A DOE R&D RESPONSE TO EMERGING COAL BY-PRODUCT AND WATER ISSUES IN THE ELECTRIC-UTILITY INDUSTRY

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ABSTRACT

While the regulation and control of air emissions will continue to be of primary concern to the electric-utility industry over the next several decades, other environmental-related issues may also impact the operation of existing and new coal-based power systems. Coal by-products are one such issue. Coal-fired power plants generate nearly 118 million tons of fly ash, flue gas desulfurization (FGD) solids, and other by-products each year, of which only 31.5% are put to beneficial use. The remaining 68.5% are disposed of in landfills and impoundments. Increased coal-based generation coupled with new air regulations will challenge the expanded beneficial-use of these materials. Water is another issue. U.S. thermoelectric power plants withdraw about 132 billion gallons of fresh water each day, more than any other sector except irrigation -- most of which is used for cooling. Competition from other users and possible future restrictions will require power plants to better manage how they use and impact freshwater resources.

This paper will discuss these potential issues and will provide a summary of the U.S. Department of Energy (DOE)/National Energy Technology Laboratory (NETL) current research and development (R&D) activities focused on: (1) the characterization and increased beneficial use of coal by-products and (2) the development of advanced water management concepts and technologies.

BACKGROUND

Coal Utilization By-products

Coal utilization by-products (CUBs) are produced by burning coal and include fly ash, bottom ash, boiler slag, and FGD waste materials. The American Coal Ash Association (ACAA) estimates that in 2001 a total of 118 million tons of coal utilization by-products (CUB)[a] were produced in the United States. Approximately 81 million tons (68.5%) of CUBs were disposed of in either landfills or impoundments, while about 37 million tons (31.5%) of the CUBs were recycled for use in a variety of beneficial applications. Some of the major beneficial applications for CUBs include use as a partial substitute for cement in concrete (fly ash), structural fill material (bottom and fly ash), blasting grit (boiler slag), and wallboard manufacture (FGD gypsum).

[a] There is no industry-wide recognized term to generically describe coal residues. DOE/NETL currently uses the term CUB to describe the various residues that result from either the combustion or gasification of coal. Previously, DOE/NETL used the term "coal combustion by-product" (CCB). The EPA uses the term "coal combustion waste" (CCW). The American Coal Ash Association, EPRI, and USWAG use the term "coal combustion product" (CCP).

The utilization of CUBs can provide significant economic benefits to coal-fired power plant operators. Based on ACAA estimates, the cost for CUB disposal ranges from $3 to $30 per ton, while the revenue for CUB utilization typically ranges from $3 to $35 per ton. As a result, the combined potential economic benefit for CUB utilization could range from $6 to $65 per ton. The wide range of costs and revenues is a result of location, disposal method, transportation, and market supply and demand.

Utilization of CUBs also provides secondary benefits such as reduced land requirements for disposal, conservation of natural resources, lower production costs for CUB users, and lower carbon dioxide emissions. Using fly ash as a cement substitute in concrete reduces the need for limestone calcination and associated fossil-fuel consumption in kilns used in making cement. As a result, each ton of fly ash used in concrete avoids approximately one ton of carbon dioxide (CO_2) emissions from cement production. The use of CUBs for surface and underground mine fill is also becoming an important application that can help minimize the environmental damage associated with acid mine drainage. In addition, utilization of CUBs for underground mine fill might help prevent mine subsidence.

In addition to relatively benign basic mineral components, CUBs from coal-fired power plants also contain trace amounts of toxic elements such as aluminum, arsenic, boron, cadmium, lead, mercury, and selenium. The U.S. Environmental Protection Agency (EPA) regulates the disposal and beneficial use of CUBs under the Resource Conservation and Recovery Act (RCRA) and currently categorizes CUBs as non-hazardous wastes under Subtitle D. Continued categorization of CUBs as a non-hazardous solid waste is an important factor in minimizing the cost of disposal and critical to CUB marketability for beneficial use applications.

Environmental regulations to reduce the emission of mercury, sulfur dioxide, and nitrogen oxide from coal-fired power plants will challenge CUB use in four respects. First, increasing concern over the fate of mercury and other trace metals removed from the power plant flue gas and captured in by-products will bring about increased scrutiny as to how these materials are to be utilized and disposed. Second, the installation of FGD technology to comply with SO_2 regulations could significantly increase the amount of solid material generated by coal-fired power plants. Third, the injection of sorbents such as activated carbon to control mercury could negatively impact the sale of flyash and FGD gypsum for cement and wallboard. Finally, NOx controls could also negatively impact the beneficial utilization of fly ash due to excessive levels of unburned carbon and/or ammonia

Power Plants and Water

Electricity production requires a reliable, abundant, and predictable source of water, a resource that is in limited supply in parts of the United States and much of the world. The process of electricity generation from fossil fuels such as coal, oil, and natural gas, as well as nuclear power, is water intensive -- each kWh generated requires on average approximately 25 gallons of water to produce[1]. This means that U.S. citizens may indirectly use as much or more water turning on the lights and running appliances as they may directly use taking showers and watering lawns.

