Fossil Energy Waste Management

Technology Status Report

Steven J. Bossart
Deborah A. Newman

February 1995

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

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Executive Summary

This report describes the current status and recent accomplishments of the Fossil Energy Waste Management (FE WM) projects sponsored by the Morgantown Energy Technology Center (METC) of the U.S. Department of Energy (DOE). The primary goal of the Waste Management Program is to identify and develop optimal strategies to manage solid by-products from advanced coal technologies for the purpose of ensuring the competitiveness of advanced coal technologies as a future energy source. The projects in the Fossil Energy Waste Management Program are divided into three types of activities: Waste Characterization, Disposal Technologies, and Utilization Technologies.

Waste Characterization. Waste characterization is needed to develop safe strategies to use or dispose of by-products from advanced coal technologies. Waste characterization ensures that the use or disposal of the by-products complies with Federal, State, and local regulations. Waste characterization also assists in setting regulations governing the management of coal by-products. The three waste characterization projects in the FE WM program focus on sampling and analyzing by-products from advanced coal technologies for their chemical, physical, and mineralogical properties.

Disposal Technologies. Activities in disposal technologies focus on ensuring that disposal practices for coal by-products are cost-effective and do not adversely impact the environment. Although utilization of by-products is desirable, some portion of the coal by-products will require disposal. In projects with Radian Corporation and the University of Kentucky, the FE WM program has constructed several small landfills around the country that contain coal by-products from advanced coal technologies. These landfills are being monitored for physical and chemical stability for at least 3 years to establish long-term trends in behavior of the landfills with the surrounding environment.

Utilization Technologies. Activities in coal by-product utilization focus on developing technologies or products that use coal by-products for beneficial purposes. Utilization includes replacement of existing materials with coal by-products in commercial products, and use of coal by-products in new technologies and products. The eight coal by-product utilization projects in the FE WM program include projects on surface and mine reclamation, treatment of hazardous waste, production of cements and concretes, road construction, and agricultural applications.

This technology status report includes a discussion on barriers to increased use of coal by-products as described in DOE's Report to Congress entitled "Barriers to the Increased Utilization of Coal Combustion/Desulfurization Byproducts by Governmental and Commercial Sectors." Also, the major technical and nontechnical challenges currently being addressed by the FE WM program are discussed. A bibliography and list of project contacts is included if the reader is interested in obtaining additional information about the FE WM program.

1 Introduction

The main goal of the Fossil Energy Waste Management Program is to identify and develop optimal strategies to manage solid by-products from advanced coal technologies for the purpose of ensuring their competitiveness as a future energy resource. The FE WM program supports the development, demonstration, and commercialization of Clean Coal Technologies (CCTs) by ensuring that the solid by-products generated by CCTs are disposed of or beneficially used in a manner that is technically, economically, and environmentally viable and acceptable to regulators and the public.

The FE WM program intentionally limits itself to identification and development of strategies to manage solid coal by-products generated by CCTs. The program does not include development of management options for solid by-products from mature coal technologies, such as pulverized coal boilers. Clean Coal Technologies can be divided into the following four categories: (1) precombustion, (2) combustion, (3) postcombustion, and (4) conversion. CCTs categorized as precombustion include physical, chemical, and biological methods to remove contaminants from coal (i.e., coal cleaning). CCTs in the combustion category include fluidized-bed combustion, furnace sorbent injection, limestone injection multistage burner (LIMB), and multistage combustion for control of oxides of nitrogen (NO_x). Postcombustion refers to advanced environmental control technologies, which include duct injection, dry scrubbing, spray drying, other advanced sulfur scrubbing technologies, and some NO_x control technologies. Conversion technologies include integrated gasification combined cycle and coal liquefaction.

The Fossil Energy Waste Management Program can be divided into three types of activities: Waste Characterization, Disposal Technologies, and Utilization Technologies.

Waste Characterization

Waste characterization is a fundamental activity in the Fossil Energy Waste Management Program: all projects in the FE WM program include waste characterization. Characterization of the chemical and physical properties of coal by-products is needed to develop safe strategies to handle, transport, and dispose or use them. Coal by-products are characterized in their disposal or utilization environments to evaluate their long-term physical and chemical stability. Predictions concerning environmental impact and structural integrity are based on characterization data.

Certain types of characterization are mandated by Federal, State, and local regulatory agencies to comply with regulations, and to assist in setting regulations to dispose or use the coal by-products. Management of the coal by-products must primarily meet the requirements of the Clean Water Act, Safe Drinking Water Act, and Resource Conservation and Recovery Act (RCRA) for protection of land, groundwater, and surface water. Databases on characterization of coal by-products from advanced coal technologies are maintained by several organizations, such as the Electric Power Research Institute, Radian, and the University of North Dakota Energy and Environmental Research Center.

There are three projects in waste characterization:

Advanced Technology Systems	<i>Coal By-Product Sampling and Distribution</i>
Ames National Laboratory	<i>Coal By-Product Characterization</i>
Universal Fuel Development Associates	<i>Geotechnical and Geochemical Characterization</i>

Disposal Technologies

Activities in disposal technologies focus on ensuring that disposal practices for coal by-products are cost-effective and do not adversely impact the environment. Although utilization of coal by-products is preferable over disposal, technologies and markets will probably not be available to use all of the coal by-products. Therefore, some portion of the coal by-products will require disposal. Currently, about 78 percent of coal by-products generated in the United States are disposed in surface landfills and other disposal facilities.

The FE WM program has established several small landfills around the country that contain coal by-products from advanced coal technologies. The by-products were placed in the landfills using various placement and compaction methods. The quantity and quality of leachate from the landfills and the physical and chemical characteristics of the landfilled coal by-product is being monitored for at least 3 years to establish long-term behavior of the landfills. Data on the long-term behavior of the coal by-products in landfills is needed by regulators and other stakeholders to support siting and permitting of disposal facilities.

There are three projects in disposal technologies:

University of Kentucky - Center for Applied Energy Research	<i>Management of Solid Waste from the Coolside Process</i>
Radian Corporation	<i>Field Study of Disposed Waste</i>
Morgantown Energy Technology Center	<i>Stabilization of Coal By-Products from Gasification Processes</i>

Utilization Technologies

Utilization technologies focus on the use of coal by-products for beneficial purposes. Utilization includes replacement of existing materials with coal by-products in commercial products, and use of coal by-products in new technologies and products. Utilization of coal by-products avoids the cost of unproductive disposal and long-term monitoring of landfills, decreases the cost of producing electricity from coal, and saves valuable land and raw material resources. Utilization technologies span the range of low-cost, high-volume uses (e.g., mine reclamation) to high-cost, low-volume uses (e.g., floor tiles). Utilization technologies being studied in the FE WM program include surface and mine reclamation, treatment of

hazardous waste, production of cements and concretes, road construction, and agricultural applications. The projects developing coal by-product utilization technologies are highly leveraged with funding from non-DOE sources. Joint funding of these projects increases the likelihood for commercial success, since DOE is not assuming the entire financial risk in developing the utilization technologies.

In 1993, about 88 million tons of flyash, bottom ash, boiler slag, and flue gas desulfurization (FGD) materials were generated in the United States. Overall, only 22 percent of these solid by-products were used for beneficial purposes (American Coal Ash Association 1994). Table 1 shows the quantities of solid by-products generated and their percentage of utilization.

Table 1. Production and Use of Coal By-Products in 1993

Material	Quantity Produced (Short Tons)	Percent Utilization
Flyash	47,756,492	22.0
Bottom Ash	14,215,711	29.8
Boiler Slag	6,228,523	55.0
FGD Material	<u>20,340,130</u>	<u>5.7</u>
TOTAL	88,540,856	21.8

Source: American Coal Ash Association. 1994.
1993 Coal Combustion Byproduct (CCB) - Production and Use.

