Office of Fossil Energy, U.S. Department of Energy • DOE/FE-0476 • Issue No. 59, Fall 2004

CLEAN COAL TODAY

A Newsletter about Innovative Technologies for Coal Utilization

News Bytes

On July 26, 2004, the U.S. Department of Energy (DOE) announced a new round of **proposals under the Clean Coal Power Initiative (CCPI)**. Thirteen proposals with a total estimated value of $6 billion and $1 billion in Federal cost-sharing were submitted. The purpose of CCPI Round 2 is to support advanced coal-based technologies that could be readily deployed commercially, with top priorities being gasification, mercury control, and sequestration. Proposals were received from: Alaska Cowboy Coal Power Consortium, Basin Electric Power Cooperative, Breen Energy Solutions, ClearStack Com- bustion Corporation, EnviRes LLC, Excelsior Energy Inc., FuelCell Energy, Inc., Medicine Bow Fuel &

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World's Largest Clean Coal-Powered Fuel Cell

A FuelCell Energy, Inc. (FCE) 2-megawatt (MW) carbonate fuel cell — Direct FuelCell® (DFC®) 3000 — was successfully installed at the Global Energy Wabash River Energy Ltd. (WREL) commercial gasification facility in Terre Haute, Indiana. The fuel cell is expected to operate on commercially supplied synthesis gas to demonstrate at industrial scale the efficiency and environmental benefits of an integrated gasification fuel cell (IGFC) cycle. The magnitude of the demonstration — the largest fuel cell power plant to be operated on coal-derived synthesis gas — should ensure that results can be transferred to utility-scale systems. This demonstration represents a significant step toward developing FutureGen zero-emission, coal-based co-production power plants that will be capable of hydrogen production and carbon capture and storage.

World's largest clean coal-powered fuel cell power plant installed at WREL

The IGFC demonstration is an integral part of the Kentucky Pioneer Energy (KPE) IGCC Demonstration Project, located in Trapp, Kentucky, and awarded under the last round of the Clean Coal Technology Demonstration Program. Original plans called for IGFC testing at Trapp; however, WREL afforded an opportunity to accelerate the IGFC portion of the technology demonstration. Both fuel cell systems and gasification are considered enabling technologies for FutureGen. Fuel cells use electrochemical conversion to generate electricity, which is not only more efficient than combustion, but essentially eliminates pollutant emissions. Gasification converts hydrocarbons, including domestically abundant coal and wastes, into a clean synthesis gas that consists primarily of hydrogen (H_2) and carbon monoxide (CO).

Testing of the FuelCell Energy DFC3000 at WREL's facility, using EGAS™ entrained flow gasifier technology, reunites earlier partners in the technology development effort. In 1993–1994, DOE and the Electric Power Research Institute helped demonstrate the FuelCell Energy carbonate fuel cell (a 20-kW sub-scale stack) operating successfully for the first time on synthesis gas from a Destec gasifier, an earlier version of the EGAS™ technology.

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"Wabash" continued...

Those efforts led directly to the current demonstration at the WREL facility. Both Fuel Cell Energy's DFC3000 and the EGAS™ technologies are commercially available, and joining the two through tests at WREL should provide valuable data for IGFC cycle development.

The 2-MW fuel cell unit being installed at WREL is composed of two 1-MW modules. Each module is in turn composed of four 250-kilowatt (kW) stacks. The 250-kW stack is the heart of FuelCell Energy's DFC power plant. The carbonate fuel cell lends itself well to IGFC because it uses both the H_2 and CO in synthesis gas as fuel, whereas CO compromises the function of lower temperature fuel cell technologies.

In all, there are six skid-mounted support units for the DFC3000. Four were installed and readied for operation while the fuel cell units were completed and tested after manufacture. They provide a number of functions, such as natural gas cleanup (natural gas will be used initially to commission the plant and as backup during the demonstration); oxidation of residual fuel from the DFC3000 anode, and heat recovery from the fuel cell exhaust; treatment of water from the DFC3000; production of pressurized air for controls; conversion of the direct current fuel cell output to alternating current; and control systems for the DFC3000. Two support units installed concurrently with the fuel cell provide further synthesis gas cleanup and synthesis gas methanation. Synthesis gas cleanup will be particularly important to the test program, as fuel cells require cleaner gas than typically available at commercial coal gasification sites such as WREL. Synthesis gas methanation, which converts some of the synthesis gas into methane, is required in order to enable use of the commercial DFC3000, which was originally designed to operate on natural gas. The DFC3000 process design benefits from cooling provided by internally reforming methane to H_2 and CO (an endothermic reaction). Internal reforming results in higher fuel cell efficiency by utilizing fuel cell waste heat and water produced by the fuel cell anode reaction to produce hydrogen, which in turn, is consumed by the fuel cell to produce electricity.

1-MW DFC fuel cell module

Operation of the 2-MW DFC3000 on natural gas is expected to begin later this year to commission the power plant and to establish baseline performance. Testing of the synthesis gas cleanup and methanation system will follow to verify that design levels of trace contaminant removal and methanation are achieved. The testing on synthesis gas then will proceed after verification testing of the syngas processing skids is complete. Performance on both natural gas and synthesis gas will be compared to expected performance established through testing of other fuel cell power plants on natural gas (*i.e.*, FCE 1-MW power plant operating at King County (near Seattle, Washington) on natural gas and digester gas) as well as on coal mine methane. This data will provide valuable input to aid simulations modeling, and also serve to identify potential problems in the fuel cell system.

DFC3000 operation on both natural gas and synthesis gas will be accompanied by emissions testing, partial load testing, and power quality testing. Emissions testing will measure average concentrations in flue gas of sulfur dioxide, nitrogen oxides as nitrogen dioxide, CO, non-methane hydrocarbons, and particulate matter; and also determine flue gas flow rate, moisture content, and oxygen and carbon dioxide concentrations.

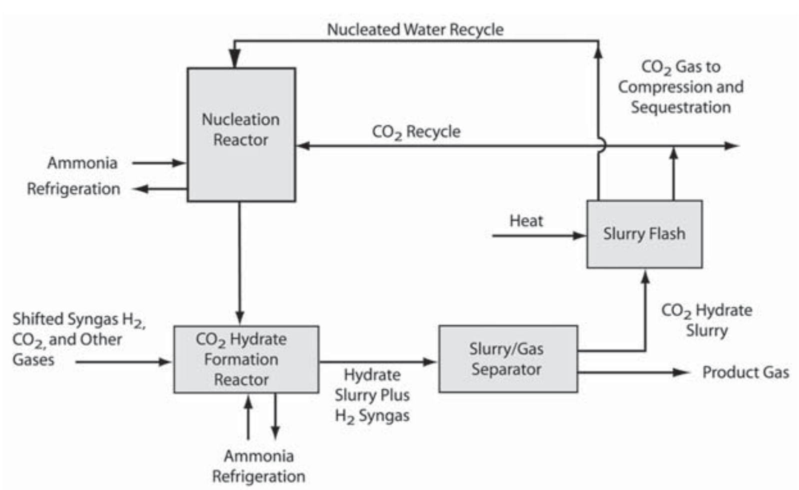
Partial load testing will characterize DFC3000 performance over a range of typical operating conditions by varying output levels and measuring fuel use, power consumption, and overall efficiency. Power quality testing is intended to evaluate the voltage, current, and frequency of the electricity produced by the power conditioning system to verify that power quality is consistent with standard UL 1741 applicable to inverters, converters, and controllers for use in independent power systems.