Thermoelectric power plants are second only to agriculture as the largest domestic user of freshwater, accounting for 39% of all freshwater withdrawals in the nation. Based on the most recent U.S. Geological Survey data, fossil-fuel-based electricity generation withdrew more than 97 billion gallons per day of freshwater in 1995, primarily for cooling. Of the total freshwater withdrawn, more than 97% is returned to the source water body.[2] The 3% that is not returned is

"consumed", mostly through evaporation from wet-cooling towers into the atmosphere. In 2001, approximately 31% of steam electric generating units[b] were equipped with cooling towers, representing approximately 38% of installed generating capacity.[3]

Power plants with closed-loop (re-circulating) cooling system require from ½ to 1¼ gallons per kW to operate, while a plant using once-through cooling withdraws about 30 to 40 times more water on a gallon per kW basis. Although once-through systems withdraw significantly greater amounts of water (a 500 MW unit can withdraw approximately 450 million gallons per day), consumptive losses are significantly less, about 10% the consumption of a similar unit equipped with a wet-cooling tower.[c] In addition to increased water consumption relative to once-through systems, recirculating wet-cooling towers have an energy penalty associated with the additional pumps, fans, and auxiliary equipment, and can also require more extensive water treatment.[1]

As a growing economy drives the need for more electricity so will it increase pressure on the use of water for generating electricity. The demand for water by the electric-utility sector will increasingly compete with demands from other sectors of the economy such as agriculture, domestic, industrial, hydroelectric, public supply, mining, and in-stream use. Concern about competition over water rights in the western United States has lead the Department of Interior to recently announce a new R&D initiative to predict, prevent, and alleviate water supply conflicts.[4] Energy production will also compete for water on a global scale. A 2003 United Nations report recognizes that sufficient water resources must be made available to sustain the world's energy needs.[5]

Current and future requirements under the Clear Water Act (CWA) and Safe Drinking Water Act (SDWA) have the potential to impact the design and operation of fossil-fuel-fired electric generators. For example, the Total Maximum Daily Loads (TMDL) program may draw attention to non-point source pollution such as atmospheric deposition of air emissions from power plants. Recently proposed regulations under §316(b) of the CWA will likely limit the amount of water power plants use by requiring the installation of wet or dry closed-loop cooling systems and other measures in order to protect aquatic organisms. Drinking-water regulations that would require additional limits on arsenic and other trace metals could also affect how power plants dispose of coal by-products. Further, on a state or regional basis, the lack of available freshwater has prevented the siting and permitting of new power plants, not only in the water-challenged West but also in the eastern and southeastern United States.

The extraction of fossil fuels for power plants, such as coal mining and oil and gas production, can also have an impact on both the availability and quality of U.S. surface and ground water resources. Acid mine drainage and other water quality issues are often attributed to current and abandoned mining operations. The extraction of coal-bed methane (CBM) is the fastest growing area of domestic natural gas production. Large volumes of produced waters are associated with CBM and often present disposal issues.

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[b] Steam-electric generating units include regulated and unregulated fossil-fueled and combustible renewable-fired plants of 100 MW capacity and greater, representing a total nameplate capacity of 478 gigawatts.

[c] Comparison of consumptive loss is based on "on-site" water consumption represented as a net loss resulting from decreased return to the source water body. In addition to sensible heat transfer, wet-cooling towers provide evaporative cooling with evaporative losses to the atmosphere. Once-through systems return nearly all of the withdrawn water to the original source water body, but at a higher temperature. There will be some additional downstream evaporative losses due to the increased water temperature.

DOE/NETL INNOVATIONS FOR EXISTING PLANTS PROGRAM

A comprehensive, integrated environmental R&D program is being carried out under the DOE Office of Fossil Energy's Innovations for Existing Plants (IEP) program. The program, which is managed by DOE/NETL, encompasses both in-house and contracted research on advanced, low-cost environmental control systems and ancillary science and technologies that can help the existing fleet of coal-based power plants meet current and future environmental requirements. The program also provides high-quality scientific information on present and emerging environmental issues for use in regulatory and policy decision making. The research directly supports the Administration's Clear Skies Initiative and the May 2001 National Energy Policy recommendations concerning the environmental performance of coal-based power systems. Partnership and collaboration with industry, Federal and state agencies, research organizations, academia, and non-government organizations are critical to the success of the program.

The IEP portfolio includes bench-scale through field-scale R&D related to the control of mercury, nitrogen oxide (NOx), particulate matter, and acid gas emissions from power plants, as well as research in the area of ambient air quality and atmospheric chemistry, and solid by-products. In addition, in response to the growing tension between freshwater availability and quality and electricity production, the IEP program has been broadened to include research directed at power-plant related water management issues. The following sections will discuss two components of the IEP program, the solid by-product and the water management program components, in more detail.

DOE/NETL's CUB Research

The goal of the DOE/NETL CUB activity is to increase the percentage of coal by-products used commercially in the U.S. from current levels of about 32% to 50% by 2010. A portfolio of projects are being carried out that are focused on evaluating the potential fate of mercury and other trace metals during the disposal, processing, and utilization of CUBs. In addition, research is being conducted to characterize the impact of ammonia and activated carbon on by-product use and disposal. A description of each of these projects is provided below.

While this paper highlights DOE/NETL's environmental characterization research, the CUB program also sponsors a number of projects directed at developing new and expanding existing markets for coal by-products. Additional information on all of DOE/NETL's CUB projects can be found at: http://www.netl.doe.gov/coalpower/environment/ccb/index.html.

