ENHANCING THE ENVIRONMENTAL PERFORMANCE OF COAL-FIRED POWER PLANTS – DOE'S INNOVATIONS FOR EXISTING PLANTS PROGRAM

Thomas J. Feeley, III
Technology Manager
Innovations for Existing Plants Program
National Energy Technology Laboratory
Office of Fossil Energy
U.S. Department of Energy

ABSTRACT

The U. S. Department of Energy (DOE) has established a set of national priorities that includes the goal to promote secure, competitive, and environmentally responsible energy systems that serve the needs of the public. The Innovations for Existing Plants (IEP) program, managed by the Office of Fossil Energy's National Energy Technology Laboratory (NETL), provides technological solutions to the myriad of environmental issues (air, solid, and water) affecting the existing fleet of coal-based power plants representing more than 320 gigawatts (GW) of generating capacity. The program also provides high-quality scientific information on present and emerging environmental issues for use in regulatory and policy decision making.

The IEP program focuses on the development of advanced technologies for controlling emissions such as mercury, particulate matter, and nitrogen oxides from coal-fired power plants. In addition, the program includes research related to the characterization and utilization of coal combustion and gasification by-products and power plant air quality issues. Research has also recently been initiated to address the intimate link between thermoelectric power generation and water quality and sustainability. The activities carried out under the IEP program help to maintain coal's strategic role in the nation's energy mix while meeting the challenge of providing America with reliable, affordable, and environmentally sound energy well into the 21st century.

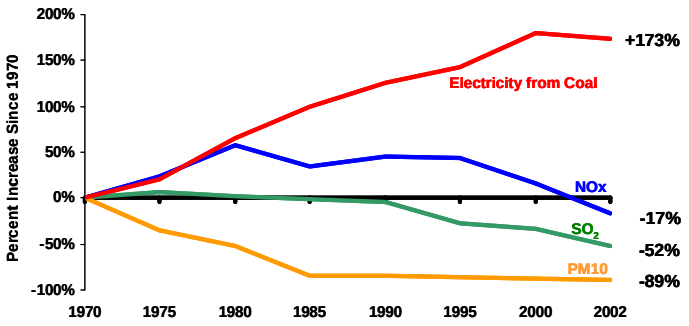
BACKGROUND AND REGULATORY DRIVERS

More than one billion tons of coal per year is currently mined in the United States, with well over 900 million tons used domestically. About 90% of all coal consumed in the U.S. is used for electricity generation, representing more than half of all domestic electricity production. As electricity demand is anticipated to grow by nearly 1.8% annually over the next 20 years, by the year 2025 more than 100 GW of new coal-fired steam-electric generation is expected.[1] While tomorrow's electricity generation may likely see an increase in advanced systems such as integrated gasification combined cycle (IGCC) technology, the United States will continue to rely on the existing fleet of pulverized–coal (PC)-fired power plants. These units (nearly 320 GW capacity) currently generate over 1,900 billion kilowatt-hours per year of electricity and represent the baseload supply of stable

and affordable energy that has fueled the nation's economic growth and prosperity for decades.

Since passage of the 1970 Clean Air Act (CAA) and subsequent amendments in 1977 and 1990, tremendous strides have been made in reducing emissions of sulfur dioxide (SO_2), nitrogen oxides (NOx), and particulate matter (PM) from coal-fired power plants. For example, full implementation of the acid rain provision of the 1990 CAA Amendments (Title IV) provides in an annual cap on power plant SO_2 emissions of 8.9 million tons, down from a 1970 level of nearly 16 million tons. In addition, NOx emissions have been reduced from 6.0 million tons in 1996 to 4.2 million tons in 2003. Beginning in 2003, a portion of the NOx reductions is a result of implementation of the NOx State Implementation Plan (SIP) call. The NOx SIP call requires plants in the Eastern U.S. to reduce NOx emissions during the 5-month summer ozone season to a level equivalent to 0.15 lb/10^6Btu. Finally, the installation of controls on essentially the entire fleet of coal-fired plants brought about a dramatic decrease in primary particulate emissions. Annual emissions of particulates smaller than 10 micrometers (PM10) in 2003 were less than 250,000 tons compared with early-1970 emission levels that exceeded 1.6 million tons[2]. Figure 1 presents a summary of U.S. coal use for power generation and air emissions trends. The declines in emissions of SO_2, NOx, and PM10 are made even more dramatic in light of the fact that during the last three decades there has been nearly a two-fold increase in coal consumed to produce electricity.

Figure 1 – U.S. Coal Use and Emissions



While the environmental performance of the Nation's coal-fired plants has steadily improved over the last thirty four years, further restrictions on emissions have been proposed in response to issues such as mercury, acid rain, ground-level ozone, nitrification of aquatic ecosystems, ambient fine particulate matter, and visibility impairment (regional haze).

With regards to mercury, coal-fired power plants are the largest single source of man-made emissions in the United States, emitting approximately 48 tons annually. In December 2000, EPA determined the need to regulate mercury from power plants because of the "plausible link" between emissions and environmental and human-health impacts. On January 30, 2004, EPA published a notice of proposed rulemaking that included two primary options to reduce mercury emissions from coal-fired power plants. The first is to regulate mercury as a hazardous air pollutant under CAA Section 112 that would establish maximum achievable control technology (MACT) emission rate limits. Under this set of standards EPA estimates that U.S. coal-fired mercury emissions could be reduced by up to 29% from 1999 baseline emissions. Compliance would be required by 2008, or three years after the rule is implemented. The second option is to regulate mercury under CAA Section 111 that would institute performance standards for new units and a nationwide cap-and-trade allowance program applicable to new and existing sources. This option would be implemented in two phases. The first phase, beginning in 2010, would require a mercury emissions cap equivalent to the co-benefit reductions of existing SO_2 and NO_x control technology (anticipated 34 ton cap equivalent to 29% reduction from 1999 baseline levels), while the second

phase would require a 15 ton cap (approximately 69% reduction from 1999 baseline levels) beginning in 2018. The EPA plans to issue the final mercury rule by March 2005.