The 2-MW IGFC demonstration at WREL will provide valuable operational data for future product development, and is expected to validate that second-generation fuel cells represented by the DFC3000 are compatible with synthesis gas and able to significantly enhance the efficiency and environmental performance of gasification-based power systems. As such, the demonstration is a vital step toward developing FutureGen, achieving energy independence, and eliminating environmental concerns associated with conventional fossil fuel fired boiler power generation.

HYDRATE PROCESS TO CAPTURE AND SEQUESTER CO_2 FROM COAL SYNGAS

Over the past several years, a new process has been under development that selectively separates carbon dioxide (CO_2) from a high-pressure, sour, shifted synthesis gas stream and uses it in a process to form hydrates of CO_2 and H_2S. The process was patented by Dwain F. Spencer, the founder and owner of SIMTECHE, and is being tested at bench scale in a joint effort of the U.S. Department of Energy (DOE), National Energy Technology Laboratory (NETL), Los Alamos National Laboratory, Nexant Inc., and SIMTECHE. DOE has been investigating economical methods to separate CO_2 from mixed gas streams at high pressures. Based on preliminary testing and analysis, the hydrates process offers significant potential to reduce CO_2 capture costs by 50 percent, and could make an important contribution to a gasification-based FutureGen zero-emissions plant of the future.

In this process (see graphic below), high-pressure, sour, shifted synthesis gas, produced in a coal or other fossil fuel gasification or partial oxidation process, is cooled to approximately 34 °F and contacted with a recycle water stream to form a CO_2 and hydrogen sulfide (H_2S) hydrate slurry without dissolving or forming hydrates from other gaseous components. The three-phase fluid enters a high-pressure gas-liquid separator; the product H_2 and other gases are separated at high pressure and can be further treated as necessary for their final uses. The CO_2-H_2S hydrate slurry then is fed to a flash reactor where process heat is utilized to regenerate a high pressure CO_2-H_2S gaseous stream, at typically 550–900 psia. The gas streams then are dried and compressed to be ready for pipeline transport, and injection into an appropriate sequestration repository.



SIMTECHE process block flow diagram

The liquid water stream, containing dissolved CO_2 and H_2S, is recycled to a nucleation reactor, where it comes in contact with recycle CO_2 and H_2S to form hydrate "precursors" that facilitate hydrate formation in the main contactor/formation reactor. The main reactor is a tubular reactor, which provides adequate residence time for the full reaction of the CO_2 and H_2S to form hydrates and remove the maximum amount of CO_2 from the multi-component gaseous stream. Typically, 70–80 percent of the CO_2 can be removed from the product gas in a single pass. With proper management of both CO_2 and H_2S recycle, over 80 percent of CO_2 may be removed. The CO_2 hydrate formation reaction is exothermic, and hydrate formation is highly temperature-dependent; therefore the primary reactor must be adequately cooled to permit the CO_2 hydrate formation to proceed to completion. The base process uses ammonia as the coolant in a refrigeration cycle, with the refrigerant condenser providing the flash reactor heat.

One very important discovery is the concept and subsequent development of CO_2 hydrate "promoters," which permit the CO_2 to continue to form CO_2 hydrates at thermodynamic conditions beyond those necessary for pure CO_2 hydrate formation. Specifically, they can both increase the temperature at which CO_2 hydrates may form, as well as decrease the minimum CO_2 hydrate formation pressure. As a consequence, much greater CO_2 removal can be achieved. Three types of CO_2 hydrate promoters have been identified: gaseous promoters, *e.g.*, H_2S or SO_2; liquid promoters such as carbon tetrachloride and other organic liquids; and highly water-soluble organic salt compounds, such as per-alkyl-onium salts that have the greatest effect on CO_2 hydrate formation conditions.

Process development is under way in two parallel, integrated projects. Nexant Inc. and SIMTECHE perform

See "Hydrates" on page 4 ...

"Hydrates" continued...

the engineering and project management tasks. Los Alamos National Laboratory performs the experimental portion of the program and operates three experimental test rigs. These rigs include: equilibrium batch testing; $CO_2/H_2/H_2S$ continuous flow reactor operations to demonstrate CO_2 hydrate separation in short duration (~10 minute) runs; and the latest experimental platform, the Engineering Test Model (ETM), which permits CO_2 separation to minimum hydrate formation pressure conditions and continuous, steady-state runs of up to two hours.

Overall, the CO_2 hydrates process can result in a residual concentrated stream of hydrogen capable of fueling zero-emission power plants of the future, as well as a concentrated CO_2 stream available for use or sequestration.

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Editor:
Phoebe Hamill

Phone: 202-586-6099

Fax: 202-586-1188

***E-mail*:**
phoebe.hamill@hq.doe.gov

http://www.netl.doe.gov/cctc/newsletter/newsletter.html

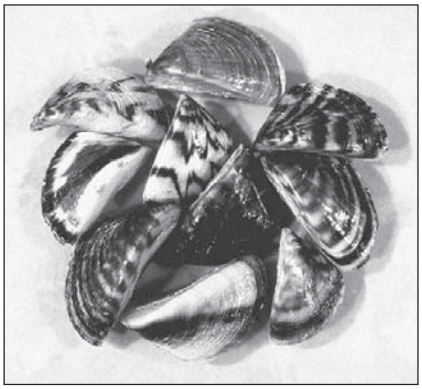
Comments are welcome and may be submitted to the Editor.

DOE Pursues Environmentally Friendly Zebra Mussel Control

In an effort to address an unusual problem associated with water intake at power plants, the U.S. Department of Energy (DOE) has undertaken research to combat the proliferation of zebra mussels — a non-native species of mussel that has been blocking pipes that deliver drinking water to cities, and process water to factories and power plant cooling towers. Economic damage to electric utilities has reached $1 billion since the late 1980s, with total economic impacts approaching $2 billion. Ecological damage — eliminating native mussel species and disrupting the food chain — also has been significant. The zebra mussel problem has arisen due to introduction of a non-native species, most likely transported to North American waters as planktonic (*i.e.*, floating) larvae or as attached juveniles or adults on debris in the freshwater ballast of transatlantic ships. Ballast contamination has been identified as the source of 36 of the 50 non-native species that have entered U.S. waters through the St. Lawrence Seaway — the entryway to the Great Lakes and other U.S. waterways.