CUB Analysis from Activated Carbon Injection Mercury Control Field Demonstrations – *ADA-Environmental Solutions*

ADA-ES and Reaction Engineering have conducted an analysis of the ash by-products sampled during the field testing of activated carbon injection (ACI) conducted in 2001 and 2002 at four power plants.[6,7,8,9] The four plants sampled were Alabama Power's E. C. Gaston, We Energies' Pleasant Prairie, and PG&E's Brayton Point and Salem Harbor. Leaching analyses were conducted on the combined activated carbon-flyash by-products that were sampled during the ACI testing using the standard toxicity characteristic leaching procedure (TCLP) and another procedure developed by the University of North Dakota Energy and Environmental Research Center (UNDEERC) known as the synthetic ground water leaching procedure (SGLP). For the Gaston, Pleasant Prairie, and Salem Harbor ash samples the amount of mercury in the leachate was below the 0.01 µg/L measurement detection limit, with only two exceptions. Detectable

amounts of mercury in the range of 0.01 to 0.07 µg/L was leached from most of the Brayton Point samples. However, the results from all four plants indicate that amount of mercury leached from the samples is approximately two orders of magnitude lower than the 2 µg/L maximum contaminant level (MCL) for mercury under the federal EPA primary drinking water regulations.

CUB Analysis from Wet FGD Reagent Mercury Control Field Demonstrations *– Babcock & Wilcox/McDermott Technology*

In 2001, Babcock & Wilcox and McDermott Technology, Inc. (B&W/MTI) carried out full-scale field testing of a proprietary liquid reagent to enhance mercury capture in coal-fired power plants equipped with wet FGD systems.[10] The field testing was carried out at Michigan South Central Power's Endicott Station and Cinergy's Zimmer Station. The Endicott Station utilizes a limestone wet FGD system with in-situ forced oxidation, while the Zimmer Station utilizes a magnesium enhanced lime wet FGD system with ex-situ forced oxidation. Coal byproduct testing was conducted on fly ash, FGD gypsum, FGD centrifuge fines, and process waste water. For both plants the majority of mercury was found in the wet FGD slurry fines rather than the gypsum. There was no significant mercury detected in any of the process liquid streams. B&W/MTI also evaluated the by-product stream samples for their potential to volatilize mercury at elevated temperatures. Test results suggest that mercury will not be re-released into the environment from the gypsum during wallboard production.

Characterization of Coal Combustion By-Products for the Re-Evolution of Mercury into Ecosystems *– CONSOL Energy*

CONSOL Energy is conducting an extensive evaluation of the CUBs from 14 coal-fired power plants representing a range of coal ranks and air pollution control device configurations.[11, 12] Leaching and volatilization tests of bottom ash, fly ash, wet and dry FGD scrubber solids, and products from activated carbon injection tests are being carried out. Testing is also being conducted on products made from CUBs such as cement, gypsum wallboard, and manufactured aggregates. In addition, ground water monitoring wells at two CUB disposal sites will be evaluated quarterly over one-year for mercury leaching. Mercury leaching rates from the CUBs were measured using the standard TCLP. Preliminary results indicate that a minimal amount of mercury is leached from the CUBs with less than 1 µg/L of mercury detected. (Note: The primary drinking water standard concentration for mercury is 2 µg/L.)

Mercury volatilization tests are being conducted on CUB samples of ash, FGD solids, spray-dryer solids, manufactured aggregate, and FGD-gypsum wallboard using a procedure developed by CONSOL. Preliminary volatilization test results indicate there was no measurable release of mercury from any of the ash samples after six months of exposure. The project began in August 2000 and is scheduled for completion in December 2003.

Mercury and Air Toxics Element Impacts of Coal Combustion Byproduct Disposal and Utilization *– University of North Dakota Energy and Environmental Research Center (UNDEERC)*

UNDEERC is evaluating the potential release of mercury and other air-toxic elements during the disposal and beneficial use of CUBs. Laboratory and field-testing will be conducted on various ash and FGD by-products from conventional and advanced pollution control systems. CUBs from bituminous, subbituminous, and lignite fuels will be included in the evaluation. The potential release mechanisms to be evaluated include leaching, vaporization at ambient and elevated

temperature, and microbiologically induced releases. Results are not yet available. The three-year project is scheduled for completion by December 2005.

Speciation and Attenuation of Arsenic and Selenium at Coal Combustion By-Product Management Facilities *- Electric Power Research Institute (EPRI)*

EPRI is conducting a three-year investigation of the potential for groundwater impacts of arsenic, selenium, chromium, and mercury leaching from CUBs. Leachate sampling and testing will be conducted at approximately 25 active or closed CUB disposal sites. Three of the disposal sites will be selected for more detailed field investigations of arsenic and selenium leaching and attenuation. Results from this study are not yet available. The project is scheduled for completion by September 2005.

Fate of Mercury in Synthetic Gypsum Used for Wallboard Production *– US Gypsum*

USG Corporation is conducting a two-year study to measure potential losses of mercury from synthetic FGD gypsum during the wallboard manufacturing process. Testing will be conducted at three wallboard manufacturing plants using synthetic FGD gypsum produced from five power plants. The five power plants represent a broad cross-section of synthetic gypsum sources including bituminous- and Texas lignite-fired boilers, with and without NOx SCR controls, and limestone- and lime-FGD processes. The field testing includes mercury measurements of all input and output process streams in order to obtain complete mercury balances for the wallboard manufacturing plants. Samples of the synthetic FGD gypsum will also be evaluated in laboratory simulation tests as a means of comparison to the field measurements. In addition, TCLP leaching tests will be conducted on the wallboard products to determine potential mercury release in municipal landfills. The project is scheduled for completion by October 2005.