In addition, several multi-pollutant-control bills have been introduced in Congress to address mercury emissions from utility power plants for the first time, including the Clear Skies Act that embodies the recommendations made in the President's February 14, 2002 Clear Skies Initiative. These proposals also target further reductions in SO_2 and NOx beyond the existing acid rain and ozone requirements of the CAA.

Sulfur dioxide and NOx emissions reductions have also been targeted under EPA's proposed Clean Air Interstate rule (CAIR). The proposed reductions in both SO_2 and NOx are intended to assist the eastern U.S. achieve compliance with the fine particulate matter (PM2.5) and eight-hour average ozone National Ambient Air Quality Standards (NAAQS). The proposed SO_2 and NOx emission reductions would be implemented in two phases, with a Phase I compliance date of January 1, 2010, and a Phase II compliance date of January 1, 2015. The SO_2 and NOx region-wide emissions and caps are shown in the table below. The EPA plans to issue the final CAIR rule by the end of 2004.

For primary particulate matter, essentially all coal-fired plants utilize electrostatic precipitators (ESPs) or fabric filters (baghouses). However, future regulatory developments may require higher collection efficiencies, particularly for submicron particles, that may not be achievable with existing technologies. Moreover, the existing population of ESPs is aging with concomitant impacts on performance. In addition, Section 313 of the Emergency Planning Community Right to Know Act - known as the Toxic Release Inventory (TRI) – requires electric utilities to make public their annual releases of specific air "toxics" such as acid aerosols like sulfuric acid (H_2SO_4), hydrogen chloride (HCl), and hydrogen fluoride (HF) from coal-fired power plants. While TRI is solely a reporting requirement, the public's interpretation of and reaction to the data could bring about pressure to further control air toxics. Irrespective of the how or why, the future may see a call for further controls on primary particulate and air toxic emissions from coal-based power systems.

Coal-fired power plants also generate significant quantities of solid byproducts such as fly ash. The American Coal Ash Association estimates that more than 88 million tons of ash (fly and bottom) were generated in 2003, along with another 29 million tons of flue gas desulfurization (FGD) by-product[3]. Other methods of electricity generation from coal, such as IGCC and fluidized bed combustion (FBC), also generate a solid by-product. Collectively, DOE/NETL refers to these materials as coal utilization by-products (CUBs).

Currently, CUBs are regulated as solid waste under the Resource Conservation and Recovery Act (RCRA), with management requirements typically left to individual states. Although the "Bevill amendment" to RCRA exempted CUBs from classification as hazardous waste, EPA has continued to revisit the appropriateness of that exemption. Approaches to reduce mercury emissions from coal-fired power plants will likely lead to increased concentrations of mercury in fly ash or other coal by-products. Because the behavior and stability of mercury in the solid by-products is not clearly understood, the long-term regulatory status of CUBs remains uncertain. Further, the call for more stringent emission reductions through multi-pollutant regulations has the potential to alter the future utilization of CUBs and may make certain by-products unsuitable for current applications.

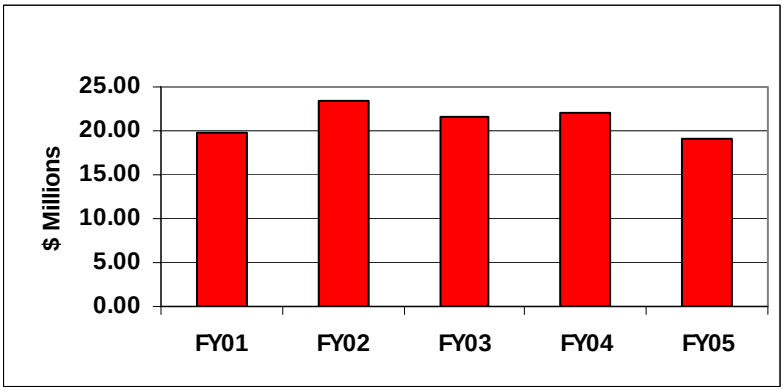
Finally, there is also an inextricable link between coal-based power plants and water. Thermoelectric power plants rank only slightly behind irrigation in terms of freshwater use in the United States, withdrawing over 132 billion gallons per day primarily for cooling.[4] Concerns about freshwater sustainability brought on by persistent drought, competition with domestic, industrial, agricultural, and in-stream use sectors, and other factors are impacting the operation of existing coal-based power plants and the siting and permitting of new plants. This has become most apparent in parts of the West, Southwest, and Southeast where conflicts over water rights are an almost a daily occurrence. Further restrictions on cooling water withdrawal under the Clean Water Act and potential tighter drinking water and effluent standards for mercury, arsenic, and other trace metals will also place added pressures in the future on how coal-fired power systems use and impact the Nation's limited freshwater resources.