The zebra mussel, *Dreissena polymorpha*, is native to the Ural River in the Caspian Sea Basin of Russia. Expansion of commercial boat traffic through newly constructed canals aided the spread of this species from Russia into most of Europe during the 19th century. Zebra mussels were found for the first time in North America in 1988 in Lake St. Clair, the water body connecting Lake Huron with Lake Erie (two of the Great Lakes). The common name of these mussels is derived from the zebra-like stripes on their shells.

An ongoing research effort, funded by DOE's National Energy Technology Laboratory (NETL) Division of Advanced Research and the Division of Innovations for Existing Plants, is aimed at biologically controlling established mussel populations in the cooling water intake systems of electric power generation plants. The project is centered at the New York State Museum's Field Research Laboratory in Cambridge, New York, with additional experimentation at Russell Station, a coal-fired plant operated by Rochester Gas & Electric. Research efforts are focused on evaluating the effectiveness of a microbial toxin naturally produced in the cells of *Pseudomonas fluorescens* — a common soil bacterium. This bac-

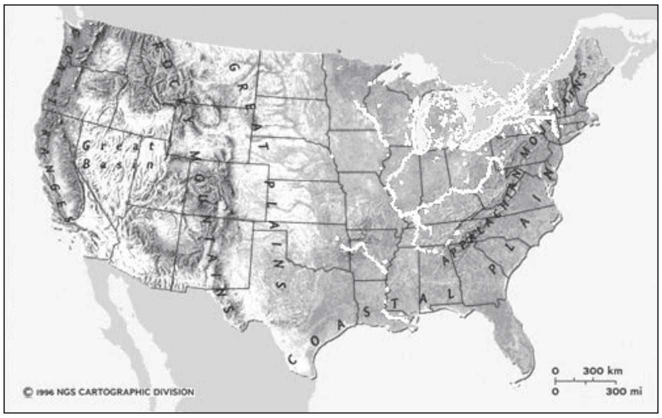


Examples of various shell stripe patterns in 1-inch zebra mussels (above) and pipes clogged with zebra mussels (below).

terium produces a toxin that targets the zebra mussel without affecting other aquatic animals, including native freshwater mussels. When a zebra mussel ingests artificially high densities of this bacterium, the biotoxin within these bacterial cells destroys the mussel's digestive system. Results obtained so far indicate that, in zebra mussel populations held in tanks and small pipes, a better than 90 percent mussel mortality can be routinely achieved. Dead bacterial cells are equally as effective against zebra mussels as live cells, providing clear evidence that the mussels die from a biotoxin, and not from infection.

A commercial formulation based on this microbe is being developed, and will contain dead cells, thus further reducing environmental concerns. Techniques are being refined that will kill the bacteria without any reduction in their lethality to zebra mussels. Other major research priorities of this current NETL project are to learn how to economically mass-produce the bacterial cells, to further confirm the bacterium's environmental safety in trials required for product registration by the U.S. Environmental Protection Agency (EPA), and to further demonstrate the bacterium's effectiveness in killing zebra mussels in power plant water pipes.

In addition to these biological control methods, other continuing research efforts include development of filters, and antifoulant coatings such as paints and liquid metal compounds; and the use of electrical fields to prevent attachment of larvae. The zebra mussel problem is not limited to the Great Lakes region. This invasive mussel, which can thrive in a wide range of water quality and temperatures, has colonized many waterways throughout the Missouri-Mississippi-Ohio river drainage, from the Canadian border to the lower Mississippi River and toward the northeastern United States.



Zebra mussel distribution (shown in white) throughout the United States

Though small in size (maximum length is typically about 1 inch), zebra mussels have become the most troublesome freshwater biofouling organism in North America. Even after mussels are killed by a control technique such as chlorine or mechanical controls, the shells and decaying tissues may remain behind, causing additional problems. As with all invasive species, prevention is still the best weapon against initial infestation.

UPCOMING EVENTS

September 14 and 16, 2004
Coal Combustion Partnerships Workshop
Sponsors: NETL, U.S. EPA, American Coal Ash Association
Location: Las Vegas, NV (**14th**), and Austin, TX (**16th**)
Contact: William Aljoe
(412) 386-6569

September 21–22, 2004
Fourth Annual DOE/UN/EU Fuel Cell/Gas Turbine Hybrid Technology, Systems, and International Programs
Sponsors: DOE; United Nations; European Union; National Fuel Cell Research Center; and Pacific Rim Consortium on Energy, Combustion, and the Environment
Location: Irvine, CA
Contact: National Fuel Cell Research Center
(949) 824-1999

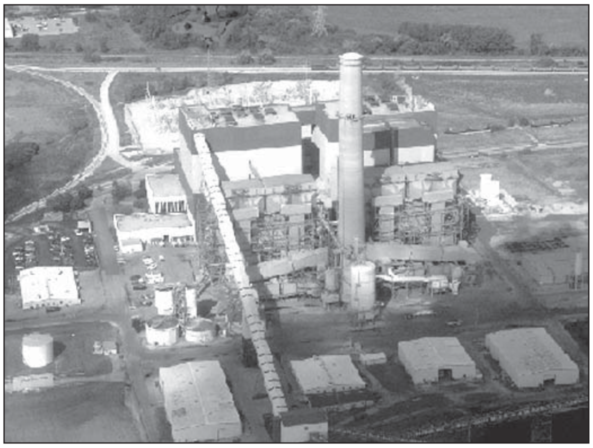
October 12-14, 2004
Western Fuel Symposium – 19th International Conference on Lignite, Brown, and Subbituminous Coals
Sponsors: EERC, DOE/NETL, EPRI
Location: Billings, Montana
Contact: Kimberly Yavorsky
kimberly.yavorsky@netl.doe.gov
(412) 386-6044

October 18-19, 2004
3rd Annual US-China Clean Energy Workshop
Sponsors: DOE Office of Fossil Energy
Location: Morgantown, WV
Contact: Peter Rozelle
peter.rozelle@hq.doe.gov
(301) 903-2338

NETL Reviews Field Data on Mercury Speciation

As reported in the Spring issue of *Clean Coal Today,* the U.S. Department of Energy (DOE) has been carrying out an active mercury control R&D program at the Office of Fossil Energy National Energy Technology Laboratory (NETL). While coal-fired power plants have been identified as the anthropogenic source that produces the largest mercury emissions in the United States, atmospheric concentrations of mercury are generally too low to constitute a health or environmental hazard. However, once mercury leaves the atmosphere, it can convert to methylmercury and bioaccumulate in terrestrial and aquatic environments, leading to potentially harmful human exposure.

The coal combustion process releases mercury in one of three basic forms: gaseous elemental mercury (Hg^0) – relatively unreactive and can persist in atmosphere for months to years; gaseous oxidized mercury (Hg^{2+}) – reacts and returns to earth's surface relatively quickly through wet or dry deposition; and particulate-bound mercury – a stable chemical form, virtually all of which is removed at the plant via high-efficiency particulate control devices. Environmental impacts of the first two forms — Hg^0 and Hg^{2+} — are varied since atmospheric reactions cause the mercury speciation profile to change after it is released.