By the year 2000, the amount of flyash, bottom ash, and boiler slag is expected to increase by only 8 percent. However, the generation of FGD material is expected to double. This increase is due to installation of advanced FGD systems on power plants to meet stricter sulfur emission regulations established in the Clean Air Act amendments of 1990. Therefore, a major emphasis of the FE WM program is to develop utilization technologies for the FGD materials, since their current utilization rate is only about 6 percent.

There are eight projects in utilization technologies:

University of Pittsburgh

*Treatment of Metal-Laden Hazardous Waste
 with Advanced Coal Technology By-Products*

**Michigan Technological
 University**

*Use of Coal By-Products from Low NO_x
 Technologies*

Praxis Engineers

*Utilization of Lightweight Materials
Made from Coal Gasification Slags*

**West Virginia University -
National Research Center
for Coal and Energy**

*Use of AFBC Residues To Remediate
Active Acid Mine Drainage in an
Underground Mine*

**Southern Illinois University
at Carbondale**

*Dry FGD By-Products in an Underground
Mine To Control Surface Subsidence*

**University of Kentucky -
Center for Applied Energy
Research**

*Dry FGD Reclamation Using Addcar™
Highwall Mining System*

Dravo Lime Company

*Land Application Uses of Dry FGD
By-Products*

U.S. Department of Agriculture

*Utilization of FBC Ash in Agricultural
Applications*

2 Project Status

Waste Characterization

Advanced Technology Systems *Coal By-Product Sampling and Distribution*

The DOE's Clean Coal Technology Demonstration Program is aimed at demonstrating the commercial readiness of advanced coal-based technologies by building and operating the CCTs at large scale. Currently, there are 45 projects in the CCT program (Clean Coal Technology Demonstration Program 1994). In September 1994, Advanced Technology Systems (ATS) was awarded a contract to collect representative solid by-product samples from up to five operating CCTs. ATS will distribute the samples to specified analytical laboratories for physical and chemical characterization. Currently, ATS is developing a methodology for selecting sites to be sampled and is in the process of final site selection. Sampling procedures are being developed for each site to ensure that the samples are representative of steady-state operation.

Ames National Laboratory *Coal By-Product Characterization*

Ames National Laboratory (NL) has been analyzing by-products from advanced coal technologies to determine if they contain hazardous contaminants. Potential organic contaminants include phenols, ketones, single- and double-ring aromatic hydrocarbons (e.g., benzene, naphthalene), and poly-aromatic hydrocarbons. Potential inorganic contaminants include compounds of arsenic (As), beryllium (Be), cadmium (Cd), cobalt (Co), lead (Pb), mercury (Hg), nickel (Ni), manganese (Mn), zinc (Zn), selenium (Se), antimony (Sb), and chromium (Cr). Ames NL analyzed solid by-products samples generated during operation of six pilot-scale or demonstration-scale advanced coal technologies. These facilities included a pressurized fluidized-bed combustor, a research carbonizer facility, a plant using duct injection of hydrated lime for control of sulfur emissions, and a facility using ammonia injection for NO_x control.

Ames NL analyzed both extracts and leachates from the by-product samples. Analysis of the extract yielded data on the total quantity of a contaminant in the by-product sample. Analysis of the leachate under the toxicity-characteristic-leaching procedure (TCLP) yielded information on whether the by-product sample would be classified as hazardous or non-hazardous according to RCRA regulations. The concentration of organic compounds in the by-product samples was quite low. The highest concentration of total organic compounds in any by-product sample was 30 parts per million by weight (ppmw). The highest concentration of organic compounds in the leachate was only 0.4 ppmw. The concentration of elements in most by-product samples was below the Maximum Concentration Limit (MCL) for drinking water. No elements in the by-product samples exceeded the MCL for waste water.

Ames NL is also studying the hydration reactions of the by-products to better understand the cementitious nature of some by-products. They discovered that prior hydration of spent bed material (SBM) from a fluidized-bed combustor (FBC) was necessary to control heat release and expansion when using SBM in concrete. Ames NL produced no-cement concrete from mixtures of SBM with class C or class F flyash. They were able to attain a 90-day strength of 8,000 pounds per square inch (psi) using a ratio of 1:3 SBM-to-class C flyash. A 90-day strength of 5,000 psi was attained in a no-cement concrete composed of a mix of 1:1 SBM-to-class F flyash. They are working with a large cement manufacturer to assess whether FBC or FGD by-products can be economically used in the manufacture of portland cement.

In 1995, Ames NL will analyze coal by-product samples received from Advanced Technology Systems.

Universal Fuel Development Associates *Geotechnical and Geochemical Characterization*

Universal Fuel Development Associates is analyzing the chemical and physical properties of solid by-products from advanced coal technologies to generate the basic data needed to properly design management systems for disposal or utilization of the coal by-product. Universal Fuel Development Associates collected and analyzed 34 solid by-product samples from 17 different advanced coal technology facilities, including coal gasifiers, fluidized-bed combustors, and advanced flue gas desulfurization facilities. The by-products were analyzed for bulk chemical content, physical engineering properties, and mineralogy. Results indicated that standard, commercial equipment could be used to handle and dispose of these solid by-products. However, some by-products have attributes that require special handling during transportation and disposal. Some by-products are self-hardening upon contact with water, and release significant amounts of heat during hydration. The by-products set up slowly in a matter of hours or days, but care must be taken to avoid setting up during temporary storage or transportation. For some by-products, it is recommended that the by-product be partially hydrated under controlled conditions prior to transport to the disposal site.

The properties of some by-products make them suitable for use as blasting grit, aggregate for asphalt concrete, de-icing agents, structural fill, soil stabilization additives, waste stabilization additives, landfill cover, and roadbase.

Disposal Technologies

University of Kentucky - Center for Applied Energy Research *Management of Solid Waste from the Coolside Process*

In June 1991, DOE awarded a contract to the Center for Applied Energy Research at the University of Kentucky to develop safe disposal practices for managing solid by-products from the Coolside Process. In the Coolside Process, hydrated lime and a water spray with a sodium additive are injected into the flue gas on the "cool side" of the air preheater, immediately upstream of the electrostatic precipitator. The water spray humidifies the flue gas to within 10 to 20 percent of saturation, and the sodium additive increases sulfur capture. The solid waste generated is composed primarily of flyash, calcium hydroxide [$\text{Ca}(\text{OH})_2$], calcium sulfite (CaSO_3), and calcium sulfate (CaSO_4), with lesser quantities of sodium sulfite (Na_2SO_3), sodium sulfate (Na_2SO_4), and calcium carbonate (CaCO_3). The research project includes chemical and physical characterization, laboratory column tests, field concrete lysimeter tests, and liner compatibility evaluations.

The Coolside Process was successfully demonstrated at the Ohio Edison Edgewater plant in 1990 to 1991 as part of DOE's CCT demonstration program. The University of Kentucky collected 70 tons of solid by-products during the CCT demonstration. Between September and November 1992, three concrete lysimeters were filled with Coolside solid waste, while a fourth lysimeter was filled with Class F flyash. The concrete lysimeters are 8 feet long by 8 feet wide by 10 feet deep (Figure 1), and hold about 20 tons of material. In each lysimeter, 1 foot of Ottawa sand was placed at the bottom, followed by 7 feet of solid by-product, and 2 feet of soil for cover. The first lysimeter was loosely filled with Coolside waste; the second lysimeter was filled with Coolside waste and compacted at 18 psi, which is equivalent to compaction achieved by a rubber tired loader; the third lysimeter was filled with Coolside waste and compacted to 95 percent of its optimum dry density (i.e., standard compaction). The fourth lysimeter was loosely filled with flyash. The four lysimeters surround a central chamber that is used for access to leachate collection bottles and instrumentation. The lysimeters are instrumented with neutron moisture probes, thermocouples, and stress gauges.

Many trace elements, including silver, beryllium, cadmium, cobalt, nickel, mercury, lead, and zinc, have either not been detected or have been found at the detection limits in only one or two samples in the leachates from both laboratory column and field lysimeter experiments. Other elements, including barium, chromium, manganese, and titanium, were found at low concentrations in early samples, but rapidly declined in concentration to below detection limits. Elements of environmental concern that were present in consistent and measurable concentrations include arsenic and selenium. Arsenic had a maximum concentration of 11 ppmw, and selenium had a maximum concentration of 2.3 ppmw in a sample from the field lysimeter tests.

