Office of Fossil Energy, U.S. Department of Energy • DOE/FE-0530 • Issue No. 80, Spring/Summer 2009

CLEAN COAL TODAY

A Newsletter About Innovative Technologies for Coal Utilization

News Bytes

Secretary of Energy Steven Chu announced an agreement with the FutureGen Alliance that advances the construction of the first commercial-scale, fully integrated, carbon capture and sequestration project in Mattoon County, Illinois. The June 12, 2009 provisional agreement includes a number of activities to be pursued through early 2010, at which time a decision will be made to either move forward or discontinue the project. For details, see the Fossil Energy News Spotlight at http://www.fe.doe.gov. ◆

On May 15, 2009, Secretary Chu announced that $2.4 billion from the American Recovery and Reinvestment Act was to be used to accelerate carbon capture and storage (CCS) technology. At press time, two funding Opportunity Announcements (FOAs) had been posted. For

See "News Bytes" on page 7...

Inside This Issue

CCS Conference Urges Policy Action, Near-Term Projects

More than 700 participants from government, industry, academia, and the international community met from May 4–7 in Pittsburgh for DOE's Eighth Annual Carbon Capture and Sequestration (CCS) Conference. The dialogue on the status and future of CCS was especially timely in light of the expectation that some type of carbon regulation in the U.S. is imminent, and deliberations on a post-Kyoto treaty are scheduled for December in Copenhagen. The annual conference was co-sponsored by DOE and the National Energy Technology Laboratory, in cooperation with the International Energy Agency's (IEA) Greenhouse Gas R&D Programme and the National Association of Regulatory Utility Commissioners. Exchange Monitor Publications & Forums serves as conference overseer.

Victor K. Der, Acting Assistant Secretary for Fossil Energy, addresses opening plenary

During the three-day conference, attendees heard reports from CCS researchers, project developers, and representatives of the finance community. U.S. government officials addressed policy and regulation. The Governor of Wyoming, David Freudenthal, discussed the State's aggressive efforts to be in the forefront of CCS land use regulation. Additionally, state utility commissions spoke of expanding beyond traditional Public Utility Commission (PUC) least-cost philosophy toward the long term. A public outreach session outlined communication strategies for this new and sometimes misunderstood technology. Presentations on independent policy studies by Carnegie Mellon, Stanford, and MIT contributed to the conference discussions.

A number of participants emphasized that the U.S. should not wait for the perfect plan or deliberate over the exact number of demonstration plants needed by a given date, but should start now and "learn by doing." This resolve will help us implement CCS "better, faster, and cheaper," according to Victor K. Der, DOE Acting Assistant Secretary for Fossil Energy. Der noted that CCS was to receive stimulus (American Recovery and Reinvestment Act) funds in the areas of geologic site characterization, industrial CCS, CO_2

See "CCS Conference" on page 2...

... *"CCS Conference" continued*

sequestration training and research, and the Clean Coal Power Initiative (see News Bytes). NETL's existing plant program is now focusing on post-combustion CO_2 capture.

Der stressed Energy Secretary Chu's commitment to international cooperation in CCS, continuing important work with the IEA and the Carbon Sequestration Leadership Forum. Since the conference, the Administration has rolled out its fiscal year 2010 Budget of over $880 million for the Office of Fossil Energy, of which over $179 million was requested for carbon sequestration research and development. The American Recovery and Reinvestment Act provided a $3.4 billion stimulus package for fossil energy research and development, of which $2.4 billion will be used to accelerate carbon capture and storage.

There was no lack of ideas for facilitating CCS, and progress was reported on various fronts. The Southeast Regional Carbon Sequestration Partnership announced it would be sequestering CO_2 from a coal-fired power plant in the second part of its Phase III project. Some of the other U.S. projects reported include Duke Energy's investigation of CCS for its Edwardsport, Ind., 630 MW coal-fired IGCC plant. The plant is currently under construction and scheduled to come on line in 2012. At American Electric Power's coal-fired Mountaineer plant in New Haven, West Va., Alstom's chilled ammonia process is to capture CO_2 which would be stored in a saline formation. The project, currently under construction, involves treating the combustion flue gas from a 20 MW slipstream. Mitsubishi Heavy Industries reported the company is close to commercial demonstration of its KM-CDR post-combustion CO_2 capture process. The IEA's Greenhouse Gas R&D Programme reports there are 28 large-scale CCS projects operating worldwide.