INNOVATIONS FOR EXISTING PLANTS PROGRAM

The Innovations for Existing Plants program is a comprehensive, integrated in-house and extramural research and development (R&D) effort focused on advanced technologies that assist 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 IEP portfolio includes laboratory through field-scale R&D related to the control of mercury, NOx, particulate matter, and acid gas emissions from coal-based power plants, as well as research in coal utilization byproducts, water use and management, and air quality. Funding on a fiscal year basis has averaged around $20 million over the past five years as shown in Figure 2. Key to the success of the IEP program is the partnership, collaboration and cost-sharing with industry, Federal and state agencies, research organizations, academia, and non-Government organizations.

Figure 2 – Innovations for Existing Plants Program Funding



The following is a brief summary of each of the components of the IEP program along with a capsule description of specific projects being carried out in each program area.

MERCURY CONTROL TECHNOLOGY

The mercury control technology component of the IEP program is aimed at providing a broad suite of options to respond to future requirements to reduce mercury emissions from power plants. Currently there are 26 active projects, 14 involving field testing and 12 at the bench or pilot stage. Research is being carried out at the bench- and pilot-scale through field testing of promising technologies at operating power plants. The nearer-term objective is to develop mercury control technologies that achieve 50–70% mercury capture at less than three-quarters of the baseline cost estimate of $50,000–70,000 per pound of mercury removed. The aim is for these technologies to be available for commercial demonstration by 2005 for bituminous coal plants and 2007 for lignite and subbituminous plants. The longer-term goal is to develop advanced mercury control technologies to achieve 90% or greater capture at the same cost reduction target and be available for commercial demonstration by 2010. The following is a brief summary of some of DOE/NETL's current mercury control technology R&D projects.

Phase II Mercury Control Technology Field Testing

As a result of a recent competitive solicitation, DOE/NETL selected 14 new projects to carry out long-term, large-scale field testing of advanced mercury control technology at operating coal-fired power plants. Testing will be performed at more than 30 power plant sites on a broad range of coals (bituminous, subbituminous, lignite, and blends) and air pollution control device configurations. These tests will provide important information on mercury removal effectiveness, cost, and the potential impacts on balance-of-plant operations.

- ADA -ES is evaluating the use of sorbent injection to remove mercury for a variety of coal and air pollution control equipment configurations. Testing is being conducted at four power plants: (1) Sunflower Electric's Holcomb Station that burns a blend of subbituminous Powder River Basin (PRB) and bituminous coal; (2) Detroit Edison's Monroe Station that burns a blend of PRB and bituminous coal; AmerenUE's Meramec Station that burns PRB coal; and (4) American Electric Power's (AEP) Conesville Station that burns bituminous coal.

- Amended Silicates, LLC (a joint venture of ADA Technologies, Inc. and CH2M Hill), is testing a new non-carbon sorbent, Amended Silicates™, for providing cost effective mercury capture while avoiding adverse impacts on fly ash sales. The testing is being conducted at Cinergy's 175 MW Miami Fort Unit 6 that burns bituminous coal and is equipped with an electrostatic precipitator (ESP).

- URS Group, Inc. is testing sorbent injection technology upstream of a small specific collection area ESP at Southern Company's Plant Yates Unit 1 & 2 that burns bituminous coal.

- URS is also conducting pilot-scale testing of four fixed-bed catalysts that have been shown to be effective in oxidizing elemental mercury in order to increase overall mercury capture in downstream wet FGD systems. The testing is being conducted at Georgia Power's Plant Yates that burns bituminous coal and is equipped with an ESP and wet FGD and TXU's Monticello Station Unit 3 that burns Texas lignite and is equipped with an ESP and wet FGD.

- URS is also testing EPRI's Mercury Control via Adsorption Process (MerCAP™) technology. The process involves placing a regenerable, fixed-structure gold sorbent into the flue gas stream to capture mercury. The testing is being conducted at Southern Company's Plant Yates that burns bituminous coal and is equipped with an ESP and wet FGD and Great River Energy's Stanton Station that burns North Dakota lignite and is equipped with a spray dryer adsorber and fabric filter (SDA/FF).

- The University of North Dakota Energy & Environmental Research Center (UNDEERC) is testing enhancements to activated carbon sorbent injection to increase mercury capture for plants burning low-rank lignite coals. Because of low-chlorine and high-calcium content, lignite produces higher levels of elemental mercury, which is more difficult to remove. Two different technology approaches will be evaluated: (1) injection of chlorine-based additives in conjunction with activated carbon sorbents, and (2) injection of chemically treated activated carbon sorbents. The first approach is being tested at Basin Electric's 210 MW Leland Olds Station Unit 1 and the 440 MW Antelope Valley Station Unit 1. The second approach is being tested at Great River Energy's 140 MW Stanton Station Unit 1 and the 60 MW Stanton Station Unit 10. The four plants burn North Dakota lignite and use either an ESP or SDA/FF.

- UNDEERC is also testing the effectiveness of using chlorine-based additives without supplemental sorbent injection to increase mercury oxidation and therefore enhance mercury capture at two lignite-fired plants equipped with an ESP and wet FGD. Testing is being conducted at Minnkota Power Cooperative's Milton R. Young Unit 2 that burns North Dakota lignite and TXU's Monticello Unit 3 that burns Texas lignite.

- Sorbent Technologies Corporation is testing a halogenated activated carbon sorbent that can be used as a cost effective alternative to commercial activated carbon injection for mercury capture. The testing is being conducted at Duke Energy's 140 MW Buck Plant that burn bituminous coal and is equipped with a hot-side ESP and Detroit Edison's 80 MW St. Clair Station that burns a blend of bituminous and subbituminous coal and is equipped with a cold-side ESP.