The leachate from the Coolside by-product is more alkaline and contains more dissolved ions than leachate from flyash. Total dissolved solids (TDS) in leachates from the

flyash is only 10 to 30 percent of TDS concentration in leachate from the Coolside by-product.

Figure 1. Concrete Lysimeters

Leachates from the first and second lysimeters differ significantly from leachates from the third lysimeter. They have a pH of about 10.5, compared to a pH of 12.2 for leachate from the third lysimeter. Also, chloride and sulfate concentrations are 10,000 to 16,000 ppmw in leachates from the first and second lysimeters, while the chloride and sulfate concentrations in leachates from the third lysimeter is only 5,200 ppmw. Leachates from the first and second lysimeters have significantly higher concentrations of molybdenum, boron, sodium, calcium, and potassium, while the leachate from the third lysimeter has higher concentrations of vanadium, arsenic, and aluminum. These results indicate that leachate chemistry is strongly affected by the initial moisture conditioning and compaction of the by-products.

Soil gas is being monitored for carbon dioxide in the lysimeters. Carbon dioxide concentrations exceeding 26,000 parts per million by volume (ppmv) were measured several times during the summer. For comparison, the concentration of carbon dioxide in the atmosphere is 360 to 400 ppmv. Mineralogical analysis has shown that the ettringite

[Ca₆Al₂(SO₄)₃(OH)₁₂•26H₂O] formed in the landfills was gradually breaking down into gypsum (CaSO₄•2H₂O), calcite (CaCO₃), and thaumasite [Ca₃Si(OH)₆(SO₄)(CO₃)•12H₂O] due to reaction with carbon dioxide, which is respired from plant roots.

Comparison of leachates from the field lysimeters with leachates from RCRA's TCLP and extraction procedure (EP) toxicity characteristic tests indicates that the TCLP and EP regulatory tests underestimate the maximum concentrations in field leachates by up to one order of magnitude. TCLP and EP tests on the Coolside by-products before disposal showed that the elemental concentrations in the leachates were below toxicity limits specified in RCRA, and therefore, the waste would be classified as non-hazardous.

Concentrations in leachates from laboratory column tests are well within an order of magnitude of the field results, with some values differing by only a few percent. Results from laboratory column tests appear to better predict field behavior compared to results from batch extraction of small samples, such as the TCLP tests.

In a related project, the Ohio Coal Development Office (OCDO) awarded a contract to Consolidation Coal (Consol) to develop technologies and products for using solid by-products from the LIMB and Coolside processes. Consol has fabricated pellets from the solid by-products with high strength and durability. The pelletization process consists of three steps: hydration, pelletization, and curing. Key factors in producing strong pellets include the amount of water added, curing temperature, and curing time. In spring 1995, the pellets will be used as aggregate in construction of road asphalt in a section of a highway in Ohio. The DOE and OCDO projects are jointly managed by a steering committee consisting of representatives from DOE, OCDO, the University of Kentucky, and Consol.

Radian Corporation *Field Study of Disposed Waste*

In 1986, Radian Corporation was awarded a contract to construct and monitor small landfills containing by-products from advanced coal technologies to evaluate the environmental impacts associated with disposing these coal by-products under field conditions. This project ended in 1994. The overall goal of this project was to develop reliable design, construction, and monitoring guidelines to safely and economically dispose of these coal by-products, based on behavior of the coal by-products in the field. The guidelines are expected to promote acceptance of advanced coal technologies by the commercial market, and field data will assist regulatory agencies in setting regulations for management of the coal by-products.

Radian Corporation has constructed landfills at three sites.

Colorado-Ute Site. At the Tri-State Generation and Transmission Association's (formerly Colorado-Ute Electric Association) Nucla Power Plant located in Nucla, Colorado, a landfill was constructed and filled with ash from the circulating fluidized-bed combustion unit demonstrated under DOE's CCT program.

Ohio Edison Site. At the Ohio Edison Company's Edgewater Plant in Lorain, Ohio, two landfills were constructed and filled with ash from the LIMB technology. The ash was first tested at the site under U.S. EPA sponsorship and later under DOE's CCT program.

Freeman United Site. At the reclaimed area in the Buckheart surface mine near Canton, Illinois, owned by Freeman United Coal Company, three landfills were constructed. They contain various mixtures of ash from a bubbling, fluidized-bed combustor (BFBC) of Midwest Grain Products in Pekin, Illinois, and Class F flyash.

Typically, these landfills are no more than 100 feet square by 8 feet deep and hold 600 to 900 tons of material. Figure 2 is a schematic of a typical landfill with monitoring instrumentation. Coal by-products were transported and placed in the landfills using normal industry practices. The landfills are heavily instrumented to collect data on behavior of the by-products when exposed to natural elements. Typical instrumentation includes a meteorological station for measuring temperature, precipitation, and wind; upgradient and downgradient groundwater monitoring wells; a Parshall flume for measuring water runoff; subsurface thermocouples; subsurface neutron probes for measuring moisture; and lysimeters for sampling pore waters within the landfill. The landfills have been or will have been monitored for at least 3 years following construction.

Figure 2. Typical Landfill with Monitoring Instrumentation

Colorado-Ute Site. A landfill was constructed, filled, and compacted to a depth of 8 feet with bottom ash and flyash from the Colorado-Ute circulating, fluidized-bed combustor (CFBC) in June 1989. The ash was collected from operation of the CFBC with low-sulfur subbituminous coal and limestone sorbent. As a result, the ash is relatively low in sulfate and lime content, which reduces the cementitious activity of the material. The landfill produced no leachate and virtually no surface runoff during the 5 years of monitoring.

The climate at the site is semi-arid and temperate, and the average annual precipitation is only 14 inches. The water is probably both evaporated and consumed by hydration of the CFBC ash. Hydration of cementitious compounds in the ash led to solidification of the landfill into a coherent mass within a few months following construction. The unconfined compressive strengths of core samples within the landfill averaged about 500 psi, which is adequate for physical stability of the landfill. The permeability of the landfill has increased from 0.00001 centimeters per second (cm/sec) in the first year to 0.0003 cm/sec in the third year. The moisture content of the landfill has increased from about 20 percent to over 25 percent, but has not produced leachate. Characterization of the CFBC ash using the RCRA EP toxicity characteristic test showed that both the bottom ash and the flyash are classified as non-hazardous according to RCRA regulations.

The mineralogy of the landfilled CFBC ash has changed over time. The addition of rain water to the ash has caused the formation of hydrated compounds, such as portlandite [$\text{Ca}(\text{OH})_2$], gypsum ($\text{CaSO}_4 \bullet 2\text{H}_2\text{O}$), and ettringite [$\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \bullet 26\text{H}_2\text{O}$]. The

continued presence of lime and anhydrite (CaSO_4) indicates that the landfilled CFBC ash has not been fully hydrated due to the semi-arid conditions in the region.

Ohio Edison Site. The primary constituents of the LIMB ash are flyash, unreacted lime, and calcium sulfate. The LIMB ash produces an alkaline leachate when wetted, and requires careful handling because the material becomes hot, pozzolanic, and expansive when exposed to water. Two landfills were constructed at the Ohio Edison site, differing only by the moisture content of the LIMB ash being placed in the landfill. In February 1990, the North landfill was filled with about 900 tons of LIMB ash, with a moisture content of about 26 percent.

In April 1990, the South landfill was filled with LIMB ash. Water was sprayed onto the LIMB ash during filling of the landfill. Consequently, the moisture content of the LIMB ash was about 38 percent, which corresponds to the amount of moisture needed for maximum compaction density of LIMB ash, according to laboratory results.

