M., and Richard W. Stevenson, PCA R&D Serial No. 2888, Mercury and Lead Content in Raw Materials. Portland Cement Association, Skokie, Illinois, 2006.

³³ Ibid.

the bricks did not emit mercury into the atmosphere and instead actually adsorb it on their surface from the atmosphere. Additional tests were reported to be planned with bricks made from fly ash containing greater concentrations of mercury.

Most studies of the leaching behavior of fly ash have focused on the fly ash itself. Sanchez et al³⁵ concluded that mercury is strongly retained by coal combustion residues (fly ash) and unlikely to be leached at levels of environmental concern. When leaching was observed, it was not dependent on total mercury content of the fly ash, leaching pH, or liquid-to-solid ratio. Reported mercury concentrations in laboratory extracts ranged from not detected (at 0.01 µg/L) to 0.2 µg/L.

The same study concluded that arsenic and selenium may be leached at levels of potential concern from fly ash that comes from facilities with and without mercury control technology (e.g., sorbent injection). The authors recommended further study of the leaching behavior under site-specific conditions in these cases.

Kim³⁶ also reports that very little mercury can be extracted from fly ash. In tests lasting from 30 to 180 days with five different leachant solutions, she reported that it was unlikely that the mercury solubility could exceed water quality standards.

Similar results were reported on mercury leaching by Senior³⁷, who reported on leaching from fly ash obtained from three coal-fired power plants burning coals of different rank and composition, having different particulate control devices, and operating under different conditions – but all using the same powdered activated carbon for mercury removal. Little or no detectable mercury was found to be leached from any of the ash samples using two different leaching procedures (TCLP or SGLP) for any of the ash samples. The amounts of mercury leached from these samples were reportedly about 1/100 of the primary drinking water standard. At a plant whose fly ash was tested with and without the injection of powdered activated carbon, the injection did not seem to have increased the amount of mercury leached from the ash.

Regenitter³⁸ also used TCLP and SGLP leaching procedures on fly ash and concluded that mercury is strongly retained on the fly ash. She found that mercury from fly ash subjected to

³⁴ Test of Mercury Vapor Emission from Fly Ash Bricks: Important Finding. Presentation at the Portland Cement Association Fall Meeting's Annual Technical Session Chicago, Illinois, September 11, 2007.

³⁵ Sanchez, F. et al. Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control EPA/600/R-06/008, January 2006.

³⁶ Kim, Ann, Aqueous Stability of Mercury on Fly Ash. National Energy Technology Laboratory, Mercury Control Technology R&D Program Review, July 15, 2004.

³⁷ Senior, Constance, Characterization of Fly Ash from Full-Scale Demonstration of Sorbent Injection for Mercury Control on Coal-Fired Power Plants. presentation at the 28th International Technical Conference on Coal Utilization & Fuel Systems, Clearwater, FL, March 10-13, 2003.

³⁸ Regenitter, Ellen. Release of Mercury During Leaching of Fly Ash, An Honors Thesis Presented in Partial Fulfillment of the Requirements for Graduation with Distinction in the College of Engineering at The Ohio State University 2007.

leachate solutions such as those found in municipal landfills and natural precipitation is low and almost undetectable using modern testing technology. She also concluded that the additional analyte elements identified in the analysis of data ensures that fly ash material used in concrete, once subjected to leaching, are not harmful, although she did not report what these additional analytes were. Where some leaching of fly ash did occur, she concluded that its effects do not pose public health risks. The level of mercury in leachate from fly ash material was so low that it was nearly undetectable.

Although most studies of mercury and other heavy metal leaching from fly ash are based on tests of the fly ash itself, of greater interest is the behavior of concrete made with fly ash containing mercury. McCann et al.³⁹ report on tests done with fly ash from a circulating fluidized bed coal and alternative fuel-fired cogeneration facility in Hawaii. Because some samples of fly ash exceeded permit limits for mercury (0.25 µg/L) as determined using the Synthetic Precipitation Leaching Procedure, tests were conducted to determine leaching when the fly ash was incorporated into concrete products. The study found that even when the fly ash itself exceeded the permit limit, no detectable mercury was found to be leachable from concrete containing the fly ash. The study suggested that based on the absence of any detected mercury in the concrete, the mercury in the fly ash would not limit the quantity of fly ash that could be used in the concrete (up to 90 percent cement replacement). As a result of the study, the Hawaii Department of Health proposed to increase the permit limit for mercury leached from the fly ash from 0.25 µg/L to 5.5 µg/L.