We Energies Pleasant Prairie plant

Regulators and researchers considering the most effective course of mercury control already know that it is easier to remove Hg^{2+} from flue gases than Hg^0. However, a regulatory approach allowing mercury trading will be more easily implemented if mercury from power plant emissions is mostly in the elemental form. Conversely, if mercury emissions are in the oxidized form or oxidize within the plume, trading would be less desirable because of the potential for mercury "hot spots" immediately downwind of each power plant.

Accurate modeling of the way mercury behaves requires a complete understanding of the transport and environmental fate of mercury emissions. For now, it appears that existing models overestimate the actual, measured mercury deposition in critical areas directly downwind of power plants, which may be due in part to rapid conversion from Hg^{2+} to Hg^0 within the plume. While preliminary laboratory studies and field observations suggest this conversion may be occurring, prior to 2002 there was no direct evidence of such changes within power plant plumes.

NETL and its partners have been involved in research and field measurements to determine the chemical speciation of mercury into elemental and oxidized forms, and the changes as the material is transported downwind of power plants. Field measurements were conducted at Southern Company's Plant Bowen in Georgia, and at Wisconsin Power's Pleasant Prairie Power Plant in Kenosha County Wisconsin. In both projects, instrumented aircraft measured mercury concentrations and speciation within the plumes at various distances downwind from the stacks. These data then were compared with in-stack mercury concentrations and speciation. Experiments also were conducted to determine whether the in-plume mercury reactions could be simulated by introducing stack gas samples into on-site dilution chambers.

Preliminary analysis of data at both plants suggests that a significant portion of the oxidized mercury emitted from power plant stacks is transformed to elemental mercury very rapidly upon release — between 15 percent to 66 percent of the initial oxidized mercury was converted to elemental mercury at five miles downwind. Data from the plume dilution chambers are still being evaluated.

Future work includes identifying the chemical mechanisms and reaction rates associated with the observed mercury speciation changes; incorporating the information into atmospheric mercury transport and deposition models; and preparation of technical reports, conference presentations, and peer-reviewed journal articles covering various aspects of the in-plume mercury speciation experiments.

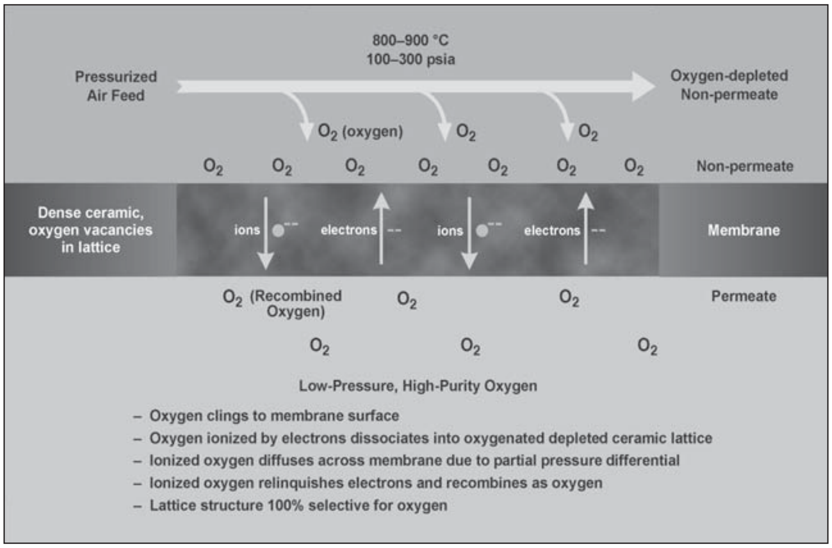
ADVANCES IN MEMBRANE TECHNOLOGY FOR AIR SEPARATION

Gas separation is expected to play an increasing role in the future electric power industry to help meet ever-growing electricity demands within tightening environmental standards. Novel power generation technologies, such as oxygen-enriched coal combustion and coal gasification provide higher efficiencies with near-zero pollution compared to conventional combustion boilers. However, these new technologies require the separation of oxygen from air and carbon dioxide from flue gases. Furthermore, as hydrogen becomes the energy carrier of the future, other gas separation technologies will be needed to separate hydrogen from hydrogen-containing gaseous fuels, such as synthesis gas (syngas) — a mixture of hydrogen and carbon monoxide. The U.S. Department of Energy's (DOE) conceptual, zero-emission, multi-fuel/product plant (FutureGen) utilizes several gas separation technologies for separating hydrogen, carbon dioxide, and oxygen.

The most prevalent gas separation process today is the separation of air into its major constituents — nitrogen and oxygen. This is commercially accomplished by using pressure swing adsorption or cryogenic processes. Adsorption methods use zeolites to filter out gases at the molecular level, while cryogenic processes use low-temperature distillation. These processes are costly operations, particularly for producing large quantities (>100 tons/day) of oxygen. In addition, cryogenically produced oxygen is at low temperature and requires additional processing for integration with the high temperature operation of a gasifier.

Membrane-based gas separation processes, however, are significantly more energy efficient and economical. The DOE's R&D investments have developed a novel class of materials that can transport oxygen anions and electrons through their lattice structure at elevated temperatures. These materials, referred to as Ion Transport Membranes (ITMs), can dramatically reduce the cost and energy requirements for separating oxygen from air and, with some modification, separating hydrogen from syngas and carbon dioxide from flue gases or fuel gas mixtures.

The ITMs are composed of perovskite ceramic oxides that can transport oxygen ions and, optionally, electrons through various "driving forces," which are responsible for moving oxygen from one side of the membrane to the other. These driving forces are determined by the end use application of the ITM. For example, an electric voltage applied across the membrane may be used to separate and compress oxygen from a low-pressure source (air) to a high-pressure oxygen stream. This method provides oxygen suitable for medical and welding applications. Other driving forces that may be employed are pressure and temperature. By varying the oxygen partial pressure (chemical potential) on one side of the membrane at temperatures ranging between 800–900 °C, oxygen anions can be made to diffuse rapidly through the membrane in an effort to equalize the partial pressures on each side of the membrane. Pure oxygen emerges from the low-pressure side of the membrane. A compressor pulls the oxygen away from the membrane and compresses it to its final delivery pressure. Electrons flow across the membrane countercurrent to the oxygen anions and complete an internal electronic circuit (see figure below). This system may be used for supplying oxygen in large quantities. The energy in the oxygen-depleted non-permeate may be used to operate a gas turbine to produce electric power or for producing steam. Thus, this application of the ITM is ideally suited for co-production of oxygen and electricity.



Oxygen separation using ion transport membrane

See "Membrane" on page 8 ...

"Membrane" continued...