Potential for Mercury Release from Coal Combustion By-Products *- UNDEERC*

Since 1998, NETL has sponsored the Coal Ash Resources Research Consortium (CARRC), which is an international consortium of industry and government directed at increasing the use of CUBs. A recent CARRC project conducted by UNDEERC is investigating the level of mercury that would off-gas from various CUBs and the potential for microbiological activity to release mercury from CUBs.[13,14] Mercury vapor release tests were conducted on six fly ash samples at ambient and near-ambient temperatures and microbiological tests were conducted on two of the samples. The fly ash samples were from two PRB coals, two eastern bituminous coals, and two South African coals. Taking into account mercury release rate data from the test blanks, it was apparent that five of the six ash samples acted as mercury sinks, rather than releasing it. The testing is being repeated with additional ash samples in an attempt to verify the results. Results from the microbiological testing are not yet available.

Environmental Evaluation of Ash in Soil Stabilization *– UNDEERC*

Under another CARRAC project, UNDEERC and the University of Minnesota conducted laboratory and field investigations to evaluate the potential release of trace elements from the utilization of fly ash as a soil stabilizer. The project included laboratory evaluation of fly ash and soil composition, laboratory leaching of stabilized soil samples, and a field demonstration to evaluate runoff water quality. Fly ash from five Xcel Energy power plants in Minnesota were used in eleven commercial sites to stabilize soils in applications ranging from road subgrade to backfilling a utility trench. Overall, results of the laboratory and field demonstration testing

indicate the use of fly ash for soil stabilization applications to be environmentally viable. The project was completed in September 2001.

Environmental Characterization of CUBs *– DOE/NETL In-house*

DOE/NETL's Office of Science and Technology is carrying out research directed at (1) providing high-quality scientific information on the environmental characteristics of coal by-products and (2) developing new CUB end-use applications. The DOE/NETL in-house research projects are summarized below.

- ***Column Leaching Tests -*** Column leaching tests are being performed on CUB samples using seven different leachant solutions - deionized water, synthetic groundwater, synthetic precipitation, acetic acid, sodium carbonate, sulfuric acid, and ferric chloride.[15,16,17] Recent studies have focused on leaching CUB materials with "higher-than-normal" concentrations of mercury. The leaching tests vary in duration from 30 to 180 days and samples are taken every two to three days. Mercury analyses of the leachate are conducted using CVAA spectroscopy. Although the data appear to vary, with one exception, all of the leaching results indicate less than 0.001% of the mercury leached from the ash samples. The exception leached approximately 0.006% of the mercury using the sodium carbonate leachant.

- ***Rapid Leaching Protocol -*** The column leaching method test results are being used by to develop a simpler, short-term, rapid leaching protocol that can be used as a screening method assessing the leaching of trace metals from CUBs. The protocol includes a serial batch test using different liquid-to-solid (L/S) ratios at controlled pH's of 8, 4, 2, and the natural pH of the material, if higher than 8. Changes in leaching and the total amount of leaching as a function of time can be assessed by testing at different L/S ratios. The continuous addition of water to the CUB material simulates the cumulative addition of natural precipitation over a period of time. If successful, the rapid leaching protocol could provide leaching results in only two to three days.

- ***Mercury Adsorption Capacity of CUB –*** Tests are being conducted to measure the mercury adsorption capacity of various fly ashes. The analysis results in the calculation of adsorption isotherms for each fly ash sample that plot the amount of mercury adsorbed versus the amount of mercury in solution. Based on adsorption tests of two fly ash samples, it appears that lost-on-ignition or unburned carbon content is the most significant ash property affecting adsorption with high-carbon ash having a higher mercury adsorption capacity than low-carbon ash.

- ***CUB as Capping Material -*** A laboratory study was carried out to evaluate fly ash as an in-situ capping material for contaminated sediments.[18] The analysis used a contaminated soil from a zinc smelter and compared the potential release of zinc to overlying water using six fly ash samples, soil, and sand as capping materials. Results of the tests indicated the uncapped contaminated soil released approximately 13 mg/L of zinc to the overlying water after 14 days exposure. The sand-capped contaminated soil released 10 mg/L of zinc, while the soil-capped contaminated soil released only 0.1 mg/L. Four of the fly ash samples performed well and released less than 0.1 mg/L of zinc. However, one of the fly ash samples did not perform well and released 55 mg/L of zinc indicating the fly ash itself contained soluble zinc. Overall, the testing indicates that fly ash may be

a cost-effective alternative to soil for use as a capping material for contaminated sediments. However, further testing is required on sediments contaminated with other trace elements before more widespread application is considered.

Coal Byproducts Research Consortium (CBRC)

Several of the environmental characterization projects are part of DOE/NETL's Combustion By-Products Recycling Consortium (CBRC) that is administered through West Virginia University's National Mine Land Reclamation Center. The American Coal Ash Association, Interstate Mining Compact Commission, and other state and corporate stakeholders provide assistance to CBRC through an advisory steering committee. Additional information on CBRC can be found at http://cbrc.nrcce.wvu.edu/CBRC/.