Conclusions

The issue of mercury in fly ash and its potential for leaching when fly ash is blended with cement is an appropriate area of concern, given the increasing mercury content of fly ash, and one that has undergone considerable study. The studies reviewed for this report indicate that leaching of mercury from fly ash used in blended cement does not occur at levels that are of environmental concern. Aside from one study that raised the possibility of leaching of arsenic and selenium, the leaching of other metals from fly ash also do not appear to pose problems. That particular study focused on leaching from fly ash itself, rather than concrete made from fly ash-blended cement, suggesting that additional study may be warranted.

The expanded use of fly ash blended cement in California is largely dependent on customer acceptance. Such acceptance, in turn, partially depends on the modification of government codes and specifications to allow greater use of fly ash-blended cement. Efforts in these areas should be encouraged to allow greater use of fly ash-blended cement.

Since fly ash suppliers set the price at less than the Portland cement it displaces, the use of fly ash-blended cement can result in a reduction in emissions at no cost to the end user. Indeed, the use of fly ash-blended cement is already increasing in California. The largest supplier of fly ash in the state is investing in a new terminal in Southern California to significantly increase its

³⁹ McCann, Robert, et al., "Risk Evaluation of Leachable Mercury from Concrete Products Made With Fly Ash," 2007 World of Coal Ash conference, Covington, Kentucky, May 7-10, 2007.

ability to supply the market⁴⁰. While the potential supply of fly ash from power plants is not an issue, reliable rail delivery is. Construction of this terminal is expected to provide a larger and more reliable supply of fly ash to concrete producers.

⁴⁰ DeCarlo, Drew K., 2008.

CHAPTER 6: Case Study 5—Biomass Combustion In California Cement Kilns

Background

The substitution in cement kilns of conventional fossil fuels (principally coal) with biomass fuels can result in significant reductions in greenhouse gas emissions. As described in the Task 3 report under Work Authorization 5, a replacement of 10 percent of the fossil fuel with biomass fuel in California cement kilns would reduce emissions by over 400,000 tonnes (metric tons) per year. This reduction occurs because the CO₂ emissions from burning biomass are the result of carbon that has relatively recently been removed from the atmosphere through uptake by plants, and therefore these emissions are not counted in GHG emissions inventories.

Biomass Combustion in Cement Kilns

Several different types of biomass are burned in cement kilns around the world⁴¹ including:

- Animal meal
- Animal grease
- Sawdust
- Wood chips
- Dry sewage sludge
- Rice husks
- Seeds
- Paper waste
- Municipal waste

These wastes may be burned in conjunction with conventional fossil fuels, namely coal, as well as other alternative fuels, such as plastic wastes, that are based on fossil fuels. Vaccaro⁴² reports up to 100 percent of the firing of cement kilns may be with alternative fuels, though it is not believed that all of these alternative fuels are biomass.

The substitution of fossil fuels with biomass fuels at cement kilns requires different types of changes, depending on the type of fuel used. In general, storage and handling facilities will be needed for the biomass fuels, unless they are already available for the conventional fuels used at the plant. Changes may also be required to the burner used in the kiln.

According to a supplier of cement kiln burners, pulverized dry biomass waste can be handled like pulverized coal in a pneumatic conveying system and blown through a conventional burner – a concentric annular channel surrounding a flame stabilizer – provided the waste fuel

⁴¹ Vaccaro, Max, 2006. Boosting Alternative Fuel Firing. *World Cement*, August 2006.

⁴² Ibid.

is not sticky⁴³. If the alternative fuel is lumpy, fluffy, or fibrous, however, a great risk of developing deposits and plugging of the burner results.

One example of biomass firing with minor plant modifications is provided by Mackes and Lightburn⁴⁴, who report on the successful testing of green wood chips at a Colorado cement kiln, as well as earlier tests with dry wood chips and wet and dry sawdust. The tests with the dry wood chips and sawdust were reported to go well. However, feeding of wet sawdust in the calciner was not successful.

Green wood chips were added to the raw mill and the coal mill of the Colorado cement plant. The raw mill was modified by adding a chute to allow the mixing of the wood chips with the crushed rock entering the raw mill. The wood chips were able to completely replace the coal normally fed with rock entering the raw mill.

Green wood chips were also mixed with equal parts coke. A mixture of 85 percent coal and 15 percent wood chips and coke were pulverized in the coal mill. The pulverized mixture was fed to all the normal plant firing points, without any modifications. The authors estimate that green wood chips could replace up to 10 percent or more of the coal used in the coal mill, merely by adding the chips to the coal bin. Significant process changes would be required to use a greater proportion of wood at all firing points.