Both landfills developed adequate load-bearing strength for landfill stability, but expansion, heaving, and cracks were experienced in both landfills. The expansion contributed to greater permeability to infiltrating water. For example, the permeability of the South landfill has increased from 10^{-7} cm/sec during the first year to 10^{-4} cm/sec at the end of the third year. The high permeability has increased the water infiltration and thus the moisture content of the landfills to about 90 percent.

Mineralogical analysis of the landfilled ash showed significant formation of ettringite (38 percent), thaumasite (20 to 35 percent), gypsum (6 to 9 percent) and calcite (7 to 8 percent). The formation of ettringite and thaumasite are connected with expansion and crack propagation in the landfill. These compounds are expected to have reached their maximum concentrations, since all available sulfate has been used in the formation of these compounds.

Characterization of LIMB ash using the RCRA EP toxicity characteristic test showed that the ash is classified as non-hazardous according to RCRA regulations. The pH of the EP leachate was about 12, which is high, but below regulatory limits for corrosivity. The pH of the leachate from the landfill is about 10.5.

The results from this study indicate that the LIMB ash can be safely disposed if engineering controls are used to properly condition and compact the materials during construction of the landfill. Steam and temperature increase were moderate and affected the moisture content of the landfilled material, but did not affect operation of the equipment.

Freeman United Site. In September 1994, Radian Corporation was awarded a 2-year contract to continue monitoring three landfills containing coal by-products at the Freeman United Buckheart Mine site near Canton, Illinois. The first landfill contains ash from the BFBC at Midwest Grain Products and was constructed in December 1990. The second and third landfills were constructed in May 1993 and contain a 50:50 mixture of the BFBC ash and Class F pulverized coal flyash. In the second landfill, about 27 percent water was added to the mixture for optimal water content, and the material was compacted with a bulldozer and roller. About 42 percent moisture was added to the mixture for the third landfill, and

the material was placed with a front end loader with no compaction. Monitoring will include analyses of groundwater quality upgradient and downgradient from the cells, leachate samples within the cells, and solid core samples within the cells.

Design Manual. Radian Corporation prepared a design manual (Weinberg et al. 1994) for disposing and using solid by-products generated by advanced coal technologies. Many of the solid by-products from advanced coal technologies become hard like cement when exposed to water. These self-hardening characteristics are attractive to landfill designers since the hardened material minimizes water infiltration and generation of leachates. The hardened material is also attractive to engineers seeking low-cost materials for road bases, structural fills, embankments, and cement mixes. In the design manual, Radian explored five different options for disposing or using solid by-products from advanced coal technologies. These options include (1) a traditional landfill system including liners and leachate collection systems, (2) an unlined landfill with minimal leachate monitoring requirements, (3) a wet disposal method based on by-product stacking, (4) use of coal by-products for mine reclamation or backfill, and (5) other uses of coal by-products, including agricultural applications, construction materials, and pollution control. Long-term monitoring data from the small landfills in Nucla, Colorado; Lorain, Ohio; and Canton, Illinois, containing by-products from advanced coal technologies assisted Radian in developing designs for the disposal options.

Morgantown Energy Technology Center *Stabilization of Coal By-Products from Gasification Processes*

Coal gasification processes that use an in-bed, calcium-based sorbent (e.g., limestone) for removal of sulfur generate ash that contains reactive, calcium sulfide. The reactivity of the ash can cause it to be classified as hazardous under RCRA. Attempts to oxidize calcium sulfide in the ash to stable calcium sulfate in a fluidized bed often result in only partial conversion of sulfide to sulfate. It is postulated that the interior of the ash particle is not oxidized because an outer layer of sulfate that formed during oxidation blocks access to the interior of the particle.

The in-house research staff at METC is investigating a wet oxidation process to solve the problem of incomplete oxidation of calcium sulfide to sulfate. The wet oxidation process involves plunging hot ash exiting the gasifier at 600 to 650°C into an aqueous solution at 50 to 75°C. The rapid quench causes the ash to fragment, which exposes the high sulfur core of the ash particle. Air is pumped into the solution to convert calcium sulfide in the ash fragments to calcium sulfate. Key operating parameters under study are reaction temperature, contact time, reaction pH, and air injection rate. Early results have shown that the wet oxidation process can oxidize over 99 percent of the calcium sulfide. Oxidation products included calcium sulfate, calcium sulfite, and thiosulfate ion.

Utilization Technologies

University of Pittsburgh *Treatment of Metal-Laden Hazardous Waste with Advanced Coal Technology By-Products*

In August 1994, the University of Pittsburgh was awarded a cooperative agreement to develop a cost-effective technology to treat metal-laden, hazardous wastes using solid by-products from CCTs. Excess lime and pozzolanic materials in some CCT by-products can chemically react with the hazardous waste and stabilize or solidify the heavy metals. A goal of the project is to convert the hazardous waste to a form in which its leachates are considered non-hazardous, thus eliminating the hazardous characteristics of the original categorical waste. The project is divided into two 1-year phases. In Phase 1, up to 10 sources of metal-laden, hazardous wastes will be treated with up to 4 sources of CCT solid by-products in laboratory-scale tests. In Phase 2, metal-laden hazardous waste will be treated using CCT solid by-products in 20-ton batches. Complete physical and chemical characterization of the CCT solid by-products, and treated and untreated metal-laden hazardous waste, will be performed in both phases.

The four by-products selected for study are a flyash from a coal-fired CFBC, a mixed-ash from a coal waste-fired CFBC Ebensburg Power Plant, flyash from a coal-fired, pressurized, fluidized-bed combustor (PFBC) at the Ohio Power Company Tidd station, and a spray drier effluent from a pulverized coal (PC) boiler at the Carneys Point Cogeneration Plant. Metal-laden hazardous wastes to be investigated include dusts from particulate control devices, sandblasting residues, thickened sludges, and contaminated soils.

Dravo Lime Company will collect and analyze samples of each coal by-product, and then distribute them to Mill Service and the University of Pittsburgh. Mill Service will determine the effective level of treatment of each metal-laden waste with each coal by-product. The effectiveness of treatment will be evaluated by the ability of the treated waste to meet TCLP limits and Best Demonstrated Available Technology (BDAT) treatment standards for land disposal restrictions (LDR).

The University of Pittsburgh will run American Society for Testing and Materials (ASTM) leaching tests and TCLP leaching tests on the coal by-products and treated waste. The TCLP tests will determine if treatment with CCT by-products will convert the hazardous, metal-laden waste to a non-hazardous material in accordance with RCRA regulations. The ASTM leaching test will more accurately simulate the expected leaching behavior of the treated material. The cost of solidification of metal-laden waste with coal by-products will be compared with the cost of current practices for treating the metal-laden wastes.

Michigan Technological University
Use of Coal By-Products from Low NO_x Technologies

Currently, the largest utilization market for flyash is cement and concrete manufacturing. This market could be threatened by the 1990 Clean Air Act Amendments, which requires a 2-million-ton reduction in emissions of NO_x compared to 1980 levels. The utility industry has responded to this requirement by retrofitting boilers with low NO_x burners to lower the NO_x emissions. Flyash generated by the low NO_x burners has high carbon content (e.g., greater than 5 percent), which limits its use in cement and concrete products. The high carbon content of the flyash requires additional air entrainment agents to be added to the concrete, which increases its production costs.

In September 1994, the Institute of Materials Processing (IMP) at Michigan Technological University (MTU) was awarded a 2-year cooperative agreement to develop technologies and products for using flyash from low NO_x burners. A separation process, patented by IMP, will be tested on flyash from low NO_x burners. In this process, cenospheres are removed by gravity separation, iron is removed by magnetic separation, and carbon is removed by a froth flotation process. Silicate spheres then remain. The flyash is composed of less than 1 percent cenospheres, 2 to 3 percent iron, 5 to 30 percent carbon, and the balance is silicate spheres.

After separation, these flyash fractions can be used for various applications. The cenospheres can be used in insulating materials and low-density concretes. After steam activation, the carbon can be used as a substitute for granular activated carbon (GAC) to adsorb contaminants such as mercury. Experiments have shown that carbon from flyash has about 30 percent of the activity of commercial GAC. Iron can be recycled as a catalyst or scrap metal. The silicate spheres can be used in concrete and cement products such as brick and blocks.