Effects of Ammonia Absorption on Fly Ash Due to Installation of SCR Technology *– GAI Consultants*

GAI Consultants has conducted a study of the effects of ammonia absorption on fly ash due to operation of selective catalytic reduction (SCR) NOx control technology.[19] The study was completed in November 2000. Major findings of this study are: (1) most of the ammonia on fly ash is present as ammonium bisulfate and ammonium sulfate salts that are highly water soluble; (2) fly ash that produces a high pH solution can potentially produce ammonia odors when wetted., while fly ash that produces a low pH solution will have negligible ammonia odors; and (3) leachate and/or surface water runoff at fly ash landfills and impoundments will contain increased concentrations of ammonia and nitrate. GAI also evaluated the potential impact of SCR-related ammonia on nitrate levels in the ground water at the three fly ash disposal sites. The results indicate that depending on local geological conditions and fly ash ammonia concentrations, excessive ground water nitrate concentrations may occur.

Flue Gas Desulfurization Byproducts Provide Sulfur and Trace Mineral Nutrition for Alfalfa and Soybean *– Ohio State University*

The Ohio State University conducted experiments in 2000 and 2001 on the utilization of two FGD by-products and natural gypsum as soil amendments to enhance the growth of alfalfa and soybean.[20] Changes in trace element concentration in both the crops and soils were measured as part of the evaluation. FGD by-products contain a readily available source of sulfur and could be a cost effective replacement for natural gypsum. During the 2000 experiments, both alfalfa soybean yields increased using the FGD byproducts. Additional experiments conducted in 2001 resulted in slightly lower increases for the alfalfa crop yields and no significant growth difference for the soybean. Overall, there were no significant differences in crop yields among the two FGD by-products and natural gypsum. Aluminum, arsenic, barium, cadmium, chromium, lead, and selenium concentrations were measured in both the crops and soils. There appeared to be relatively insignificant changes in trace element concentrations associated with the use of the FGD by-products as a soil amendment.

Water Quality Monitoring at an Abandoned Mine Site – *U.S. Geological Survey*

The U.S. Geological Survey (USGS) conducted a seven-year study on the water quality impact of using CUBs from a pressurized fluidized bed combustion (PFBC) boiler to reclaim an abandoned surface coal mine site.[21] The seven acre Fleming abandoned mine site in eastern Ohio was reclaimed with PFBC by-product provided from American Electric Power's Tidd Plant in 1994.

The study was completed in August 2002. Water quality analysis was conducted on three types of water associated with the site: (1) interstitial water using thirty-five soil-suction lysimeters, (2) ground water using twenty monitoring wells, and (3) spring water at three down-gradient locations. Overall, reclamation of the site was successful and it appears the PFBC by-product improved surface conditions for plant growth and reduced the pH of surface water runoff. Also, application of the PFBC by-product did not adversely impact water quality concentrations of toxic trace elements. However, ground water and local spring water quality at the site remains poor quality.

Boron Transport from Coal Combustion Product Utilization and Disposal Sites *– Southern Illinois University at Carbondale*

Southern Illinois University at Carbondale (SIUC) conducted an investigation on the capacity of various soil types to attenuate the leaching of boron from CUBs.[22] Boron is a significant trace element in most coals and is available in relatively high concentrations in fly ash. The boron in fly ash is highly water soluble and often is the toxic element of most concern for leaching from CUBs in both disposal and utilization applications. The adsorptive capacity of six soil types, including eleven materials, was tested at three boron solution concentrations. The following are some general observations from the test results: (1) only one of the soil samples, silica sand, did not adsorb boron; (2) the solution pH affects the soils adsorption of boron with low pH retarding adsorption; (3) the average particle size of the soils was somewhat proportional to boron adsorption with fine materials, possible due to fine clay content, more adsorptive than coarse materials; and (4) the level of dissolved solids in the solution did not appear to affect boron adsorption. Eight of the soil materials were subsequently tested to simulate the effect of acid mine drainage on boron adsorption. Overall, it did not appear that sulfates in acid mine drainage inhibit soil's boron-adsorption capacity.

Soil Stabilization and Drying by Use of Fly Ash *– University of Wisconsin*

The University of Wisconsin conducted a study to evaluate the potential for trace element leaching associated with the use of fly ash to stabilize subgrades used in highway construction projects.[23] The testing was conducted on various soil-fly ash mixtures prepared from three fly ashes and four subgrade soils that are commonly available in Wisconsin. Leachate concentrations were measured for cadmium, chromium, selenium, and silver. In general, the trace element concentrations from the fly ash-soil mixtures were 1.5 to 2.5 times lower than those from the fly ash alone and varied non-linearly with the fly ash content of the mixture. Leachate measurements were also taken from two subgrade construction field sites. The trace element concentrations were higher from the fly ash stabilized subgrade compared to the non-stabilized control subgrade. The concentration of trace elements from the field samples also agreed well with results from the laboratory column leaching tests. Based on results from the laboratory and field testing, a numerical model was developed to simulate trace element concentrations where the subgrade is stabilized with fly ash. The project was completed in February 2003.