- ADA-ES is testing two new mercury control technologies: TOXECON II™, and unique sorbents for injection into hot-side ESPs. The TOXECON II™ technology will be tested at AEP's Gavin Station which burns bituminous coal and Entergy's Independence Station which burns PRB coal. The novel sorbents for hot-side ESPs will be tested at MidAmerican's Council Bluffs Energy Center and MidAmerican's Louisa Station, both of which burn PRB coal.

- ALSTOM Power, Inc. is testing its proprietary chemically-treated activated-carbon-based sorbent, which promotes mercury oxidation. Testing will be conducted at three utilities burning different coals: (1) PacificCorp's Dave Johnston Plant which burns PRB coal; (2) Basin Electric's Leland Olds Station which burns North Dakota lignite; and (3) Reliant Energy's Portland Station which burns bituminous coal.

- GE Energy & Environmental Research (GE EER) has developed a new, cost-effective technology that combines mercury removal with nitrogen oxide emission control. GE EER will

conduct a field demonstration of its technology at Tennessee Valley Authority (TVA)'s John Sevier Station which burns a bituminous coal.

- Sorbent Technologies is testing how the injection of a specific kind of carbon (brominated powdered activated carbon (B-PAC™)) can cost-effectively reduce mercury emissions from power plants. Tests will be conducted on both cold-side and hot-side electrostatic precipitators using the brominated carbon, as well as Sorbent Technologies' own concrete-safe version of the brominated carbon. Testing will be conducted at three sites: (1) Midwest Generation's Crawford Station which burns subbituminous coal; (2) Midwest Generation's Will County Station which burns subbituminous coal; and (3) Progress Energy's Lee Station which burns bituminous coal.

- UNDEERC is evaluating the long-term feasibility of using activated carbon injection to reduce mercury emissions from a plant that burns either Texas lignite or a lignite-subbituminous coal blend. UNDEERC will conduct the field test at TXU Energy's Big Brown Steam Electric Station. The project will test several activated-carbon injection options to cost-effectively remove mercury from lignite combustion gases.

- URS is demonstrating the use of an additive in wet lime or limestone FGD systems. The additive is designed to prevent oxidized mercury from being reduced and subsequently re-emitted into power plant flue gas streams as elemental mercury. This project represents the first known demonstration in the United States of the additive to prevent mercury re-emissions from wet FGD systems in coal-fired power plants. Testing will be conducted at three sites: (1) TXU's Monticello Station which burns lignite coal; (2) Georgia Power's Plant Yates which burns bituminous coal; and (3) AEP's Conesville Station which burns bituminous coal.

Bench- and Pilot-Scale Testing

DOE/NETL is also supporting the bench- and pilot-scale development of six novel concepts.

- UNDEERC is evaluating mercury control performance of sorbent injection used in conjunction with the *Advanced Hybrid* particulate collector, a combination ESP and fabric filter (FF) system designed to optimize fine particulate collection.

- URS Corp. is evaluating the performance of several fixed-bed catalyst materials to promote the oxidation of elemental mercury in the combustion flue gas that would enhance overall mercury capture in plants equipped with wet FGD systems.

- CONSOL Energy Inc. is evaluating air heater operation at lower flue gas temperatures to condense mercury onto the fly ash that is captured in an ESP. An alkaline sorbent is injected in the flue gas to reduce the SO_3 concentration in order to prevent excessive corrosion while operating at the lower temperature.

- Southern Research Institute is testing the effectiveness of calcium-based chemicals, such as lime

and silica lime additives, to capture and oxidize mercury into a form more easily removed from a power plant's flue gas. The calcium sorbents are also capable of removing sulfur pollutants.

- Powerspan Corp. is evaluating the mercury control performance of the multi-pollutant electro-catalytic oxidation (ECO) process designed for the simultaneous removal of SO_2, NO_x, and fine particulate emissions from coal-fired plants. The ECO reactor converts elemental mercury to oxidized mercury that can then be captured in the ammonia-based reagent wet FGD absorber component of the ECO process.

- Apogee Scientific Inc. is assessing the mercury capture performance of low-cost novel sorbents as potential alternatives to commercially available activated carbon. More than 40 sorbents are being tested, including activated carbons prepared from coal, biomass, and tires; char (mildly activated carbon); unburned carbon from fly ash; and zeolite sorbents.

- UNDEERC conducted a field testing program to determine the effect NOx SCR and SNCR controls have on the speciation of mercury in the combustion flue gas and resultant enhancement of mercury captured in downstream pollution control equipment. The field testing was conducted over three years (2001-03) on a total of 12 coal-fired power plants burning a variety of coal types and equipped with an SCR, SNCR, or flue gas conditioning system. Two of the plants with SCR were tested in each of the three years to evaluate possible changes in mercury oxidation over time as a result of catalyst aging.

- CONSOL is conducting mercury speciation field-testing at ten bituminous coal-fired power plants equipped with both SCR and FGD systems. The objective of the study is to measure the level of mercury oxidation across the SCR and subsequent removal in the downstream FGD system. The 27-month long program includes testing at five plants equipped with an SCR and wet limestone FGD, three plants with an SCR and wet lime FGD, and two plants with an SCR and dry lime FGD.

- Reaction Engineering International (REI) recently completed a six-month pilot-scale mercury speciation test for five commercially-available NOx SCR catalysts using a flue gas slipstream. Parametric testing evaluated the effect of space velocity (residence time) and ammonia feed rate on mercury oxidation across the SCR catalysts. Testing was conducted at AEP's 1,300 MW Rockport Power Plant Unit 1 that burns a blend of PRB and bituminous coal.