IMP will use six sources of flyash from low NO_x burner technologies in this project. During the first year, IMP will conduct laboratory testing to further develop their flyash separation process, and make products from the separated flyash fractions. In the second year, IMP will make several tons of products from the flyash fractions in pilot-scale processing equipment. These products will be tested for their technical performance and environmental impact. An economic analysis will assist in assessing the market potential for the products.

Praxis Engineers
Utilization of Lightweight Materials Made from Coal Gasification Slags

In September 1994, Praxis Engineers was awarded a two-phase cooperative agreement to develop lightweight (30 to 50 lb/ft³) and ultra-lightweight aggregate (12 to 15 lb/ft³) from coal gasification slags. These types of aggregates could be used in a variety of applications, including nonstructural concrete, structural lightweight concrete, concrete blocks, concrete roof tiles, insulating concrete, loose fill insulation, and agricultural and horticultural uses.

In Phase 1, gasification slag will be prepared and separated into size fractions and thermally processed in an indirect-fired kiln or a direct-fired kiln to produce expanded aggregates. The temperature in the kilns is 1600 to 1900°F. During thermal processing, the slag expands like "popcorn" to produce lightweight aggregates. The direct-fired kiln is less expensive to operate, but the indirect-kiln has better control of temperature. The slag will be prepared at Pennsylvania State University and then thermally processed at the pilot-scale kilns at Fuller Company. Potential sources of gasification slag include Eastman Chemical Company's Texaco entrained-bed gasifier in Kingsport, Tennessee; Texaco's pilot-scale entrained-bed gasifier in Montebello, California; a Shell entrained-bed gasifier in Houston, Texas; a Tennessee Valley Authority gasifier in Muscle Shoals, Alabama; and a Dow entrained-bed gasifier in Plaquemine, Louisiana. The expanded aggregates will undergo ASTM and industry standard tests used in evaluating conventional aggregate materials. Various aggregate sizes and unit weights will be prepared in Phase 1. Prior characterization of gasification slag has shown that the slag is non-hazardous according to RCRA regulations.

In Phase 2, several precast concrete products and insulation concrete products will be made from the expanded slag aggregates. Several industrial partners will be involved in product manufacturing and testing. For example, current plans are to manufacture 3 tons of concrete roof tiles, 1 ton of insulating concrete, 1 ton of loose fill insulation, and a free-standing wall made from 6 tons of concrete blocks. Praxis will compare the cost of manufacturing aggregates and final concrete products using gasification slag with both the cost of slag disposal and the cost of commercial concrete products using conventional materials.

A slag sample was collected, physically separated, and processed to remove char. After physical separation and processing, the original slag sample was separated into two fractions. The char-free slag fraction was 74 weight percent of the original slag sample. The density of the char-free slag was 80 to 90 lb/ft³. The recovered char fraction was 26 weight percent of the original slag sample, and it contained 45 percent ash. Laboratory-scale batch pyroprocessing tests were conducted in a muffle furnace at a temperature of 1400 to 1600°F. The feed material for these tests was char-free slag in the 6 x 12 mesh particle size range. The expanded slag products had densities between 15 and 64 lb/ft³.

Pilot-scale tests were also conducted on the 6 x 12 mesh, char-free slag in an indirect-fired kiln. The expanded slag products had densities between 24 and 64 lb/ft³, which confirmed earlier results using the muffle furnace.

West Virginia University - National Research Center for Coal and Energy
Use of AFBC Residues To Remediate Active Acid Mine Drainage in an Underground Mine

Although the environmental impacts of surface mining are more visible, the impacts of underground mining are generally more severe. Underground mining contributes 80 to 90 percent of the acid mine drainage into our Nation's waterways. Underground mining also causes surface subsidence in many areas of the country. Acid mine drainage and mine subsidence is a prevalent problem in abandoned underground coal mines. The alkaline and cementitious nature of many of the solid wastes from CCTs makes it a prime material for treatment of acid mine drainage and mine subsidence.

In February 1994, the National Research Center for Coal and Energy at West Virginia University (WVU) was awarded a three-phase, 5-year cooperative agreement to evaluate the technical, economic, and environmental feasibility of filling abandoned underground mine voids with FBC ash to control acid mine drainage and subsidence. Both hydraulic and pneumatic methods will be evaluated for filling voids in underground mines with FBC ash. In Phase 1 of the project, WVU will develop grout formulations for hydraulically injecting ash into the mine. The grout formulations will include ash from the atmospheric-pressure CFBC operated by Morgantown Energy Associates (MEA) in Morgantown, West Virginia. Other grout ingredients include fresh water, mine water, lime, Portland cement, flyash, set retarders, and water reducers. In the laboratory, the grout formulations will be analyzed for strength, permeability, leaching characteristics, and pumping and spreading properties. Burnett Associates, under a subcontract with WVU, will optimize the design of their ash injection device for pneumatically stowing the FBC ash in the mine.

WVU conducted laboratory tests using acidic mine water as mixing water for grout formulations. Results indicate that grout made from a 50/50 mix of FBC flyash/bottom ash with mine water had a 15 percent lower 30-day compressive strength compared to grout made from a 50/50 mix of FBC flyash/bottom ash with tap water. The 30-day compressive strength of the grout made from a 50/50 mix of FBC flyash/bottom ash with mine water was about 1,000 psi, which is more than adequate for controlling surface subsidence. These results indicate that a source of fresh water at the mine may not be necessary if mine water can be used to produce grout.

In Phase 2, a small-scale field test will be performed in the Anker Energy Corporation's Fairfax underground mine in Preston County, West Virginia. Anker Energy will hydraulically inject about 1,000 cubic yards of ash grout into voids in the underground mine. Anker Energy will inject 40 to 50 tons of FBC ash into the mine using the ash injection device developed by Burnett Associates.

In Phase 3, a large-scale field demonstration of the pneumatic and/or hydraulic ash injection technology will be conducted in the Anker Energy Corporation's Longridge underground mine in Preston County, West Virginia. About 25 acre-feet of void space is available for filling with ash in the Longridge mine. Mine water samples from the Fairfax and Longridge Mines will be analyzed before, during, and after ash injection to assess the impact on water quality. Currently, the water flowing from the Longridge mine has a pH of 2.5 to 2.9, with an iron concentration of 195 milligrams per liter (mg/l) and a sulfate concentration of 1,776 mg/l.

Southern Illinois University at Carbondale
Dry FGD By-Products in an Underground Mine To Control Surface Subsidence

Southern Illinois has some problems with surface subsidence from the collapse of floors, pillars, and roofs in abandoned underground mines. In September 1993, Southern Illinois University at Carbondale (SIU-C) was awarded a 4-year, three-phase cooperative agreement to develop technologies to control surface subsidence by placing by-products from FBC and FGD processes into the voids of underground mines. Other participants in the project include the Illinois State Geological Survey, the University of Pittsburgh, Mine Systems Design, the U.S. Bureau of Mines in Spokane, the Archer Daniel Midland Company, Illinois Power, Springfield Power and Light, Illinois Clean Coal Institute, Peabody Coal Company, Eric Powell and Associates, the Illinois Central Gulf Railroad, and the Norfolk Southern Railroad. The project team is investigating technologies to handle and transport FBC and FGD by-products, and to blindly place the by-products into underground mines using pneumatic and hydraulic injection methods.

Phase 1 includes laboratory-scale development of suitable mixes of the by-products and hardware for pneumatic and hydraulic injection methods. Phase 1 also includes a field demonstration of a materials handling technology. Phase 2 consists of a surface demonstration of the blind pneumatic and hydraulic injection methods using a simulated underground mine void. Phase 3 is the field demonstration of the blind injection technologies into an abandoned underground mine. Phase 3 also includes a study of the environmental impacts associated with the practice of backfilling voids in abandoned mines with solid by-products.

