Final Project Executive Summary

Capture and Mineralization of Carbon Dioxide from Coal Combustion Flue Gas Emissions: Pilot Scale Studies at Jim Bridger Power Plant

K.J. Reddy
Department of Ecosystem Science and Management
College of Agriculture and Natural Resources
University of Wyoming

M.D. Argyle
Department of Chemical Engineering
College of Engineering and Technology
Brigham Young University

D.T. Taylor
Department of Agricultural and Applied Economics
College of Agriculture and Natural Resources
University of Wyoming

Jim Sedey
Jim Bridger Power Plant
Point of Rocks
Wyoming

Submitted to School of Energy Resources
University of Wyoming

Final Executive Summary

Coal and coal-fired power plants are crucial for supplying global energy demands. However, coal-fired power plants contribute significant amounts of carbon dioxide (CO_2) to the atmosphere through flue gas emissions. In addition, coal-fired power plants also produce significant quantities of fly ash and bottom ash as by-products. To minimize coal combustion flue gas CO_2 emissions, technologies that are cost-effective and environmentally acceptable are required. Current CO_2 capture and separation technologies include membrane separation technologies, sorbent technologies involving pressure or temperature swing processes, and use of solvents such as monoethanolamine. The CO_2 storage or sequestration processes include geologic sequestration, storage in oil and gas reservoirs, and mineral carbonation. However, these CO_2 capture, separation, and storage processes have limitations for widespread practical use due to the requirement of separation of CO_2 from flue gas and compression and transportation of CO_2 to a site where it can be safely stored or mineralized. Furthermore, CO_2 separation and capture technologies are limited by the flue gas SO_2, because SO_2 is known to affect the performance of amines, sorbents, and membrane filters.

Aqueous mineral carbonation (AQMC), a process of converting CO_2 into solid carbonates (mineralization) using silicate minerals and/or industrial solid wastes, has been studied extensively. However, most of the AQMC studies have been largely investigated at laboratory scale. In addition, AQMC process is energy intensive and it is not practical for filed applications. The objectives of this research were to 1) design and develop a pilot scale study at Jim Bridger Power Plant (JBPP), Point of Rocks, WY for direct mineralization of flue gas CO_2 using fly ash particles, 2) determine the effects of temperature and moisture content of flue gas in mineralization of flue gas CO_2, 3) determine the effect of flue gas CO_2 treatment on the mobility of trace elements including Hg (mercury), Se (selenium), and As (arsenic) in treated materials, and 4) evaluate cost economics of the proposed process.

A pilot scale accelerated mineral carbonation (AMC) process (as opposed to slurry, aqueous or storage processes) was designed and developed at JBPP. The AMC pilot process consists of - moisture reducing drum (MRD), blower unit, heater/humidifier, fluidized-bed reactor (FBR), screw conveying system, and industrial flue gas analyzer. The pilot scale AMC process was tested at JBPP by reacting flue gas with fly ash particles. The flue gas CO_2, SO_2, and NO_2 concentrations were monitored before and during the experiments by an industrial grade gas analyzer. Fly ash samples were collected from the reactor sample port from 0-120 minutes. Flue gas unreacted (control) and flue gas treated fly ash samples were analyzed for total inorganic carbon (C), sulfur (S), and mercury (Hg). Control and flue gas treated fly ash samples were analyzed with SEM-EDS (scanning electron microscope and energy dispersive spectrometry) to evaluate new mineral phases produced in flue gas treated fly ash samples. Control and flue gas treated fly ash samples were also subjected to metal water solubility, mineral fractionation, and US EPA TCLP (Toxicity Characterization Leaching Procedure) studies to determine the mobility of trace elements from flue gas treated fly ash samples. Results suggested that AMC process converted significant amounts of flue gas CO_2, SO_2, and Hg

into carbonates, gypsum, and $HgCO_3$, respectively. The SEM-EDS images revealed the formation of distinct new carbonate mineral structures in fly ash samples within few minutes of flue gas reaction. These carbonate minerals composed of Al, Ca, Mg, Na, Si, C, and S as shown by the EDS spectrum. Based on the formation of different carbonate minerals, and oxide content (Al, Ca, Fe, Mg, K, and Na) of JBPP fly ash, we estimate that AMC process could mineralize approximately 250 kg of flue gas CO_2 per tonne of fly ash. However with optimization of reactor design, better fluidization of ash particles and selection of optimum operating conditions, one can improve flue gas CO_2 mineralization capacity of fly ash particles. The results of metal water solubility and mineral fractionation studies suggested that AMC process effectively moved trace elements in the fly ash into insoluble factions. The flue gas treated fly ash samples met the TCLP requirements, and concentration of As, Ba, Cd, Cr, Pb, Se, Ag, and Hg in flue gas treated fly ash samples were well below the toxicity limits.

Results also suggest that AMC process is cost-effective ($6.25 per tonne of CO_2) with extremely low parasitic loads to operate, and it can be retrofitted to coal-fired power plants (existing and/or new) to minimize flue gas emissions into the atmosphere. All the inputs for the AMC process are available at the power plant. The process occurs at near ambient temperatures and pressures, thus minimizes the carbon footprint. The AMC process is a one-step dry process utilizing coal-fired power plant by-products (flue gas and fly ash). Flue gas CO_2 mineralized fly ash, through the AMC process, can be used as a concrete additive, soil amendment for reclamation of sodic soils and as containment materials for waste disposal sites.

The availability and potential of coal combustion ash to mineralize flue gas CO_2 were also examined in this study. The wt% of oxides in bituminous, sub-bituminous, and lignite ash was gathered from published data. Coal-fired power plants in US annually produce about 122 Mt of ash. Of this 35-40% is used for beneficial purpose (e.g., construction). However, if we use total 122 Mt, based on average oxide content of fly ash resulting from three coal types, we could annually mineralize approximately 41 Mt of flue gas CO_2. In addition, the coal ash that is available in US landfills since 1966 was also estimated from published data as a potential material to mineralize flue gas CO_2. The results suggest that coal-fired power plants in US alone produced approximately 3 Gt of total ash since 1966. Of this total ash about 810 Mt was used for beneficial purposes. Remaining 2.19 Gt of ash was disposed in landfills. This is a significant of amount of ash, which could potentially be used for flue gas CO_2 mineralization. Based on average oxide content of three coal types, we estimate that the 2.19 Gt of ash, which is available in landfills could potentially mineralize approximately 730 Mt of flue gas CO_2. The physical and chemical properties of the ash, amount that is available and close proximity of the landfills to power plants make these materials very attractive for flue gas CO_2 mineralization.

Wyoming supplies almost one third of the U.S. coal, which is used in 130 power plants in 27 states to generate electricity. Thus, Wyoming's coal is vital for the State's economy as well as for supporting ever increasing national energy demands. To sustain Wyoming's coal industry, novel flue gas CO_2 mineralization technologies that are economical and environmentally acceptable are required. The funds provided by the Clean Coal

Technology program helped us to develop a novel and cost-effective AMC process for coal-fired power plants. The pilot scale AMC process has been successfully tested at 2,200MW Jim Bridger coal-fired power plant. This process utilizes coal combustion by-products i.e., flue gas and fly ash particles to produce environmentally safe and stable minerals. The AMC process is useful not only to Wyoming but also for US and worldwide coal and power industries. However, further studies to increase the efficacy of AMC process and its integration into coal-fired power plant process are required. Such studies could be invaluable and provide vital data to accelerate the commercialization and of this technology to the industry.