DOE's ITM development efforts include the demonstration of elements in the integrated gasification combined-cycle (IGCC). The ITM also is ideally suited for thermal integration with gasification cycles such IGCC because it is able to produce very pure oxygen at high permeation rates. ITMs can help gasification technologies become commercially feasible by reducing equipment cost for oxygen production (up to one third) and reducing the loss of thermal efficiency inherent in conventional cryogenic air separation. Use of oxygen in lieu of air in IGCC reduces product stream volume that results in lower gas cleanup costs, and a nitrogen-free syngas stream that can be economically transformed through water-gas shift reaction into an almost pure stream of hydrogen and carbon dioxide.

Two different architectural approaches have been developed for ITMs used for oxygen separation — planar and tubular. The planar design allows desired gas phase mass transfer and is amenable to standard ceramic processing technologies. Planar systems are stabilized by high pressure and allow compact separation devices that will occupy a smaller volume compared to tubular systems, which in turn, is expected to reduce capital costs. High pressure feed gas flows over the planar membrane, allowing oxygen to diffuse to the interior of the membrane and be withdrawn through adjoining piping.

The tubular design uses thin ITM oxygen ion transport ceramic membranes on a robust support structure. Feed air at about 300 psi pressure and 800–900 °C temperature is introduced outside the ITM tube. Pure oxygen diffuses through the membrane to the inside of the tube. Prototypes of tubular ITM oxygen systems, including isolation devices to minimize tube failure, have been constructed and tested. Ongoing work includes tube improvements, life studies, and the conceptual design of a demonstration-scale air separation unit.

DOE's overall goal is to demonstrate an ITM-based oxygen production technology at pre-commercial scale and achieve costs and energy requirements that are approximately 33 percent lower than conventional cryogenic plants. Work on cost and performance has been completed.

An engineering evaluation was conducted on an IGCC power plant that uses a Siemens Westinghouse W501G gas turbine and a Texaco high-pressure quench gasifier operating on U.S. domestic coal. The evaluation compared the ITM technology for oxygen separation to a state-of-the-art cryogenic air separation unit (ASU). The evaluation showed that the benefits of using ITM technology for IGCC applications include a 7 percent reduction in overall plant installed capital cost, a 7 percent improvement in power output, a 35 percent savings in the installed cost of the ITM ASU versus the cryogenic ASU, a 37 percent improvement in the power requirements of the ASUs, and a 2.2 percent overall improvement in power plant efficiency. A similar evaluation was conducted on an enriched coal combustion plant operating with a 1,500 ton-per-day (tpd) ITM oxygen separation plant and a modern cryogenic ASU. The ITM oxygen plant reduced overall power consumption by 69 percent and capital expenses by 27 percent, relative to the cryogenic ASU. A portion of the savings resulted from the 35–60 percent lower compression energy required for the ITM oxygen separator, compared to the cryogenic ASU.

Efforts currently are in progress involving scaleup to a 1–5 tpd engineering prototype. Cost-optimized planer ceramic wafers have been designed and fabricated as the building blocks of membrane separation modules. They have been demonstrated at both laboratory and pilot scale, showing a record oxygen flux of 130 percent of the commercial target. Oxygen was produced at >99 percent purity at conditions typically expected in commercial operations. Test conducted on a sub-scale module showed a steady oxygen flux target rates for 5,350 hours at the commercial operating conditions of 800–900 °C and 200–300 psig without noticeable material or performance degradation. A conceptual design of a commercial-scale ITM module has been completed. The third phase is focused on addressing key issues in materials, processing, manufacturing, engineering, and integrated system development that will make the ITM a commercial success by 2008–2010.

Continued R&D by DOE and the private sector will help the ITM become a viable commercial operation the important to market penetration by IGCC and other advanced power generation systems. Apart from the power sector, DOE's Office of Energy Efficiency and Renewable Energy has identified nine energy-intensive industries that would realize significant cost, productivity, and efficiency benefits by using oxygen derived from an ITM system.

...News Bytes continued

Power LLC, Minnesota Power, NeuCo, Inc., Peabody Energy, Pegasus Technologies, Inc., and Southern Company Services. For a synopsis of the proposals go to http://www.fe.doe.gov/news/techlines/2004/tl_ccpi_round2_proposals.html

Another Round 1 CCPI cooperative agreement was signed in June 2004 with Great River Energy (GRE) for the Lignite Fuel Enhancement System. The project is expected to boost the generating capacity and efficiency of power plants that burn high-moisture lignite coal, thereby reducing air pollutants and greenhouse gases. The new technology uses waste heat to dry nearly a quarter of the moisture in the coal before it is fed into the boiler. GRE and its research partners will carry out the 45-month demonstration at the 546-MW Coal Creek Station in Underwood, North Dakota.

NETL recently received three R&D 100 awards in the coal research area. The Aspen Plus® – FLUENT® Integration Toolkit enables engineers to integrate high-fidelity equipment models, based on computational fluid dynamics, with overall process simulation models. A major chemical company has just purchased the Toolkit's software license and training. Another award was for RTI International's RTI-3 desulfurization sorbent (now known as T-2749), which has shown promising results at Chevron Texaco's research gasifier. A third award was for a hydrogen transport membrane developed with Argonne National Laboratory. The membrane has the potential to be used to separate hydrogen from coal gas streams, and is key to the eventual direct production of hydrogen from coal.

MINORITY INTERNS UNDERTAKE COAL RESEARCH

As part of the U.S. Department of Energy (DOE) Office of Fossil Energy Mickey Leland Energy Fellowship, a DOE summer internship program, 38 students have been engaged in fossil energy research projects. Nine of the students worked on coal-related projects with mentors at the National Energy Technology Laboratory (NETL), Idaho National Engineering and Environmental Laboratory (INEEL), and DOE Headquarters.

Dave Martin of Gilberton Power (left); Bob Hoppe of WMPI Pty, LLC. (right), and intern A. J. Jackson (center) in the turbine room at Gilberton Power Company (Frackville, Pennsylvania). Jackson is researching fuel moisture effects on coal gasification.

The program, named for the late Congressman Mickey Leland who was killed in a plane crash on a humanitarian mission to Ethiopia, is in its ninth year. The program is designed to provide opportunities for under-represented minority students interested in fossil energy, and who are pursuing degrees in science, engineering, or mathematics. The Leland program takes over three earlier FE internship initiatives: Historically Black Colleges and Universities, Hispanic Internship Program, and Tribal Colleges and Universities.

Students work for 10 weeks during the summer at federal R&D facilities, DOE National Laboratories, or sites of DOE stakeholders. In addition to specific research and papers, the curriculum involves career development and leadership training, as well as project-related field trips. This year's group has been working at: Albany Research Center; NETL; INEEL; National Petroleum Technology Office; National Renewable Energy Laboratory; Pacific Northwest National Laboratory; Strategic Petroleum Reserve Office; Office of Naval Petroleum and Oil Shale Reserves in Casper, Wyoming; Schlumberger, an oil field services company; and Fossil Energy Headquarters.