The conference was held at Station Square, overlooking the Monongahela River, once a major hub of the Pittsburgh & Lake Erie Railroad

Regulatory and legal issues were considered by many to be more of a barrier than technical issues. From the national standpoint, lack of a clear legislative directive establishing a price for carbon makes CCS business planning difficult. Thus, a regulatory program would be welcomed by many. David Hawkins of the Natural Resources Defense Council reported that 25 major businesses and five nongovernmental organizations had signed on to the U.S. Climate Action Partnership's agenda.

From a state standpoint, a way to speed CCS would be to clarify land use issues such as pore space ownership and trespass. Long-term stewardship is also key and there are no representative long-term liability frameworks from which to model a program. Governor Freudenthal reported on efforts by legislative committees in his state to resolve these complex issues.

Sally Benson, Director of the Global Climate and Energy Project at Stanford University, recommended pre-qualifying a cluster of promising saline aquifer storage sites to avoid regulatory hurdles and gain public acceptance. "We have determined there is a large capacity (per DOE's 2008 Carbon Sequestration Atlas II) and that's why we are here at this conference." Multi-agency teams could also speed resolution of permitting and legal issues, said Benson.

The availability of insurance can be another barrier to getting CCS projects moving and financed. Lindene Patton, Zurich Financial Services, spoke on her company's first-of-a-kind CCS policies. The policies are offered because Zurich sees CCS as a critical link to a less carbon-intensive energy future. Zurich's CCS liability policies address specified third party liabilities from the point of capture, through injection, to storage during the operational period of the facility. The policies would cover a variety of bodily injury and property damage risks, including those arising from migration of CO_2 from the intended repository.

Another of the Zurich CCS policies is designed specifically to provide financial assurance during the closure and post-closure phases for closure and post-closure plan-related permit defined liabilities. Zurich's policies do not presently address long-term stewardship risks after the operations have ceased and the closure and post- closure defined obligations are met. Patton recommended the government establish some type of safety board to resolve the "inherent

See "CCS Conference" on page 7...

RECS Grads Gain Professional Exposure

Graduates from the U.S. Department of Energy (DOE)-sponsored Research Experiment in Carbon Sequestration (RECS) program are a growing presence at conferences on carbon capture and storage (CCS), evidence that the training program is providing important professional opportunities. Fifteen RECS alums attended DOE's Eighth Annual CCS Conference in Pittsburgh. They networked with CCS professionals, and presented a total of nine technical papers and five posters.

Egemen Ogretim of West Virginia University describes his poster "Sensitivity Analysis for Crosswind-Topography Effects of CO_2 Leakage"

RECS is a two-week summer program, begun in 2004, and is funded by DOE and a growing number of corporate sponsors. Pamela Tomski of EnTech Strategies LLC devised the program for DOE. The venue is usually a university where the group meets for a week of class instruction, followed by a field trip to geological formations, power plants, or mines. In recognition of the increasing need for young professionals in the CCS field, all expenses are paid by DOE. This year's program starts in July at the University of New Mexico.

To date, over 100 students have graduated from RECS. Approximately half of the RECS participants come from foreign countries but are studying at U.S. universities or working here. This is consistent with Secretary of Energy Chu's emphasis on international cooperation, and a general acceptance that CCS (and climate change reduction) must be a global effort. The students are divided among policy analysts and researchers in such technical areas as leakage modeling, fracture propagation, and hydrodynamic trapping.

L to R: Emeka Stanley Chukwukere, Pamela Tomski, Darian Ghorbi, and Anna Kaminska

Recent RECS alum Darian Ghorbi was delighted to attend his first DOE Sequestration conference. At 23, he is a young man with a future, having landed his first job at DOE headquarters assisting the lead manager for the Regional Partnerships. Darian came to DOE through Carnegie Mellon University's Tom Johnson Engineering & Public Policy Fellowship. "My experience at RECS will likely be one of the most important of my career. In addition to solidifying my understanding of the subsurface, it allowed me to make important professional connections."

Also present at the conference was Preeti Verma, from India, a specialist in CCS at the World Resource Institute. She credits RECS with giving her the broad base needed for her policy analysis work at WRI. Preeti presented two papers and appeared on the special panel discussion on public outreach. Anna Kaminska, from Poland, studies environmental engineering at Nottingham University. She presented two posters related to mineral carbonation.