Biomass in California

Within California, significant biomass resources are available. The California Biomass Collaborative⁴⁵ estimates a gross production of 89 million bone dry tons (BDT) in 2010, with 35 million BDT technically available. (Technical biomass potential refers to the amount of biomass that is actually available on a sustainable basis, and generally amounts to about one-third of the gross biomass potential.) Figure 1 shows the gross biomass potential in 2005 by county and the approximate location of the 11 cement plants within the state. As this figure shows, all of the cement plants are located in or near counties that produce significant quantities of biomass.

As a point of reference, the California Energy Commission reports that 30.8×10^{12} Btus of coal were consumed by California cement plants in 2002⁴⁶, which translates into 1.4 million tons if it is assumed that the coal has a heating value of 11,000 Btu/lb. Replacing 10-20 percent of the coal (140,000 to 280,000 tons) with biomass at California cement plants would require only a small fraction of the technically available biomass resources that are available, even when the lower heating value of biomass fuels are accounted for.

⁴³ Ibid.

⁴⁴ Mackes, Kurt, and Charles Lightburn, "Evaluating the Use of Green Wood Chips Processed from Small-Diameter Trees as an Alternate Fuel for Making Cement." *Forest Products Journal*. April 2003.

⁴⁵ California Biomass Collaborative, 2006, "An Assessment of Biomass Resources in California, 2006"; Draft Report. California Energy Commission Contract 500-01-016, December 2006.

⁴⁶ California Energy Commission, 2006. *Inventory of Greenhouse Gases and Sinks: 1990-2004*. Staff Final Report. CEC-600-2006-013-SF. December 2006.

The potential competition for biomass resources for combustion in California should be recognized. In April 2006, Governor Arnold Schwarzenegger signed Executive Order S-06-06, which commits the state to generate 20 percent of its (in-state) electricity with biomass⁴⁹. This is expected to require an additional biomass generating capacity of 575 and 1975 megawatts in 2010 and 2020, respectively. This additional generating capacity will likely consume some biomass that would otherwise be available to cement kilns.

Biomass Cost

The economics of burning biomass in California cement kilns depends on the difference in delivered cost between the biomass fuel and the coal being displaced, and the cost of any changes needed at the plants to allow the biomass fuels to be burned. The U.S. Department of Energy reports that the average delivered cost of coal to California industries was \$57.63 per short ton in 2006⁵⁰. Because biomass wastes have heating values that typically range from 7000 to 9000 Btu per pound⁵¹ on a dry basis, as compared to 11,000 Btu per pound for coal, more biomass is needed to provide the same heating value as a given weight of coal. Using the figures cited above, 1.57 to 1.22 dry tons of biomass would be needed per ton of coal displaced. Therefore, the delivered cost of the biomass would have to be between \$36.70 and \$47.10 per ton on a dry basis to be competitive with the delivered cost of coal. The lower price would apply to biomass waste with a heat content of 7000 Btu/lb and the higher price to biomass with a heat content of 9000 Btu/lb, both on a dry weight basis. The higher price and heating value, as would apply to wood waste, is highly competitive with the figure of \$40 ton used by Williams et al.⁵² for assessing the potential for producing ethanol from wood wastes. These prices for fuel at cement plants are based on the assumption that any capital costs for plant modifications to burn the biomass waste are negligible.

Emissions Benefits

The emission reductions that result from displacing coal with biomass fuels are directly proportional to the amount of coal displaced. The average carbon content of bituminous coal is 80.1 percent,⁵³ which translates to CO₂ emissions of 2.94 tons of CO₂ per ton of coal displaced assuming complete combustion.

⁴⁹ *Bioenergy Action Plan for California: Progress to Plan*, California Energy Commission, July 2007, CEC-100-2007-006.

⁵⁰ U.S. Department of Energy, Energy Information Agency, Washington DC, *Average Price of Coal Delivered to End Use Sector by Census Division and State*. See: <http://www.eia.doe.gov/cneaf/coal/page/acr/table34.html>.

⁵¹ California Biomass Collaborative, 2006.

⁵² Williams, R.B, B.M. Jenkins, and M.C. Gildart, "Ethanol Production Potential and Cost from Lignocellulose Resources in California." 15th European Biomass Conference & Exhibition, May 7 to 11, 2007, Berlin, Germany.

⁵³ *North American Combustion Handbook*, 1986. *Volume I: Combustion Fuels, Stoichiometry, Heat Transfer, Fluid Flow, Third Edition*.