Varra Coal Ash Burial Project – *CGRS, Inc.*

CGRS, Inc. completed a study in August 2002 to determine the feasibility of using bottom and fly ash as a fill material for the reclamation of a flooded gravel quarry located in Colorado.[24,25] Ash for the project was provided by Public Service Company of Colorado's Cherokee Generating Station. The study included both laboratory leaching tests and water quality monitoring of a field pilot-scale ash burial site to evaluate the potential impact of fly ash on local groundwater. Overall, aluminum, boron, iron, and manganese were the most leachable of the trace elements,

but results indicated that none of the samples exhibited characteristics of a hazardous waste. The field testing was conducted using fly ash admixtures placed in un-lined trenches excavated to at least seven feet below the water table. The one admixture consisted of fly ash with gypsum and the other fly ash with sodium. Boron was the most mobile and prevalent trace element measured with the monitoring wells. Elevated concentrations of molybdenum, sulfate, selenium, chloride, and fluoride were measured in water samples from the ash, but dropped below regulatory or background levels within a month of the ash placement. Except for boron and nitrite, water quality samples taken from the ash deposits for the last sampling event met drinking water standards. Drinking water standards were not exceeded in monitoring wells located 50 feet down-gradient from the ash trench. Overall results from the field testing indicate that utilization of the fly ash to reclaim the gravel quarry is environmentally feasible.

Effects of Large-Scale CCB Applications on Groundwater: Case Studies – *West Virginia University*

West Virginia University is preparing case studies on how past and present mine reclamation applications of CUBs have impacted groundwater quality.[26] The project includes the collection of existing data on mine site geologic characterization, CUB analysis, and pre- and post- CUB application water quality. Additional water quality samples are being collected from CUB mine reclamation sites and analyzed for trends in trace-element concentration. The leaching potential for six CUBs is being tested using the mine water leaching procedure developed by the National Mine Land Reclamation Center. Results from this study are not yet available.

Environmental Effects of Large-Volume FGD Fill *– GAI Consultants*

GAI Consultants is conducting a study to monitor the environmental effects of using fixated FGD by-product material provided by Reliant Energy as a large-volume structural fill at the Rostraver Airport near Pittsburgh, PA.[27] The 472,000 ton embankment was started in January 2001 and is scheduled for completion in 2003. The environmental monitoring during construction includes surface water and ground water testing. Pre-construction, construction, and post-construction surface water monitoring is being conducted at six sampling locations and private well monitoring at twelve locations. A unique aspect of this project is the use of honeybees as environmental indicators of potential air quality impacts at the site as a result of using the FGD by-product material. The honeybees serve as samplers of local air pollution conditions in lieu of scientific sampling instrumentation. The bees and bee products (honey, beeswax, and propolis) are periodically tested for arsenic, selenium, barium, and manganese. First quarter 2003 monitoring reports indicate that the majority of water sample analyses were within permit limits. Monitoring at the inlet to the site sedimentation pond had a boron concentration of 3.37 mg/L which was slightly greater than the 3.15 mg/L permit limit. Water quality analyses from the twelve monitoring wells showed no exceedances of the primary drinking water maximum contaminant levels (MCL). However, there were a few exceedances of the secondary drinking water MCL for aluminum, chloride, iron, and manganese. A final report for this project is not yet available.

Environmental Performance Evaluation of Filling and Reclaiming a Surface Coal Mine with Coal Combustion Byproducts *– Ish, Inc.*

Ish, Inc. is conducting an environmental evaluation on the use of CUBs to fill and reclaim a surface coal mine site.[28] The subject of the evaluation is Peabody Mining Company's Universal Mine site that is located in Indiana and has been filled with approximately 1.2 million tons of CUBs provided from Cinergy's Wabash River Power Plant. The research consists of both

laboratory and field studies. The laboratory studies are being conducted at Purdue University and include leaching and attenuation analyses of the CUB and mine-spoil materials with a focus on arsenic and boron. The field studies include the installation of 16 groundwater monitoring wells and long-term collection of data on groundwater and surface water quality at the site. Cinergy has been conducting quarterly compliance monitoring at the site since 1988. The collection of water quality data from the new monitoring wells was initiated in May 2001 and is scheduled for completion in September 2003. However, it is anticipated that additional water quality monitoring will be conducted during 2004-06. Preliminary analysis of results show that arsenic, boron, and sulfate are present in the water from the monitoring wells located in the ash fill. The arsenic is attenuated in the groundwater immediately down-gradient from the ash fill while the boron concentration attenuates further down-gradient. There does not appear to be any significant attenuation of sulfate. The speciation of arsenic in the various monitoring wells is also being analyzed and preliminary results show the presence of both arsenic (III) and (V). A final report for this project is not yet available.

The Effect of Mercury Controls on Wallboard Manufacture *– Tennessee Valley Authority*

Tennessee Valley Authority is conducting a laboratory study to examine thermal decomposition profiles and leaching characteristics of mercury in wet FGD by-product materials and gypsum wallboard. The one-year study is scheduled for completion in 2004. The study includes mercury measurements using a laboratory-scale wallboard manufacturing process. Results from this study are not yet available.

The Impact of Adsorption on the Mobility of Arsenic and Selenium Leached from Coal Combustion Products – *Southern Illinois University at Carbondale*

Southern Illinois University is conducting a laboratory study on down-gradient soil adsorption of arsenic and selenium that have leached from CUBs used in fill applications. Accounting for soil adsorption is an important issue since it will minimize the potential environmental risk of arsenic and selenium leaching into the groundwater. The adsorption characteristics of eight soil types will be tested. The project was awarded in July 2003 and results are not yet available.