One handling and transportation technology that is being considered in the project is a heavy-duty, collapsible intermodal container (CIC) system developed by SEEC, Incorporated, for transporting coal and coal by-products. The container is 110 inches in diameter and 10 feet high, and can hold about 20 tons of material. The container can fit in a railroad car or on a flatbed truck. The CIC was successfully demonstrated in field tests at the Baldwin Power Plant of Illinois Power. During the demonstration, three 9-foot diameter empty CICs were secured to a metal frame, loaded onto a flatbed truck, placed under the flyash silo, and connected to the ash discharge port. Each CIC was filled by gravity flow with about 20 tons of flyash in 10 minutes. The flatbed truck was moved along a rail siding, where the CICs were crane-loaded into a three-bay coal rail car. The three CICs were transported by rail to Norfolk, Virginia, where they were loaded onto barges, then reloaded into the rail car and returned to Illinois. SIU-C will compare the SEEC technology with pneumatic trucks and pressure differential rail cars for transportation and handling of coal by-products.

Ash placement technologies under investigation are high-density pneumatic blind injection (Figure 3) and high-density slurry or paste blind injection (Figure 4). The goal of both injection methods is to place the materials about 300 feet away from the injection point at a rate of 50 to 100 tons per hour.

Laboratory tests have shown that wetting a mixture of flyash and FBC ash releases significant heat, and can raise the temperature of the mix to about 225°F. The temperature rise and potential for swelling will be considered when selecting the mixtures and injection methods during the demonstration test. Preliminary results have shown that 25 to 30 percent

Figure 3. High-Density Pneumatic Blind Injection of Ash

moisture should be suitable for pneumatic placement of FBC ash into underground mines. A minimum of 25 to 30 percent moisture is needed to cause cementitious reactions. It is desirable to inject material with low moisture content because excess water would further weaken the floors and ceilings in the underground mine, and lower the throw distance of the materials. For use in the pneumatic injection method, SIU-C has prepared flyash and spent bed ash mixtures ranging from 50 to 100 percent flyash. The TCLP results on the materials in the mixes show that they are non-hazardous. The compressive strength of the flyash, spent bed ash, and water mixtures is about 30 to 40 psi, which is adequate for control of surface subsidence. In selecting the proper mix of flyash, spent bed ash, and water, SIU-C will consider environmental impact, strength of materials, ratio of flyash-to-spent bed ash compared to typical generation ratio, and mix flowability.

Laboratory tests have shown that about 20 to 25 percent moisture added to a mixture of 60 percent dry scrubber sludge, 36 percent Class F flyash, and 4 percent lime produces a suitable paste for hydraulic injection into underground mines. After placement, this mixture

Figure 4. High-Density Slurry or Paste Blind Injection of Ash

will harden to produce compressive strengths of 400 to 500 psi. SIU-C is considering adding 3 to 4 percent inexpensive plasticizers to the mixtures.

The site for the field demonstration in Phase 3 will be the Peabody Coal Company No. 10 mine located in Christian and Sangamon Counties, Illinois. Background data on local surface subsidence shows movement occurring at an approximate rate of 0.25 to 0.50 inches per year. SIU-C will install additional inclinometers to measure surface subsidence. A geological study of the injection areas is being conducted using data obtained primarily from Peabody Coal Company. The underground mine voids, which will be injected with coal by-products, lie well below potable water levels and are essentially dry.

University of Kentucky - Center for Applied Energy Research
Dry FGD Reclamation Using Addcar™ Highwall Mining System

Highwall mining is a technological breakthrough in coal mining that recovers coal reserves behind the highwall created by surface mining. The Addcar™ Highwall Mining System is the first efficient and reliable system to enter commercial production and sales. It consists of a remotely controlled, camera-guided continuous miner that connects to a series of belt conveyer cars, each 40 feet in length. The cars transport the coal back to the launch vehicle located outside the coal mine entrance. Conveyer cars are added without interrupting mining as the system advances. In this way, previously unminable coal can be recovered efficiently with the highwall miner. Also, the technology is inherently safer than conventional mining, since no personnel go underground, which also eliminates the need for costly roof bolting.

In October 1993, the Center for Applied Energy Research (CAER) of the University of Kentucky was awarded a two-phase, 4-year project to develop methods to backfill the highwall mine adits with dry FGD by-products and/or FBC ash (Figure 5). There are several advantages of using highwall adits and associated mining technology for this purpose. Most of the system can be located outside the mine and operational complexities are reduced. Also, there is no danger to personnel from dust and heat release because the adits are created and filled robotically. Using FGD by-products and FBC ash as a structural backfill for highwall adits include the following advantages:

- Long-term abatement of mine subsidence and reduced hillside slump;
- Recovery of additional coal after eliminating load-bearing coal strata;

Figure 5. Pneumatic Placement Method

- Long-term abatement of acid mine drainage from sealing the mine with low-permeability, alkaline materials; and
- Preservation of deep coal for future mining by reducing the percolation of ground water.

Fluidized-bed combustion ash and dry FGD by-products, such as those produced by spray dryers and lime burner injection, exhibit cementitious behavior when wetted. This is due to the presence of free portlandite or lime in the FBC and dry FGD by-products. Strengths, which approach that of concrete, have been recorded for cured FBC and FGD by-products. The cementitious minerals that develop in the FBC and FGD by-products are calcium sulfo-aluminates, primarily ettringite. FBC and FGD by-products differ from conventional portland cement in that calcium alumino-silicates are the primary cementitious minerals in the latter. The FBC and FGD by-products are also found to expand upon wetting due to both ettringite and gypsum formation. This characteristic, which is undesirable in most applications, is advantageous for backfilling mines because the material may completely fill the adits and become a self-stressing roof support structure.

In Phase 1, the University of Kentucky is conducting laboratory tests to determine the strength stability, heat release, and expansion properties of various mixtures of flyash and bottom ash collected from a Midwestern fluidized-bed combustion co-generation plant. Mixtures of flyash from pulverized coal boiler plants and FBC ash are also being investigated. A complete suite of environmental tests, including both column and batch leaching tests, are also being conducted on the materials. Results indicate that optimum strength is achieved by pre-hydrating the by-products before emplacement in the mine. Both pneumatic and hydraulic transport systems are being considered for filling mine adits with the by-products.

In Phase 2, the University of Kentucky in collaboration with MTI, Incorporated, an Addington subsidiary, will demonstrate the use of FBC ash to backfill a highwall adit in a test mine located in Greenup County, Kentucky. During the field demonstration, an 11.5-foot by 4-foot adit will be backfilled, and the fill will be instrumented with thermocouples and pressure sensors.

Dravo Lime Company
Land Application Uses of Dry FGD By-Products

In September 1991, Dravo Lime Company was awarded a cooperative agreement to develop utilization applications from dry by-products generated by FGD processes. The project is being co-sponsored by the DOE, the Ohio Coal Development Office, American Electric Power, Ohio Edison Company, the Electric Power Research Institute, and Ohio State University. Utilization applications being developed in the project include the following:

- Lime substitute for growing crops;
- Reclamation of acid and toxic mine spoils in active abandoned surface minelands, and stabilization of coal refuse;
- Construction material for road embankment and structural fill; and
- Low-grade cement to stabilize soil.

In the first phase of this project, 54 by-product samples were collected and analyzed from 15 facilities using dry FGD processes or FBC plants. Cyclone and bed ash from the American Electric Power Tidd pressurized fluidized-bed combustion facility was selected for more extensive bench-scale and field-scale studies. The PFBC ash is highly alkaline and primarily contains flyash, anhydrite (CaSO_4), and an unspent dolomite sorbent.