Nine students prepared papers relating to coal. In the environmental area, one student studied air monitoring systems, while another looked at indoor ambient air quality as it relates to respiratory disease in the Navajo Nation, where local coals are often used for domestic heating and cooking. Another study looked at geological sequestration of carbon dioxide. Other papers investigated advanced techniques for modeling fly ash leaching, simulating gas turbine combustor performance, and performing density imaging on fluidized bed combustors. Technologies, such as fuel cell/turbine hybrids and coal gasification also were researched, as were hydrogen separation membranes and advanced materials for high temperature corrosion resistance.

INTERNATIONAL INITIATIVES

CHINA/U.S. INDUSTRIAL BOILER WORKSHOP A MAJOR SUCCESS

On June 10–11, 2004, nearly 150 attendees gathered at China's Hall of Science and Technology in Beijing to review new efficient industrial boiler technologies — including such concepts as combined heat and power — in order to reduce CO_2/greenhouse gases, SO_2, NO_x, mercury, and fine particulate/$PM_{2.5}$ emissions from industrial boilers. The focus of the workshop was primarily coal, but also included natural gas and co-firing these fuels with biomass.

Madam Yang Qijuan, Vice Secretary General of the Chinese Society of Power Engineering, introduces speakers during the welcoming address and opening remarks

The workshop — the first of its kind ever held in China — was sponsored by the U.S. Environmental Protection Agency and China National Development and Reform Commission, along with several Chinese boiler manufacturers. It was organized by the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), U.S. National Renewable Energy Laboratory, Chinese Society of Power Engineering, and Tsinghua University. The workshop supported the Cleaner Air and Cleaner Energy Technology Cooperation agreement between the United States and China. The Agreement is part of the larger Technology Cooperation Agreements Pilot Project designed to help developing and transition countries attract investment in clean energy technologies. The China market for energy and environmental technologies — including clean and efficient industrial boilers — is substantial due to growing economic development and investments, tightening regulations, and high visibility initiatives such as preparations for the Beijing 2008 Summer Olympics.

The workshop was particularly timely in view of China's great need for modernizing its industrial boilers to use improved technologies for stoker-fired systems, or circulating fluidized-bed boilers fired by coal or biomass. Since China's population is so large and relies heavily on boilers with relatively small design capacities to provide steam and hot water inside factories and building as well as district heating, China manufactures and uses more industrial boilers than any other nation. China has over 500,000 existing industrial boilers representing nearly 860,000 MWt and strong new boiler manufacturing growth at about 6 percent per year. Although natural gas markets are developing along with biomass/waste fuels, China's industrial boilers largely use coal, consuming over 400 million metric tons per year. These boilers annually discharge over 100 tons of mercury (over twice the amount emitted by U.S. utility boilers, and nearly 8 times that of U.S. industrial boilers), 750 million metric tons of CO_2, 6.3 million metric tons of SO_2, and 6 million metric tons of particulate. Much of this pollution is due to outdated boiler designs and equipment in need of repair as well as the widespread use of low-grade raw coal. As a result, boiler efficiencies (typically 50–75 percent) are well below the 80–90 percent figure for modern designs.

Over the two days, attendees heard some 35 presentations, and four in-depth panel discussions. The agenda included technology updates and market opportunities for coal preparation technologies to improve coal quality, cofiring of natural gas and biomass in coal-fired boilers, energy management services, instrumentation and process control systems, operator training, as well as related issues for China's rapidly expanding utility boiler sector. The Chinese were particularly interested in learning about U.S. technologies and regulatory considerations, to assist them in planning their own technology focus and environmental and efficiency standards.

Following the workshop, participants toured Tsinghua University's extensive combustion and gasification R&D facilities and several large district heating plants in Beijing. The China organizers have been asked to prepare a summary report and proposals for future recommendations for presentation to high level government officials.

NETL Hosts Foreign Service Officer Coal and Power Training

The U.S. Department of Energy's National Energy Technology Laboratory (NETL) conducted its annual week-long training course on coal and power technologies for the U.S. Department of State's Foreign Service Officers (FSO) during July 19–23, 2004. This is the fifth summer that NETL has organized the FSO course, which provided an overview of electricity generation, transmission, and distribution. Emphasis was placed on the technological changes occurring in the coal and power industries, where DOE and a variety of industrial partners are fostering research toward ultra-clean co-production FutureGen plants, with hydrogen and electricity production and other uses, coupled with the sequestration of carbon dioxide (CO_2) from fossil fuels. Presentations were given by 21 experts from industry and academia on a wide variety of coal-related topics including mining, preparation, combustion, gasification, and by-product utilization. There also were presentations on natural gas-based power generation using turbines and various distributed generation technologies, such as fuel cells and microturbines. The participants visited two coal mines, two coal-fired power plants, a natural gas-fired power plant, and a solid oxide fuel cell manufacturing facility.

Scott Smouse (top left), NETL's International Coordination Team Leader, shown with NETL support staff and FSO course participants

Since FSOs may be involved in technology transfer, NETL's course provides them much needed background about U.S. companies and technologies that can be used to help meet power demands around the globe in an environmentally friendly manner. The class also educates FSOs on technological advances achieved through DOE's coal and power programs and their applicability to developing countries rapidly expanding their energy and power sectors.

NETL organizes this course at the request of the Foreign Service Institute, which was established in 1947 to provide FSOs with relevant training as they move to postings in countries around the world. This year's participants included 10 representatives from the Department of State and the Department of Commerce stationed in Abu Dhabi, Bulgaria, China, Kazakhstan, Kosovo, Japan, and Mexico.

Cooperative Research with Norway

A recently signed Memorandum of Understanding (MOU) between the U.S. and Norway formalizes the dialogue already underway in various energy R&D areas, and should provide a higher focus for existing and future cooperative projects between the two countries. The MOU for collaboration in energy research, development, and demonstration was signed May 23, 2004, in Amsterdam by DOE Secretary Spencer Abraham and Einar Steensnaes, then Oil and Energy Minister of Norway's Royal Ministry of Petroleum and Energy. The MOU covers various areas of fossil energy R&D and would potentially involve a number of activities related to carbon sequestration, hydrogen, and advanced power systems. The new agreement follows an earlier agreement reached at the U.S.-Norway Roundtable held in Washington, DC, in January 2003.

Just prior to the signing, a Bilateral Cooperation Workshop was held in New Orleans, May 10–11, 2004, to start defining specific areas of cooperation. The Workshop agreed to an organizational structure with Acting Fossil Energy Assistant Secretary Mark Maddox as National Director for the United States and Odd Sverre Haraldsen, Deputy Director General, Ministry of Petroleum and Energy, as his Norwegian counterpart. Fifty attendees from the U.S. and Norwegian government, industry, academia, national laboratories, and other research institutions formed focus groups on carbon sequestration, hydrogen, new energy technologies, systems analysis, and scientific exchanges. The United States and Norway are already cooperating in a number of areas such as the Baseline Gravity Survey (a monitoring effort) at Sleipner CO_2 Storage Site (see next article). The focus group discussed existing mechanisms for cooperation that might be more fully exploited, as well as new methods for collaboration. Gap analyses were recommended in many cases in order to avoid duplication and leverage resources. The variety of carbon storage demonstration projects under way in North America (such as the Frio Brine Pilot CO_2 Project, the Mountaineer CO_2 Project, and the Weyburn CO_2 Monitoring Project) were considered to offer opportunities for Norwegian participation and information sharing, as was the multi-national CO_2 Capture Project. SINTEF, in cooperation with Store Norsk-Spitsbergen Kulkompagni, also expressed interest in comparing coalbed methane and CO_2 storage feasibility studies, exchanging information, and possibly cooperating on a project in Europe similar to CONSOL's Enhanced Coalbed Methane project.