- UNDEERC conducted mercury measurements at three Midwest Generation coal-fired power plants to develop mercury emissions speciation data and determine mercury emissions variability. The mercury continuous emissions monitors were evaluated and verified using the Ontario Hydro test method.

- UNDEERC conducted long-term testing of mercury continuous emission monitors at two power stations: First Energy's Sammis Plant and Texas Utilities' Monticello Plant. Although bench-, pilot-, and full-scale data have been generated that show the potential of these instruments to provide accurate results, reliable longer-term continuous operation of these instruments is needed.

- NETL's in-house research group is developing two mercury control concepts. The THIEF process removes mercury from coal combustion flue gas by adsorption/absorption onto thermally activated sorbent produced in-situ. The sorbent consists of semi-combusted coal, which is extracted from the furnace and then injected into the flue gas downstream of the air preheater. In addition, a photochemical mercury removal process, dubbed the GP-254 process, uses 253.7-nm ultraviolet light to induce many components of flue gas to react with elemental mercury and subsequently cause an increase in the fraction of oxidized mercury. The oxidized mercury species can then be captured near the radiation zone or in downstream particulate control or wet FGD pollution control equipment. Small-scale laboratory testing using simulated flue gases have been used to demonstrate the process. A preliminary cost analysis suggests that annual operating costs for the GP-254 process could compete with activated carbon injection systems.[5]

NOx CONTROL TECHNOLOGY

In view of current and future NOx emission regulations, the development of advanced NOx control technologies remains an important part of the IEP program. Ten projects in various stages of completion are being carried out to address three specific performance goals. These goals are to develop combustion control technologies for existing plants with a NOx emission rate of 0.15 lb/10^6 Btu by 2007 and 0.10 lb/10^6Btu by 2010, while achieving a levelized cost savings of at least 25% compared to state-of-the-art SCR control technology. A longer-range goal is to further develop a combination of advanced combustion and SCR control technologies to achieve a NOx emission rate of 0.01 lb/10^6 Btu by 2020. The technologies under development are: (1) to have negligible impact on balance-of-plant issues, (2) applicable to a wide range of boiler types and configurations, and (3) capable of maintaining performance over a wide range of feed coals and operating conditions. The research portfolio includes advanced combustion controls, advanced flue gas treatment, and integrated control systems.

- ALSTOM recently completed pilot-scale testing of an ultra-low-NOx integrated combustion system for tangential-fired boilers capable of holding NOx emissions to 0.15 lbs/10^6 Btu for bituminous coal and 0.10 lb/10^6 Btu for subbituminous coal without increasing the amount of unburned carbon in the fly ash. Among the technologies evaluated were finer coal grinding, oxidative pyrolysis burners, windbox auxiliary air optimization, and various burner zone firing arrangements in concert with overfire air. Other technologies, such as an advanced boiler control system, coal and airflow balancing, and a carbon burn out combustor, were evaluated. Nineteen commercial boilers firing subbituminous coal that utilize aspects of the technologies demonstrated in this project are achieving NOx emissions at or below 0.15 lb/10^6 Btu.

- Praxair recently completed pilot-scale testing of a process using oxygen-enhanced combustion and over-fire air for reducing NOx emissions below 0.15 lbs/10^6 Btu. The process replaces a small fraction of the combustion air with oxygen. In addition to the reduction in NOx, benefits can be achieved in the areas of reduced unburned carbon and opacity, increased boiler efficiency, and reduced fan limits. Demonstrations at two utility boilers have proven these benefits of the technology while decreasing the NOx emissions.

- McDermott Technology, Babcock & Wilcox, and Fuel Tech are conducting pilot-scale testing to develop a low-cost integrated NOx control system applicable to wall-fired boilers that combine an ultra-low NOx burner with selective noncatalytic reduction (SNCR). NOx emissions of less than 0.20 lb/10^6 Btu were achieved on high volatile bituminous and subbituminous coals.

- The Gas Technology Institute is conducting pilot-scale testing of a NOx control technology known as METHANE de-NOx that integrates natural gas-fired coal preheating, low-NOx burners, and overfire air. Preheating the coal allows the nitrogen in the fuel to form molecular nitrogen instead of NOx. The potential market encompasses wet- and dry-bottom boilers of varying configurations.

- REI recently conducted field-testing of the Rich Reagent Injection (RRI) process combined with overfire air and SNCR for NOx reduction at two coal-fired power plants with cyclone burners – Conectiv's 138 MW B.L. England Unit 1 and AmerenUE's 500 MW Sioux Unit 1. RRI uses injection of ammonia or urea into the lower furnace to non-catalytically reduce NOx emissions. A NOx emission rate of approximately 0.25 lb/10^6 Btu was achieved during the testing.

As the NOx control technologies currently underdevelopment move toward demonstration and commercialization, the NOx program targets are continuously reevaluated. In light of the proposed EPA CAIR rule and Congressional multi-pollutant legislation, the challenge will be to develop cost-effective NOx control technologies for the smaller, older, less efficient power plants that are not easy candidates for the current state-of-the-art SCR controls because of space constraints and the reluctance of owners to invest large capital expenditures in the aging plants. In response, DOE/NETL has initiated the following five projects that target both the existing fleet and new capacity.

- ALSTOM will develop an enhanced combustion, low NO_x pulverized coal burner, and integrate the burner into its own state-of-the-art low NO_x firing systems. This integrated approach will provide an option for meeting proposed legislation calling for less than 0.15 lb/10^6 Btu of NOx at three-fourths the cost of SCR. ALSTOM will conduct large pilot-scale testing in its industrial-scale burner facility in Windsor, Connecticut.