Lime Substitute. After extensive greenhouse tests, Ohio State University conducted a field study in Eastern Ohio using three acidic agricultural soils having a pH of 4.6, 4.8, and 5.8. Cyclone and bed ash from the Tidd PFBC were applied to these soils at rates between zero and double the lime requirement of the soils. Corn and alfalfa were planted in the soils, and soil samples were taken after initial application of FGD by-products and every 6 months thereafter. Results indicated that the soil pH increased as a result of applying the FGD by-products. The pH increased to slightly greater than 7 when adding the PFBC ash at double the lime requirement. Alfalfa yields increased in all three soils as a result of applying the PFBC ash. However, there were no visible effects on corn yield. The studies also showed that calcium, magnesium, and sulfur concentrations increased in the soil, while aluminum, manganese, and iron concentrations decreased in the soil with increasing PFBC ash application rates. Aluminum, manganese, and iron are toxic to most plants. There were no detrimental impacts to the quality of the soil from application of PFBC ash.

Reclamation. About 3.5 million acres of land in the U.S. have been surfaced mined for minerals and require reclamation. One possible method to restore the environment at surface mines is to use alkaline FGD by-products to neutralize the acidity in these areas. Ash from the pressurized fluidized-bed combustor at American Electric Power's Tidd Demonstration Plant in Brilliant, Ohio, was used to evaluate the effectiveness of neutralizing a mine spoil sample obtained from an abandoned surface mine in Franklin Township, Ohio.

In a greenhouse experiment, the PFBC ash was added directly to the mine spoil at rates between 0 to 240 tons per acre, or it was mixed with sewage sludge at an application rate of 60 tons of sewage sludge per acre. Supplemental fertilizer was added to the mixtures, and fescue was planted. After an initial growth period of 3 months, the fescue was harvested each month for a total of six harvests. Fescue did not grow unless the mine spoil was amended with PFBC ash or sewage sludge. For the first three harvests, the fescue growth was greater when sewage sludge was added to the PFBC ash. Before the last three

harvests, fertilizer was added to the area that contained only the PFBC ash and mine spoil, and the growth was greater than the growth previously produced by the sewage sludge/PFBC ash combination. The soil amendments were effective in raising the pH of the mine spoils to levels suitable for vegetation. The leachate concentrations of aluminum and manganese decreased, which is important because these elements are considered toxic to most plants.

To demonstrate reclamation of acid surface mines with FGD by-products, six 1-acre watersheds were constructed at the Fleming Abandoned Mine Land located in Franklin Township, Tuscarawas County, Ohio. The site consists of about 45 acres of unreclaimed spoil and coal refuse. A mixture of 71 percent AFBC ash and 29 percent yard waste compost were applied to two of the watersheds. The application rate of this mixture was 175 tons per acre. Two watersheds were treated with 125 tons per acre of AFBC ash, and two watersheds were reclaimed with re-soil and limestone. The site was seeded in late October 1994 and has produced vegetation. Adjacent areas around the watersheds were reclaimed with PFBC ash and compost for comparison. The project participants will monitor the quality and quantity of groundwater and surface water. In addition, soil samples will be periodically collected and analyzed to evaluate migration of heavy metals and nutrients.

Construction Material. Several successful demonstrations show that PFBC ash can be used as a road construction and repair material. In late 1993, approximately 3,000 tons of PFBC ash from Tidd were used to stabilize a failed embankment on Ohio State Highway 541. In 1994, the same material was used to construct a road base on a portion of the highway. Highway 541 was re-opened in March 1994. Also, approximately 5,000 tons of PFBC ash from Tidd were used to stabilize a failed embankment on Ohio State Route 83 in Guernsey County, Ohio.

Soil Stabilization. Ohio State University has investigated the use of the Tidd PFBC ash and a mixture of wet FGD by-products, lime, and flyash to stabilize the soils in animal pens. Results of compressive strength tests on mixtures of these materials showed that the material can withstand the loads of the animals and equipment used to clean the pens. The permeability of the mixtures was low, which alleviates concerns of animal wastes leaching into the groundwater.

Cattle lot stabilization tests were conducted at Ohio State University's Eastern Ohio Resource Development Center using PFBC cyclone ash from Tidd. The dry cyclone ash was first blended into the top 20 centimeters of soil in a 1,300-square-meter cattle feedlot that had very low strength due to high water and organic content. Strength gains in the PFBC ash-amended soil were rapid. A cover of 20 to 30 centimeters of a blend of cyclone ash and bed ash from Tidd was placed over the stabilized feedlot. Results showed the feasibility of constructing a stabilized base using PFBC ash. The stabilized feedlot reduces the amount of energy that cattle expend in moving to and from the feed troughs, which increases the weight gain of the cattle, and lowers feed costs.

In August 1993, Dravo Lime Company mixed 1,200 metric tons of wet FGD scrubber sludge and flyash from American Electric Power's Conesville Power Station with 5 percent lime to construct two lots, one for storing hay bales and one for feeding brood cows. Each lot was 1,200 square meters. The compressive strength of the mixture was as high as 400 psi after 9 months. Both lots performed satisfactorily. Future performance tests will evaluate the effects of freeze and thaw on the long-term structural integrity of the materials.

U.S. Department of Agriculture
Utilization of FBC Ash in Agricultural Applications

FBC ash from the Black River Co-Generation Plant in Watertown, New York, is being applied to local farmland to provide lime and other nutrients for growing crops. When the ground is too wet for spreading ash, or there are standing crops in the field, the ash is used as a low-strength concrete to stabilize dairy barn feedlots. The stabilized feedlots provide a place for cattle to escape from muddy conditions during the rainy seasons in the spring and fall. Farmers have reacted positively to the stabilized feedlots because dairy cattle feed more efficiently on the stabilized feedlot, and are less likely to contract hoof diseases and mastitis. Also, nitrogen, phosphorus, and fecal coliforms from cattle manure are less likely to contaminate the local groundwater. Stabilized feedlots are also expected to result in less soil erosion.

One concern about the use of FBC ash to stabilize dairy feedlots is the potential for toxic materials to leach from the stabilized feedlots. Preliminary laboratory results indicate that leachate quality from stabilized feedlots using FBC ash is not likely to be a problem in the field. However, field tests would confirm the laboratory results and demonstrate the benefits of using FBC ash in agricultural applications to regulatory agencies and the public.

In September 1994, DOE awarded a 1-year interagency agreement to the U.S. Department of Agriculture (USDA) to investigate the use of FBC ash for agricultural applications. In this project, about 10,000 square feet of the feedlot will be stabilized with about 100 tons of FBC ash from the nearby Black River Co-Generation Plant in Watertown, New York. An adjacent 10,000-square-foot feedlot will remain unstabilized for comparison. The high lime content of the FBC ash will cause the ash-soil mixture in the stabilized feedlot to form a low-strength concrete. The USDA will periodically collect and analyze leachate samples from both feedlots for nitrate, phosphorus, sulfate, and heavy metals to determine the water quality beneath the stabilized and unstabilized feedlots.

In a controlled experiment, six soil core samples from the stabilized feedlot and six soil core samples from the unstabilized feedlot will be fitted with a bottom cap, a leachate collection system, and installed in an area adjacent to the dairy feedlot. Each core sample will be 2 feet in diameter and 2 feet deep. Two cores each from stabilized and unstabilized areas will be treated with cow urine, or cow feces, or left untreated. The USDA will periodically collect and analyze leachates from the core samples for nitrate, phosphorus, sulfate, and heavy metals to determine the water quality beneath the stabilized and unstabilized cores.

The USDA will also investigate at their laboratory in Beltsville, Maryland, the movement of calcium, nitrogen, and phosphorus through soils using plastic columns. The columns will be surface-amended with various mixtures of FBC ash and manure. The USDA will simulate rain in the columns and will periodically collect and analyze leachates for calcium, phosphorus, and nitrogen content. At the conclusion of the tests, the soil cores will be sliced and analyzed to quantify movement of nutrients within the core.

Also, the USDA will grow blackberries in a small outdoor plot using various mixtures of FBC ash, manure, and straw. The plots will be evaluated for plant growth, nutritional status of the plants, and leaching of metals such as boron, cadmium, and arsenic.