One activity recommended for scientific exchange already is bearing fruit. A training workshop in CO_2 capture and geologic storage for 10 Norwegian and 10 U.S. graduate students, as well as early career professionals, was held at St. John's College in Santa Fe, New Mexico. The course, designed by EnTech Strategies, LLC and Los Alamos National Laboratory, was a comprehensive technical program on the various elements of carbon capture and storage in which 25 of the top U.S. scientists in the field gave talks. Kinder Morgan CO_2 Company also provided the group with a tour of its SACROC CO_2 facility in Snyder, Texas, where the company has been safely handling CO_2 for decades in its enhanced oil recovery operations.

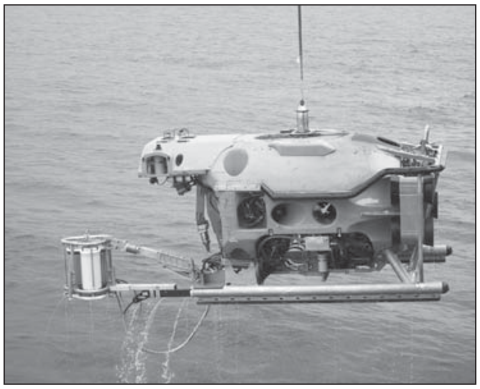
Other possibilities suggested by the focus groups include exchange of data on hydrogen storage materials, because both the United States and Norway are working on nanomaterials and metal hybrid materials. Experts also recommended data be shared on small-scale hydrogen reformers, and cited the need for improved understanding of the characteristics of pressurized hydrogen-rich combustion. The integration of novel concepts into existing energy systems was another area of interest. New compression technologies (such as the Ramgen technology developed through cooperation of the private sector and DOE) were specifically mentioned, as well as co-production, high temperature membranes, and fuel cells with CO_2 collection (through the use of a manifold integrated with separation techniques).

DOE is in the process of developing an action plan based on meeting recommendations.

CO_2 Sequestration Monitoring in Norway's North Sea

As part of an international CO_2 sequestration project at the Sleipner gas field located in Norway's North Sea, the U.S. Department of Energy (DOE) and its partners are looking closely at seismic data and reservoir simulation models with plans for repeating, in 2005, an undersea gravity monitoring survey done in 2002. The CO_2 extraction effort at Sleipner is the first commercial project of its kind. The Saline Aquifer Storage Consortium (SACS) began work in 1998, and the effort is being facilitated by the International Energy Agency, of which DOE is a member. DOE's monitoring work began several years later with team members from the University of California's Scripps Institute of Technology, the Norwegian company Statoil, and SACS. Monitoring should have applicability to CO_2 from coal that is sequestered in land-based geologic formations.

At the site, 1 million tons per year of excess CO_2 is extracted from natural gas and injected into a porous saline aquifer (the Utsira formation) at about 1,000 meters below the sea floor. The monitoring method uses 4-dimensional and time lapse seismic techniques to take measurements based on changes in density of the formation fluids due to CO_2. When CO_2 is injected into the storage reservoir, the overall density of the pore space decreases. This decrease in density has an effect on the local strength of the gravitational field. By monitoring how the local gravity field changes with time, researchers can assess the extent to which CO_2 has been contained in the reservoir.



Remotely operated vehicle with gravimeter array being lifted out of the North sea after a survey

The first phase of this work was carried out in August 2002. Thirty concrete benchmarks were placed on the ocean floor, and measurements were taken via remotely operated gravimeter. In relative gravity surveys, uncertainty is a function of the measurements; thus, each benchmark was visited at least three times. The goal is to find relative changes that are small (*i.e.*, repeatable with a very small variation). The repeatability for a single gravimeter is estimated to be 4.3 microGal (μGal). For time-lapse measurements, there is additional uncertainty associated with the reference benchmark, determined from stations outside the CO_2 area, of about 1–2 μGal. Therefore, the final detection threshold for time-lapse changes is about 5 μGal. Detection thresholds are an indication of how small a measurement can be and still be confidently "seen" and is thus not a random signal or noise. These results are considerably better than the pre-survey expectations of 10 μGal, and increase the likelihood of detecting time-lapse changes. Depth measurements were made simultaneously with the same instrument package. Single observation relative depth estimates have a repeatability of 0.5 centimers, which makes monitoring of small vertical sea floor movements in the area possible.

Gravimeter array shown with sea floor concrete monuments prior to emplacement

The original survey provided a limited amount of information about the injected CO_2. Initial modeling, done by making simple Bouguer corrections to the sea floor gravity data, shows that detailed models of local geologic features in the surrounding strata are needed to back out the signal of the injected CO_2. Thus, further modeling based on updated seismic results, borehole measurements, and sea floor bathymetry is underway. The 2005 survey should provide an independent and reliable means to quantify the CO_2, because any gravity change over time will be due to the changing CO_2 volume, not the presumed stable geologic setting.

Several gravity forward models have been examined. These have been built using both seismic data and reservoir simulation models. The maximum predicted time-lapse gravity signal from these models ranges from 3–16 μGal/year, depending on CO_2 density and flow geometry. This modeling will be important in interpreting the future time-lapse gravity results, and the conclusions drawn from the time-lapse gravity will have a significant impact on seismic and reservoir models.