- Babcock & Wilcox will develop and demonstrate an advanced NOx control technology to reach an ultra-low emission target 0.10 lb/10^6 Btu of NOx when burning high-volatile eastern bituminous coal. Along with co-participant American Air Liquide, Babcock & Wilcox will use a "layered" strategy that combines deep air staging, continuous corrosion monitoring, advanced combustion-control enhancements, and proprietary combustion techniques involving oxygen injection.

- FERCo will use a three-pronged approach to demonstrate how the operating costs of SCR can be reduced. FERCo and its team will first develop an *in situ* device to collect real-time SCR performance data by continuously measuring catalyst activity. The results of this analysis will provide timely information about catalyst deactivation to enhance decision-making about boiler operating conditions that negatively impact catalyst activity, and subsequent catalyst

replacement to lessen overall SCR operating costs.

- REI will apply field testing and combustion modeling to evaluate a technology called advanced layered technology application (ALTA) as a means to achieve emissions below 0.15 lb/10^6 Btu of NOx in a cyclone boiler. The technology combines deep staging from overfire air, Rich Reagent Injection, and a novel selective non-catalytic reduction approach. Tests will also evaluate the impact on balance-of-plant issues such as the amount of unburned carbon in the ash, slag tapping, waterwall corrosion, ammonia slip, and heat distribution.

- In another project, REI will develop and verify the performance of a fundamentally different approach of burner design for NOx control. The objective of the burner design is to achieve homogeneity of the combustion products in the boiler. REI will conduct pilot-scale testing to optimize the near-burner combustion system and reagent injection, as well as computational modeling to guide the optimization and demonstrate its promise at full-scale.

FINE PARTICULATE AND ACID GAS CONTROL TECHNOLOGY

While the IEP program is not currently funding research in the area of fine particulate and acid gas control, several projects have recently been carried out directed at better managing these pollutants from coal-fired power plants. The goal of these projects was to achieve an outlet emission level of 0.01 lb/10^6Btu or less and 99.99% collection efficiency of primary particles in the 0.1 to 10 micron particle size range or to reduce acid gases by 90% or more at a levelized cost savings of at least 25% over conventional state-of-the-art controls (i.e., ESPs and baghouses). The projects are described below.

Project Descriptions

- UNDEERC has developed a new concept in particulate control called an advanced hybrid particulate collector (advanced hybrid). The advanced hybrid closely integrates ESP and filter bag technologies into the same housing. The advanced hybrid has less than half the normal number of ESP components and 65%–75% fewer bags than a conventional fabric filter.

- LSR Technologies tested the Advanced ElectroCore system, which is a polishing device for under-performing ESPs that also has multi-pollutant control capabilities. The system consists of a conventional upstream ESP, a dry SO_2 scrubber, a particle precharger and an Advanced ElectroCore separator.

- ADA-ES has developed and tested a family of cohesivity modifying flue gas conditioning agents. Improving the cohesivity and agglomeration of fly ash particles via flue gas conditioning is a proven means of increasing the collection efficiency of an ESP.

- URS Corp. has completed testing of furnace injection of calcium- and/or magnesium-based alkaline sorbents on full-scale utility boilers to control emissions of H_2SO_4. Sulfuric acid is a TRI species that can cause a variety of plant operation problems such as air heater plugging and

fouling, back-end corrosion, and plume opacity. These issues will likely be exacerbated with the installation of SCR for NOx control as SCR catalysts can oxidize a portion of the flue gas SO_2 to SO_3.

AIR QUALITY RESEARCH

Thirteen projects are being performed under the air quality research component of the IEP program. These projects fall in to three general categories of research -- monitoring, modeling, and emissions characterization. The ambient monitoring and modeling activity is designed to obtain a better understanding of the contribution of coal-fired power plants to concentration and composition of ambient particulate matter less than 2.5 micron in size (PM2.5) and regional haze. Emissions characterization is designed to obtain detailed information on fine particulate and mercury emissions from coal-based power systems, both in-stack and in the resultant plume. A description of the projects is provided below.

Project Descriptions

- CONSOL Energy is addressing indoor and outdoor air quality through a project called SCAMP (Steubenville Comprehensive Air Monitoring Project). The objective of SCAMP is to measure the concentrations of PM2.5 and other potential air pollutants at ambient monitoring stations in and around Steubenville, OH, and relate them to the human exposure.

- In cooperation with key stakeholders including EPA, local and state environmental agencies, industry, and academia, Advanced Technology Systems has established the Upper Ohio River Valley Project (UORVP), a network for monitoring and characterizing PM2.5 in the Upper Ohio River Valley.

- In 2002, TVA completed a study to collect and interpret air quality data in the Great Smoky Mountains National Park. This study provided a better understanding of the relationship between coal-fired electric utility boiler emissions and PM2.5, ozone, and nitrogen loading, the associated impact of these pollutants on the environment, and the need for future control strategies.

- Southern Research Institute (SRI) is operating a research station in North Birmingham, Alabama for monitoring PM2.5 within that region.

- In 2003, Carnegie Mellon University (CMU) completed a project to develop a state of the art dilution sampler to simulate the dilution and cooling processes that coal combustion products undergo in the atmosphere. The initial objective of this investigation was to determine the quantity and characteristics of secondary PM2.5 emissions from a pilot-scale pulverized coal combustor, with later application to full-scale power plants.

- In 2002, TVA completed a study to assess the impact of the installation of a high-efficiency wet scrubber and NOx control technology on primary and secondary fine particulate formation at the Cumberland Power Plant.