3 Other Activities

Report to Congress

In Section 1334 of the Energy Policy Act of 1992, the Congress of the United States charged the Secretary of Energy to "conduct a detailed and comprehensive study on the institutional, legal, and regulatory barriers to increased utilization of coal combustion by-products by potential governmental and commercial users." Coal combustion by-products were defined in the Act to be, "the residues from the combustion of coal including ash, slag, and flue gas desulfurization materials." In July 1994, DOE submitted a Report to Congress entitled "Barriers to the Increased Utilization of Coal Combustion/Desulfurization Byproducts by Governmental and Commercial Sectors" (1994). The report identifies the barriers to increased by-product utilization and recommends actions to be taken to increase the utilization of coal combustion by-products.

The main barriers to increased by-product utilization include inadequate engineering and environmental information, inefficient technology transfer, lack of government leadership in development and promotion of coal by-product utilization, inadequacies of state programs to promote beneficial reuse, and perception of coal by-products as "waste."

The lack of discrimination between coal by-products by Federal and State regulatory agencies is a key regulatory barrier to increased by-product utilization. Without this discrimination, the "waste" designation can trigger case-by-case approval which makes utilization impractical. Also, regulatory agencies need to develop and adopt regulatory compliance tests that realistically predict environmental impacts.

The main legal barrier to increased use of coal by-products is the potential for liability associated with use of a material designated as "waste." The concern among producers and users of coal by-products is that their liability is unacceptably extended beyond that normally associated with use of a commercial material.

The report includes several recommendations to increase the use of coal by-products.

1. Executive Order No. 12873, "Federal Acquisition, Recycling, and Waste Prevention", will be fully implemented with due consideration to use of coal by-products. This includes development of Federal procurement programs that promote the use of coal by-products.
2. DOE and industry will contribute to a database addressing environmental concerns related to coal by-products from advanced coal technologies. The database will assist EPA in determining that coal by-products should fall under Subtitle D of RCRA. This action transfers responsibility of regulating coal by-products to the States.
3. The DOE will work with State and local governments to identify issues or concerns regarding the use of coal by-products within their jurisdictions.

4. DOE will work with State and local governments and coal by-product producers to transfer information targeted to specific utilization markets that addresses environmental and health considerations, engineering properties, and beneficial aspects.
5. DOE will work with EPA, other Federal agencies, and State and local governments to review and revise existing specifications and regulations relating to use of coal by-product uses, and develop new specifications and regulations, if necessary.
6. DOE will participate in highly cost-shared demonstrations that will evaluate the viability and environmental acceptability of high-volume, coal by-product utilization applications, such as bridge and highway construction.
7. DOE will work with technology suppliers and utilities to explore ways to make coal by-products more usable.

Technology Transfer

Recently, the Fossil Energy Waste Management Program has participated in several conferences and workshops for the purpose of transferring program information to regulators; by-product generators, users, and technology developers; and other interested parties.

- April 24-29, 1994. Presented poster session at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage in Pittsburgh, Pennsylvania.
- September 7-8, 1994. Organized and sponsored a Mine Reclamation Workshop at METC.
- September 12-16, 1994. Organized and chaired a session entitled "The Effects of Clean Air Act Amendments on By-Product Utilization" at the Eleventh Annual International Pittsburgh Coal Conference in Pittsburgh, Pennsylvania.
- November 2, 1994. Organized and sponsored a workshop on Mineralogical/Chemical Transformations in Coal By-Products at the Center for Applied Energy Research, University of Kentucky, Lexington, Kentucky.
- January 15-19, 1995. Presented paper and received award on Report to Congress at the American Coal Ash Association's 11th International Symposium on Use and Management of Coal Combustion By-Products in Orlando, Florida.

4 Major Challenges

The Fossil Energy Waste Management Program faces several major technical and non-technical challenges in developing management strategies for solid by-products from advanced coal technologies. The management strategies must be technically, economically, and environmentally viable and acceptable to the coal industry, the public, regulators, and other stakeholders.

Technical Challenges. Technical challenges in the program include the safe handling and transportation of coal by-products to ensure that excessive dusting and premature cementation does not occur during initial handling, temporary storage, or transportation. The expansive and heat release properties of some by-products must be controlled or taken into account when considering handling, transportation, and final management options for the coal by-products.

Regulatory Challenges. Regulatory challenges include uncertainties about how by-products from advanced coal technologies will be regulated in future revisions to RCRA. For example, by 1998, EPA will rule on how solid by-products from FBCs will be managed under RCRA.

Wide variability in state regulations for managing solid by-products discourages potential users of coal by-products. To promote beneficial reuse of coal by-products, regulations from state to state need to be more consistent.

The "waste" stigma associated with solid materials generated by advanced coal technologies impacts the way that regulatory agencies and the public view management of solid by-products.

Much work is needed to remove the barriers to utilization of coal by-products, including legal issues over long-term liability and lack of industrial specifications for using coal by-products.

5 Project Contacts and Schedules

The following is a list of the name, address, and phone number of the principal investigator for each project. The schedule for each project is shown in Figure 6.

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Figure 6. Project Schedules

Note: Numbers indicate project phase with DOE decision point between phases.

Figure 6. Project Schedules (Continued)

M95001150E

6 Acronyms and Abbreviations

As	arsenic
ASTM	American Society for Testing and Materials
ATS	Advanced Technology Systems
Be	beryllium
BDAT	Best Demonstrated Available Technology
BFBC	bubbling, fluidized-bed combustor
C	centigrade
$\text{Ca}_6\text{Al}_2(\text{SO}_4)_3(\text{OH})_{12} \bullet 26\text{H}_2\text{O}$	ettringite
CaCO_3	calcium carbonate or calcite
$\text{Ca}(\text{OH})_2$	calcium hydroxide or portlandite
$\text{Ca}_3\text{Si}(\text{OH})_6(\text{SO}_4)(\text{CO}_3) \bullet 12\text{H}_2\text{O}$	thaumasite
CaSO_4	calcium sulfate or anhydrite
CaSO_3	calcium sulfite
$\text{CaSO}_4 \bullet 2\text{H}_2\text{O}$	gypsum
CCB	coal combustion by-products
CCT	Clean Coal Technology
Cd	cadmium
CFBC	circulating, fluidized-bed combustor
CIC	collapsible intermodal container
cm/sec	centimeters per second
Co	cobalt
Consol	Consolidation Coal Company
Cr	chromium
DOE	U.S. Department of Energy
EP	extraction procedure (RCRA)
F	Fahrenheit
FBC	fluidized-bed combustion/combustor
FE	Fossil Energy
FGD	flue gas desulfurization

GAC	granular activated carbon
Hg	mercury
IMP	Institute of Materials Processing
lb/ft³	pounds per cubic feet
LDR	land disposal restrictions
LIMB	limestone injection multistage burner
MCL	maximum concentration limit
MEA	Morgantown Energy Associates
METC	Morgantown Energy Technology Center
mg/l	milligrams per liter
Mn	manganese
MTU	Michigan Technological University
Na₂SO₄	sodium sulfate
Na₂SO₃	sodium sulfite
Ni	nickel
NL	National Laboratory
NO_x	oxides of nitrogen
OCDO	Ohio Coal Development Office
Pb	lead
PC	pulverized coal
ppmv	parts per million by volume
ppmw	parts per million by weight
PFBC	pressurized, fluidized-bed combustor
psi	pounds per square inch
RCRA	Resource Conservation and Recovery Act
Sb	antimony
SBM	spent bed material
Se	selenium

SIU-C	Southern Illinois University at Carbondale
TCLP	toxicity characteristic leaching procedure (RCRA)
TDS	total dissolved solids
U.S.	United States
USDA	United States Department of Agriculture
WM	Waste Management
WVU	West Virginia University
Zn	zinc

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Figure 1. Concrete Lysimeters

Figure 2. Typical Landfill with Monitoring Instrumentation

Figure 3. High-Density Pneumatic Blind Injection of Ash

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Figure 4. High-Density Slurry or Paste Blind Injection of Ash

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Figure 5. Pneumatic Placement Method

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