The change in transportation emissions should also be considered when considering the net reductions in GHG emissions. Most coal in California is imported from Utah; biomass is more likely to be moved by truck. Rail transport is approximately three times as fuel-efficient as truck transport⁵⁴ using the same diesel fuel, and thus has 1/3 the greenhouse gas emissions on a per-ton-mile basis. However, the travel distance is considerably longer. If the average rail distance from Utah is taken as 500 miles, and the average truck distance for biomass waste is taken as 100 miles, then the emissions from transportation of the biomass will be less than those of the coal displaced, provided the moisture content of the biomass is not too great.

The co-firing of biomass waste with coal in cement kiln can be done without increasing regulated pollutant emissions. In some cases, reductions in criteria air pollutants such as CO and NO_x have been observed with co-firing^{55 56}.

Emissions of toxic and particulate matter pollutants should also be reduced when biomass such as wood wastes, displace coal because wood contains less ash, sulfur, heavy metals (for example, mercury) than coal⁵⁷.

Conclusions

The use of biomass fuels in California cement kilns represents a large potential source of GHG emission reductions. As shown by the work of the California Biomass Collaborative, the available quantities of biomass in the state are far greater than the amount of biomass that could be consumed by the cement industry.

The technical feasibility to displace coal with biomass is assessed through test burns at the cement kilns. The experience of cement plants outside California has been promising, and use of biomass to meet at least part of the fuel demand is a common practice in the industry, particularly outside the United States.

The relatively high price of coal in California suggests that emission reductions may be achieved at relatively low or no costs. Using a figure of \$40/ton of biomass, and assuming 50 percent more biomass fuel would be needed to provide the same heating value as the coal suggests that GHG emission reductions from fuel combustion in the could be achieved at a cost of less than \$1/ton of CO₂.

At present, the *Bioenergy Action Plan for California* does not specifically address potential industrial consumers of biomass, such as cement plants. To better coordinate potential sources of bioenergy among electricity generators, biofuel producers, and industrial energy consumers,

⁵⁴ *Freight Railroads and Greenhouse Gas Emissions, 2008*. Association of American Railroads, Policy and Economics Department, February 2008.

⁵⁵ Vaccaro, 2006.

⁵⁶ Knies, Eric and Stephen Miller, 2003. Environmental Constraints. Cement Americas, November 2003.

⁵⁷ Mackes and Lightburn, 2003.

consideration should be given to expanding the scope of the action plan to promote biomass use in cement kilns, and possibly other large industrial energy consumers.

Glossary Of Terms

µg	Microgram, a metric unit of weight
ARB	Air Resources Board, a California air quality regulatory agency
BDT	Bone dry tons
Blaine	A measure of fineness related to particle size and used to determine cement quality
BTU	British Thermal Unit, a unit of energy
Calcine	To heat to a high temperature but without fusing in order to drive off volatile matter or to affect changes (such as oxidation or pulverization)
CDM	Clean Development Mechanism
Energy Commission	California Energy Commission
Cement	Binder used along with sand and rock to make concrete
Certified Emissions Reductions (CER)	A Certified Emission Reduction (CER) is the technical term for the output of Clean Development Mechanism (CDM) projects, as defined by the Kyoto Protocol . A unit of Greenhouse Gas reductions that has been generated and certified under the provisions of Article 12 of the Kyoto Protocol , the Clean Development Mechanism (CDM).
CO ₂	Carbon dioxide
CO ₂ e	Carbon dioxide equivalent
Concrete	A hard strong building material made by mixing a cementing material (such as portland cement) and a mineral aggregate (such as sand, gravel and rock) with sufficient water to cause the cement to set and bind the entire mass
Dalma Cement Limited	A cement-making plant located in India
DCBL	Dalmia Cement (Bharat) Limited
GBFS	Granulated blast furnace slag
GGBFS	Ground, granulated blast furnace slag

GHG	Greenhouse gas
L	Liter, a metric unit of volume
Mysore Cements Limited	A cement-making plant located in India
OPC	Ordinary Portland cement
PCA	Portland Cement Association
pH	A measure of acidity or basicity of a solution
Portland cement	A hydraulic cement made by finely pulverizing the clinker produced by calcining to incipient fusion a mixture of clay and limestone or similar materials
ppb	Parts per billion
PPC	Portland pozzolanic cement
SGLP	Synthetic ground-water leaching procedure
Short ton	Equals 2,000 pounds
TCLP	Toxicity Characteristic Leaching Procedure
Tonne	Metric ton (equals 0.9072 short tons)
USGS	U. S. Geological Survey