- DOE/NETL is an active collaborator in the Pittsburgh Air Quality Study (PAQS) at CMU. PAQS is comprised of three inter-related components: 1) ambient PM measurements, 2) source characterization, and 3) deterministic and statistical air quality modeling. This effort will permit clarification of the contribution of coal-fired power plants to fine ambient PM2.5. The resources from DOE/NETL will be leveraged with resources from EPA and other organizations.

- EPRI, TVA, and UNDEERC conducted field studies at two coal-fired power plants to characterize the speciation of mercury in the stack plume. The tests included simultaneous mercury measurements in the stack and stack plume using aircraft instruments. The in-stack and stack plume measurements are being compared to determine whether the speciation of mercury changes as it is transported downwind in the plume.

In addition to air quality activities, DOE/NETL has initiated research directed at better understanding the potential health effects associated with coal-fired power plant emissions.

- EPRI is conducting a study titled "Toxicological Evaluation of Realistic Emissions of Source Aerosols" known as TERESA. The objective is to investigate and clarify the impact of the sources and components of PM2.5 on human health via a set of realistic animal exposure experiments. The DOE-sponsored portion of the TERESA program, is designed to assess the toxicity of coal combustion emissions in the Midwestern and Eastern U.S. by exposing laboratory animals to actual plant emissions that have been "aged" and converted to reaction products in a manner that simulates the conversion experienced by coal power plant plumes in the atmosphere en route to ambient receptor sites.

- Brookhaven National Laboratory (BNL) is performing an assessment of the reduction in human health risk that may be achieved through reduction in coal plant emissions of mercury. The primary pathway for mercury exposure is through consumption of fish. The most susceptible population to mercury exposure is the fetus. Therefore, the risk assessment focuses on consumption of fish by women of child-bearing age.

- The University of Pittsburgh will conduct a study titled "Design and Feasibility Assessment for a Retrospective Epidemiological study of Coal Fired Power Plant Emissions in the Pittsburgh, Pennsylvania Region," to determine if a retrospective epidemiological study could produce reliable health-effects estimates for coal-fired power plant emissions. The work involves initiating a comprehensive inventory and assessment of air-monitoring data in the Pittsburgh region with similar inventory and assessment of available health data from 1999 to 2003. An overall strategy will be developed and assessed based on the project's ability to isolate the effects of coal-plant emissions on human health in the Pittsburgh region.

- EPRI will evaluate the potential for adverse cardiopulmonary effects from short-term exposure to coal plant and traffic-related particulate matter by conducting a multi-site field study. The project features a mobile ambient particle concentrator coupled with a mobile toxicological laboratory to evaluate the effects of particulate matter from different sources. The mobile equipment will be deployed in three locations – one (Ambassador Bridge, Detroit, MI) where the

PM2.5 is dominated by traffic emissions, one (M.K. Goddard State Park, northwest PA) where secondary PM2.5 from coal plant emissions is dominant, and one in an urban area (Steubenville, OH) containing a mix of coal plant, traffic and other industrial source emissions. Animal data that is directly comparable to exposure in humans will be generated, combining toxicology, epidemiology and exposure assessment.

- Lovelace Biomedical & Environmental Research Institute is conducting a toxicological evaluation of cardiorespiratory effects by exposing rats and mice of various strains (ages, and gender) to a mixture of particulate matter and gases from a laboratory coal combustor whose emissions have been processed to simulate actual downwind emissions from coal-fired power plants. Coal-emissions exposure data will be compared with diesel and gasoline emissions, hardwood smoke, and street dust using an identical experimental protocol. Evaluations will be conducted using the National Environmental Respiratory Center's framework, allowing for direct comparisons among source categories and providing a database of health effects analyses extending across a variety of source compositions.

COAL UTILIZATION BY-PRODUCTS

The goal of the CUB research activity is to increase the use of coal utilization byproducts (Cubs) in the United States from current levels of about 35% to 50% by 2010. Achieving this goal will be challenging 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 fly ash 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.

Many of the DOE/NETL CUB projects are being conducted through two consortia - CARRC and CBRC. Since 1998, DOE/NETL has sponsored the Coal Ash Resources Research Consortium (CARRC)[6]. CARRC is an international consortium of industry and government representatives, scientists, and engineers working together to advance coal ash utilization and is administered by the UNDEERC. Also formed in 1998, DOE/NETL's Combustion By-Products Recycling Consortium (CBRC)[7] is administered through West Virginia University's Water Research Institute. Academia, industry associations, federal and state regulatory agencies, and power generators provide assistance to CBRC through an advisory steering committee.

The following is a brief description of CUB R&D projects focused on the evaluation of potential environmental impacts and development of utilization applications for both combustion and gasification byproducts.

- USG Corporation is performing 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 four power

plants. The four power plants represent a broad cross-section of synthetic gypsum sources including bituminous- and Texas lignite-fired boilers, with and without SCR NOx controls, and limestone- and lime-FGD processes.

- EPRI is conducting a three-year investigation of the potential for ground water 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.

- UNDEERC is evaluating the potential release of mercury and other air toxic elements associated with the disposal and beneficial use of coal utilization by-products. 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, volatilization at ambient and elevated temperature, and microbiologically induced releases.

- PPL Generation is conducting pilot-scale testing of an ozonation process for the post-combustion treatment of fly ash to mitigate the adverse effects of unburned carbon when the ash is used as a cement replacement in concrete. Treating the fly ash with ozone produces a passivating oxide layer on the unburned carbon that would allow high-carbon fly ash to be used in concrete without adversely affecting the air entrainment admixtures used to control the concrete's workability and freeze-thaw properties.