Quantifying CCBs for Agricultural Land Application - *UNDEERC*

UNDEERC is conducting a one-year laboratory study to assess the potential environmental characteristics of CUB utilization for agricultural applications. The study will develop and test a process for qualifying CUBs for use as an agricultural soil amendment. Bottom ash, fly ash, and FGD material samples are being provided by AmerenCILCO's Duck Creek Power Station. Leaching tests will be conducted using the synthetic groundwater leaching procedure. Results are not yet available.

Coal Combustion Products Partnership (C^2P^2) Program

DOE/NETL also participates in the Coal Combustion Products Partnership (C^2P^2) program sponsored by EPA. Initiated in 2003, C^2P^2 is a cooperative effort of EPA and the CUB industry to help promote the beneficial use of CUBs. In addition to EPA and DOE/NETL, ACAA, Department of Transportation, and the Utility Solid Waste Activities Group are co-sponsors of the program. C^2P^2 members are working with federal and state agencies and industry organizations to reduce or eliminate legal, institutional, economic, market, informational, and

other barriers to further utilization of CUBs. Additional information on the C^2P^2 program can be found at the EPA web site: http://www.epa.gov/epaoswer/osw/conserve/c2p2/index.htm

DOE/NETL's Power Plant Water Management R&D

The goal of the IEP program's water R&D activities is to reduce the overall impact of power plant operations in terms of both water use and water quality. This new research effort was initiated in recognition of the intimate relationship between power plants and water. To help define the R&D that needed to be done, DOE/NETL, along with Los Alamos and Sandia National Laboratories, sponsored a workshop on July 23-24, 2002, entitled *Electric Utilities and Water: Emerging Issues and R&D Needs.* The workshop brought together representatives from government, industry, academia, state and local agencies, and other research organization to discuss power plant and water R&D needs.[29] Based on the results of the workshop as well as discussions with key stakeholders, DOE/NETL issued a competitive solicitation in December 2002 entitled *Innovative Water Management Techniques and Concepts for Coal-Fired Electric Utility Boilers*. The solicitation included four areas of interest:

- Non-Traditional Sources of Process and Cooling Water
- Innovative Cooling Technology
- Advanced Cooling Water Intake Technology
- Advanced Pollutant Measurement and Treatment Technology

The solicitation resulted in the selection of five projects in three of the four areas of interest:

Area of Interest: Non-Traditional Sources of Process and Cooling Water

Strategies for Cooling Electric Generating Facilities Utilizing Mine Water: Technical and Economic Feasibility *- West Virginia Water Research Institute*

The West Virginia Water Research Institute at West Virginia University will assess the feasibility of using underground mine water in the northern West Virginia and southwestern Pennsylvania region as a source of cooling water for power plants. The amount of mine water available, the quality of the water, and the types of water treatment needed are all factors that will be analyzed during this one-year effort. The use of this non-traditional water source not only reduces the amount of fresh surface and groundwater used in the cooling process but it also helps prevent flooded mines from overflowing into rivers and streams thus reducing adverse ecological impacts.

Water Extraction from Coal-Fired Power Plant Flue Gas *- UNDEERC*

UNDEERC, along with the Siemens Westinghouse Power Corporation, will test and evaluate a desiccant-based dehumidification process that removes water from the exhaust gas of coal-fired power plants. This two-year project will attempt to develop an economical and environmentally beneficial technology with the ability to substantially reduce the water consumption of fossil fuel-fired power plants by recovering a large fraction of the water present in the plant flue gas. An engineering evaluation will also be performed to determine how such technology can be

integrated into various power-generating systems, not only to recover water and improve efficiency but also to reduce emissions of acid gases and carbon dioxide.

Use of Produced Water in Recirculated Cooling Systems at Power Generation Facilities *– EPRI*

Produced waters are a by-product of natural gas and CBM extraction and can often present a disposal issue. Produced waters could serve as a source of make-up water for re-circulating cooling systems in water poor areas of the nation, thereby minimizing or eliminating the disposal concern. EPRI, in collaboration with Public Service of New Mexico, Pacific Northwest National Laboratory, Ceramem, and Water and Waste Water Consultants, Inc., have been awarded funding for a two-year project to evaluate and develop the use of produced waters at a New Mexico power plant. The project will investigate the feasibility of using produced water to meet up to 25% of the approximately 16 million gallons/day cooling water demand at the San Juan Generating Station.

Area of Interest: ***Advanced Cooling Water Intake Technology***

Environmentally-Safe Control of Zebra Mussel Fouling *- New York State Education Department*

Zebra mussel colonization on cooling water intake structures can cause significant plant outages. There is a need for economical and environmentally safe methods for zebra mussel control where this invasive species has become problematic. Researchers with the New York State Education Department will conduct a three-year study to evaluate a particular strain of a naturally occurring bacteria *Pseudomonas fluorescens* that has shown to be selectively lethal to zebra mussels but benign to non-target organisms. Testing will be conducted on the house service water treatment system for Rochester Gas and Electric Corporation's Russell Station that withdraws 4 to 5 million gallons/day from Lake Ontario. This project will be completed in 2005.