ACTIVE CCT DEMONSTRATION, PPII, AND CCPI PROJECT STATUS

CCT DEMONSTRATION STATUS

JEA – *ACFB Demonstration Project*. The third demonstration phase test burn using 100 percent coal (Illinois #6) was completed from June 8–14, 2004, in the 300-MW JEA Large-Scale Circulating Fluidized-Bed (CFB) Combustion Project. Data analysis is in progress and final results should be known in several months. The 300-MW project at JEA's Northside Station, Unit 2, is the largest CFB combustor operating at commercial scale anywhere in the world. The first test burn began January 5, 2004, and was completed 11 days later. The second test burn ran from January 16–31, 2004. All tests were conducted at 100, 80, 60, and 40 percent of full load. Emissions were monitored at each load level and were well below permitted values. Four coal blends are being tested as part of the demonstration project. (Jacksonville, FL)

Kentucky Pioneer Energy (KPE), L.L.C. – *Kentucky Pioneer Energy Project.* FuelCell Energy (FCE) has requested a no-cost-to-DOE time extension in order to complete installation and demonstration testing of the fuel cell at the Wabash River site. FCE proposed test program revisions include an increase to 100 percent Kentucky coal in the amount of coal gasified during the six month demonstration period. The KPE extension request will allow the development of additional project information permits and zoning timelines. (Trapp, KY and West Terre Haute, IN)

Southern Company, Inc. – *Demonstration of Advanced Combustion Techniques for a Wall-Fired Boiler.* The purpose of the project was to evaluate the use of GNOCIS and other computerized process control software to further optimize operation of Plant Hammond Unit 4. The project ended on April 30, 2003. The Final Report was issued. A Post Project Assessment was completed in March 2004. (Coosa, GA)

Tampa Electric Co. – *Tampa Electric Integrated Gasification Combined-Cycle Project.* Tampa's Polk Power Station completed demonstration operations at the end of October 2001 with over four-and-one-half years of successful commercial operation. A Final Report has been issued, and the Post Project Assessment is in review. (Polk County, FL)

TIAX (formerly Arthur D. Little, Inc.) – *Clean Coal Diesel Project.* After running the test on the two-cylinder engine on coal water slurry, it was discovered that some bags in the baghouse had been damaged. Equipment modifications are being developed to prevent this from happening again. After modifications are implemented, testing will resume. (Beloit, WI)

Western SynCoal LLC (formerly Rosebud SynCoal® Partnership) – *Advanced Coal Conversion Process (ACCP) Demonstration Project*. In January 2003, Westmoreland Power, Inc. transferred ownership of Western SynCoal LLC to ENPRO, of Butte, Montana. DOE received the draft Final Report in March 2004, and is finalizing the report. (Butte, MT)

PPII STATUS

Otter Tail Power Company – *Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector (AHPC) Technology*. A 450-MWe demonstration is being conducted on a cyclone boiler firing coal from Wyoming's Powder River Basin. Powder River Basin (PRB) coal, a western coal, produces fly ash that is among the most difficult to collect with ESPs. The AHPC has been cleaning the full flow from the power plant since October 25, 2002. Otter Tail Power Company continues to operate the particulate control device and obtain superior particulate removal as evidenced by stack opacity in the 0 percent range. Demonstration testing has shown mixed results. Superior particulate removal has been accompanied by increasing operating costs due to increasing overall pressure drop or premature bag failure. Partial bag replacements have been occurring at 6-month intervals while bag life in the range of 5–7 years was expected. Otter Tail Power Company is in the design phase to modify the control device to increase its size in an attempt to control pressure drop/operating costs. (Big Stone City, SD)

Sunflower Electric Power Corp. – *Demonstration of a 360-MWe Integrated Combustion Optimization System.* The combustion optimization sensors package consisting of the Burner Profiler, loss-on-ignition/furnace exit gas temperature (LOI/FEGT) sensors, and carbon monoxide sensors is operational. Data are being archived on the MKE computer and by EtaPRO, which also collects plant performance data. The low-NO_x burner modifications and coal-balancing dampers have been installed. The coal-balancing dampers on Mill C are operating in automatic mode. System performance is being monitored. The automated coal flow balancing system on Mill C is operational following resolution of a cable problem. Sunflower continues to evaluate the impacts of overfire air on furnace exit gas temperature. (Garden City, KS)

Tampa Electric Company, Big Bend Power Station Tampa – *Neural Network Sootblower Optimization Project.* This project is demonstrating the use of a Neural Network driven Intelligent Sootblowing System (NN-ISB) operating on a 445 MWe Wall-Fired Pressurized Slagging unit. The goal is to sequence the sootblowing in response to real-time events or boiler conditions determined by data gathering sensors. Buildup of soot and slag in the upper portions of a boiler can adversely impact heat transfer to the boiler tubes, unit efficiency, and emissions. During 2004, the NN-ISB was successfully operated in closed loop mode without operator intervention. System optimization is ongoing and will be completed prior to benefits demonstration in early fiscal year 2005. Test data to date has shown reduction in NO_x levels in the range of 10–20 percent and boiler efficiency improvements in the range of 0.5–1 percent. Successful application of this sootblowing system has developed significant technical information advancing neural network technology's acceptance within the electrical generating industry. (Apollo Beach, FL)

Universal Aggregates, LLC – *Commercial Demonstration of the Manufactured Aggregate Processing Technology Utilizing Spray Dryer Ash.* This Power Plant Improvement Initiative project is in the operations phase. Modifications to the pugmill, pug sealer, and extruder are being made to produce a consistent product from the spray dryer ash removed from the Birchwood Power Facility. Modifications to the equipment and additives are being tracked and documented along with the corresponding characteristics of the material produced. The project is scheduled to end in May 2005. (King George, VA)

CCPI STATUS

NeuCo, Inc. – *Integrated Optimization Software*. The project is slightly ahead of schedule. The Combustion Optimization module is installed in cyclone-fired boilers Units 1 and 2 in Dynergy Midwest Generation's Baldwin Energy Complex in Baldwin, Illinois. Initial results of the module operation indicated that NO_x levels at full load were 20 percent lower than NO_x levels without the optimization module. Four other optimization modules (SCR, sootblowing, performance, and profit optimization) are scheduled to be on line by August 2005. Formal product release will be made in the coming year. (Baldwin, IL)

We Energies – *TOXECON™ Retrofit for Mercury and Multi-Pollutant Control*. This CCPI project was initiated in April 2004. National Environmental Policy Act requirements were completed for this project prior to award. The project is currently in the engineering design phase. An initial design review meeting was held, and the participant has submitted a Project Management Plan. Balance of Plant engineering design is ongoing. Specifications for the baghouse design and other subsystems have been developed, and requests for bids have been issued for these items. (Marquette, MI)

Western Greenbrier Co-Generation, LLC – *Western Greenbrier Co-Production Demonstration Project.* Negotiations were completed and the project was awarded in April 2004. Budget Period 1 – Project Definition is under way. Conceptual layout of project equipment and subsystems on the proposed project site has been completed. Environmental data gathering is under way. Electricity interconnection options for transmitting the power into Ohio, Pennsylvania, New Jersey, or New York are being investigated. Plans are to initiate construction in fall 2005 or spring 2006. (Rainelle, WV)

Great River Energy – *Lignite Fuel Enhancement*. The cooperative agreement was awarded in July 2004. The project is to design, build, and operate a lignite drying system and demonstrate the benefits of firing lower-moisture, low-rank coals. GRE will be assisted by team members including Barr Engineering Company, Electric Power Research Institute, Lehigh University, and Falkirk Mining and Couteau Properties Company. The project period is from July 2004 to April 2008. National Environmental Policy Act requirements were completed for this project prior to award. (Underwood, ND)

U.S. DEPARTMENT OF ENERGY
FE-20
1000 INDEPENDENCE AVENUE
WASHINGTON, DC 20585-1290