- The University of Kentucky is evaluating large volume utilization options for gasifier slag. The slag will be characterized and beneficiated into three products: frit (a glass-like slag), coarse carbon, and fines. The beneficiated products will then be evaluated for large volume and higher-value utilization options.

- Mississippi State University is developing industrial and structural foam products that utilize gasifier slag. Testing will be conducted to optimize the slag content in foamed material, and material properties of slag foams will be evaluated. Quantification of slag foam process economic will be performed.

- DOE/NETL's in-house R&D group is investigating the potential impacts of mercury and other metals on the utilization and disposal of Cubs by conducting of extensive long-term leaching tests to quantify the release of mercury and other heavy metals from fly ash and scrubber solids.

WATER MANAGEMENT

Eight new projects have been initiated to address the intimate link between water and power plants. The goal of this component of the IEP program is to develop advanced technologies and concepts to ensure that sufficient water is available to operate coal-based power systems and to minimize potential impacts of plant operations on water quality. The research is focused on (1) the use of non-traditional water (e.g., mine water and produced water from oil and gas extraction) for cooling, (2)

advanced water recovery and cooling technology, (3) advanced cooling water intake technology, and (4) advanced wastewater treatment and detection technology.

The following is a brief description of the projects.

Project Descriptions

- 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.

- UNDEERC, along with the Siemens Westinghouse Power Corporation, are testing 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 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.

- Produced waters are a by-product of natural gas and coalbed methane 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 is investigating 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.

- The colonization of zebra mussels on cooling water intake structures can lead to 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 are conducting 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 is being 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.

- 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 are conducting 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 is included in the work in order to evaluate an integrated passive treatment system for removal of these trace compounds.

- Lehigh University is working on a project that 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 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. Also, the pure water condensate could be used for cooling tower make-up or other facility water needs.

- The University of Florida is investigating 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.

SUMMARY

Over the past three decades the electric-utility sector has made tremendous strides in reducing air emissions, controlling effluent discharges, and managing the use and disposal of solid byproducts. However, environmental issues across all three media (air, water, and solids) continue to challenge the operation of the more than 300 GW of existing coal-fired generating capacity in the United

States, as well the permitting of new power plants. In response, DOE/NETL will continue to partner with industry, academia, and other research organizations as part of its Innovations for Existing Plants program in carrying out an integrated R&D effort directed at providing the technology and science to enhance the environmental performance of coal-fired power plants. As such, the IEP program will play its part in a broader DOE mission to help maintain a balanced energy mix in the United States well into the 21st century. Further detailed information on the IEP program and projects can be found at www.netl.doe.gov/coal/E&WR.

ACRONYMS AND ABBREVATIONS

AEP—American Electric Power
ALTA—Advanced Layered Technology Application
BNL—Brookhaven National Laboratory
CAA—Clear Air Act
CAIR—Clean Air-Interstate Rule
CARRC—Coal Ash Resources Research Consortium
CBRC—Combustion By-Products Recycling Consortium
CCPI—Clean Coal Power Initiative
CMU—Carnegie Mellon University
CUBs—Coal utilization by-products
DOE—U.S. Department of Energy
ECO—Electrocatalytic oxidation
EPA—Environmental Projection Agency
ESPs—Electrostatic precipitators
FBC—Fluidized bed combustion
FGD—Flue gas desulfurization
GE EER—GE Energy & Environmental Research
GRE—Great River Energy Corporation
GW—Gigawatts
H_2SO_4—Sulfuric acid
HCl—Hydrogen chloride
HF—Hydrogen fluoride
IEP—Innovations for Existing Plants
IGCC—Integrated gasification combined cycle
MACT—Maximum achievable control technology
NAAQS—National Ambient Air Quality Standards
NETL—National Energy Technology Laboratory
NOx—Nitrogen oxides
PAQS—Pittsburgh Air Quality Study
PC—Pulverized-coal
PM10—Particulates smaller than 10 micrometers
PM2.5— Particulates smaller than 2.5 micrometers
PRB—Powder River Basin
R&D—Research and development

RCRA—Resource Conservation and Recovery Act
REI—Reaction Engineering International
RRI—Rich Reagent Injection
SCAMP—Steubenville Comprehensive Air Monitoring Project
SDA/FF—Spray dryer adsorber and fabric filter
SIP—State Implementation Plan
SO_2—Sulfur dioxide
SRCs—selective catalytic reduction systems
SRI—Southern Research Institute
TERESA—Toxicological Evaluation of Realistic Emissions of Source Aerosols
TRI—Toxic Release Inventory
UNDEERC—University of North Dakota Energy & Environmental Research Center
UORVP—Upper Ohio River Valley Project

REFERENCES

[1] EIA, "Annual Energy Outlook 2004 With Projections to 2025", January 2004.
[2] National Air Quality and Emissions Trend Report, 2003, http://www.epa.gov/air/airtrends/aqtrnd03/ (last accessed 10/04).
[3] http://www.acaa-usa.org/PDF/2003_CCP_Survey(10-1-04).pdf
[4] Solley, W.B., Pierce, R.B. and Perlman, H.A., "Estimated Use of Water in the United States in 1995", U.S. Geological Survey Circular 1200, United States Government Printing Office, 1998.
[5] Granite, Evan; Pennline, Henry, Photochemical Removal of Mercury from Flue Gas. *Industrial & Engineering Chemistry Research*, October 2002.
[6] http://www.undeerc.org/carrc/
[7] http://wvwri.nrcce.wvu.edu/