Area of Interest: ***Advanced Pollutant Measurement and Treatment Technology***

Fate of As, Se, and Hg in a Passive Integrated System for Treatment of Fossil Plant Waste Water *- Tennessee Valley Authority (TVA) & EPRI*

Mercury, arsenic, and selenium are pollutants often present at trace-levels in power plant flue gas and wastewater. In addition, ammonia "slip" from selective catalytic reduction systems (SCRs) for reduction of NOx emissions can appear in wastewater streams such as FGD effluents and ash-sluice water. TVA and EPRI will conduct a three-year study of a passive treatment technology to remove trace levels of arsenic, selenium, and mercury as well as ammonia and nitrate from fossil power plant wastewater. An extraction trench containing zero-valent iron for removal of trace contaminants will be included in the work in order to evaluate an integrated passive treatment system for removal of these trace compounds. This project will be completed in 2006.

In addition to five projects selected under the Innovative Water Management solicitation, the IEP program is supporting two additional water projects.

Use of Coal Drying to Reduce Water Consumed in Pulverized Coal Power Plants *– Lehigh University*

This project will determine the feasibility of using low-grade power plant waste heat to dry low-rank coals prior to introduction into the boiler. Heat from condenser cooling water will be

extracted upstream of the cooling tower and used to dry the coal. Lowering the temperature of the return cooling water will reduce evaporative loss in the tower, thus reducing overall water consumption. In addition, drying the coal prior to combustion can improve the plant heat rate and efficiency, thus reducing overall air emissions. Data from lab-scale testing will be used to develop drying models and to assist in the design of a full-scale prototype dryer module for Great River Energy Corporation's (GRE) Lignite Fuel Enhancement Project funded under DOE's Clean Coal Power Initiative (CCPI). The project will be completed in 2005.

Demonstrating a Market-Based Approach to the Reclamation of Mined Lands in West Virginia *- EPRI*

EPRI will demonstrate a market-based approach to abandoned mine land (AML) reclamation by creating marketable water quality and carbon emission credits. The project will involve the reclamation of thirty acres of AML in West Virginia through (1) the installation of a passive system to treat acid mine drainage, (2) application of fly ash as a mine soil amendment, and (3) reforestation for the capture and sequestration of atmospheric carbon dioxide (CO_2). Water quality and CO_2 uptake will be measured and conventional economic principals will be used to develop the costs and environmental benefits of the remedial treatments. Potential eco-credits include water quality credits due to decreased acid mine drainage and other benefits resulting from the soil amendment, as well as potential credits for carbon dioxide sequestration due to the more than 36,000 seedlings planned for the site. This project is expected to be complete in 2004.

University Coal Research (UCR) Program

Several water projects are funded through the University Coal Research (UCR) Program. The UCR Program, incepted in 1980 by Congressional direction, provides opportunities for fundamental research conducted at U.S. colleges and universities.

A Novel Concept for Reducing Water Usage and Increasing Efficiency in Power Generation *- University of Pittsburgh*

The University of Pittsburgh is developing a cooling system that uses ice to cool the intake air for combined-cycle plants. This process could potentially help U.S. power generation facilities reduce water usage, increase total power output during peak periods, and lower fuel costs through higher efficiency. Although several types of intake air cooling have been used on natural gas fired turbines, the use of a chilling system linked to ice thermal storage offers the benefit of making ice during off-peak periods and then using that ice to cool intake during peak loads therefore increasing the output available for sale during peak demand period. This project will be completed in 2003.

An Innovative Fresh Water Production Process for Fossil Fired Power Plants Using Energy Stored in Main Condenser Cooling Water *- University of Florida*

The University of Florida will investigate an innovative diffusion-driven desalination process that would allow a power plant that uses saline water for cooling to become a net producer of freshwater. Hot water from the condenser provides the thermal energy to drive the desalination process. Using a diffusion tower, saline water cools and condenses the low pressure steam and freshwater is then stripped from the humidified air exiting the tower. This process is more advantageous than conventional desalination technology in that it may be driven by waste heat

with very low thermodynamic availability. Cool air, a by-product of this process, can be used to cool nearby buildings. This project will be completed in 2005.

Clean Coal Power Initiative

Research to better manage how power plants use water is also being carried out under DOE's Clean Coal Power Initiative (CCPI) program. CCPI is a cost-shared partnership between government and industry directed at the commercial-scale demonstration of advanced coal-based, power generation technologies.

Lignite Fuel Enhancement *– Great River Energy*

Great River Energy will design, construct, and operate a prototype lignite drying system at its 546 MW Coal Creek Generating Station in Underwood, North Dakota. In addition to the primary goal of increased generation efficiency and reduced air emissions from the utilization of high-moisture coals, substantial reductions in cooling water requirements will also be recognized. This project will be completed in 2007.[30]

CONCLUSION

As the demand for coal-based electricity increases, so will the need to increase the environmentally safe use of the solid by-products from power plants. It will also require that we find innovative ways to minimize the impact of power plant operations on freshwater resources. In response, DOE/NETL is partnering with industry, Federal and state agencies, research organizations, and academia in carrying out a comprehensive R&D program focused on: (1) the environmental characterization and increased beneficial use of coal by-products and (2) the development of advanced water management concepts and technologies. This research will help to maintain coal's strategic role in providing the Nation with secure, reliable, affordable, and environmentally sound energy well into the 21st century.

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