Jeffrey Bielicki, a newly minted Harvard PhD in energy policy, spoke on the spatial deployment of CCS. Jeff is an alumni mentor and part of the RECS faculty. Jason Heath presented a poster on caprock analysis. He is finishing his PhD at New Mexico Tech and works at Sandia National Laboratory supporting the Southwest Partnership on Carbon Sequestration.

RECS graduates hold an impressive range of jobs. Dr. Weon Shik Han (who was also a conference speaker) is on the instruction research staff at the University of Utah's Energy and Geoscience Institute. Another graduate, Chris Stepanian, was a founding team member of Aspen Aerogels, (blanket insulation), while Dr. Kurt Zena House patented and licensed an electrochemical process to expedite the ocean's natural ability to absorb CO_2. Nathan Whitehouse is a New York City attorney specializing in carbon finance. Vanessa Nunez-Lopez is a Senior Reservoir Engineer at Chevron Energy Technology Co. Vanessa reflects the opinions of many in describing her RECS experience as "invaluably hands-on" exposure to a brand new occupational field.

For information on RECS, see http://recsCO2.org. ■

NETL ISSUES NEW SYSTEMS STUDIES ON COAL AND BIOMASS

The U.S. Department of Energy, Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) has recently completed two systems studies examining how existing technologies can use coal and biomass together in order to fuel both the transportation and electricity sectors, while simultaneously lowering greenhouse gas emissions. The two reports are part of the diverse portfolio of NETL studies to inform decision-making of both government policymakers and RD&D managers, as well as to provide valuable analyses to stakeholders (see Fall/Winter 2007 Clean Coal Today).

The latest studies, published in January 2009, are *Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass* and *Conversion of Domestic Coal and Biomass Resources into Power with Net-Zero GHG Emissions*. Gasification is utilized as a base technology in both studies, as tests have successfully demonstrated that a feedstock containing up to 30 percent (by weight) biomass with coal can be processed in a large-scale, commercially available gasifier. The coal-biomass technologies discussed in the reports can also accommodate carbon capture and storage (CCS). CCS in geologic formations has been demonstrated at scales of over one million metric tons per year, and DOE and its partners have an active commercial-scale demonstration program.

PRODUCING LOW-CARBON DIESEL FUELS

Some two-thirds of U.S. transportation fuels are imported, and subject to crude oil price volatility, with attendant economic and energy security impacts. The transportation sector emits more CO_2 than any other end-use sector of the economy (34 percent of total CO_2 emissions). Conversion of coal into liquid fuels decreases the need for imports. With CCS these fuels can have approximately the same greenhouse gas (GHG) emissions as similar petroleum-derived fuels. However, increasing emphasis on further reducing the GHG emissions profile of coal-to-liquids (CTL) fuels has led to interest in the co-feeding of coal and biomass to combine benefits of coal's low-cost and the GHG reduction benefits of biomass. Thus, from both an energy security and environmental standpoint, the Low-Carbon Diesel Fuel study is timely.

While coal-to-liquids (CTL) plants produce over 150,000 barrels per day globally, there are no coal-and-biomass-to-liquids facilities in existence. The study evaluates the economic feasibility and lifecycle GHG emissions of converting domestic supplies of coal and biomass to diesel fuel using a commercially available indirect liquefaction process coupled with CCS. According to the NETL study, Coal to Liquids and Coal and Biomass to Liquids (CTL/CBTL) can be a near-term (within three-to-five years) option.

In the study, diesel fuel produced from coal and coal-biomass mixtures is compared against a "petroleum baseline," defined by the Energy Independence and Security Act of 2007 (EISA 2007) as year 2005 lifecycle greenhouse gas emissions from gasoline and diesel fuel produced by U.S. refineries.

Specifically, *Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass* finds that:

- The ultra-low-sulfur diesel fuel produced by CTL and CTBL plants could meet EISA 2007 government procurement requirements (i.e. be Section 526 compliant) with a lifecycle GHG emission level lower (5 to 63 percent) than the petroleum-derived diesel.
- CTL plants with CCS are economically feasible (i.e., achieve a 20 percent internal rate of return), when the crude oil price is above $86 per barrel (assuming a carbon price of $0 per metric ton CO_2-equivalent), and CBTL plants that blend up to 15 percent biomass (by weight) are feasible when crude oil exceeds $95/bbl. These fuels become competitive at lower oil prices if a carbon tax is in place, per figure on p. 5.
- Producing diesel fuel exclusively from biomass, without the economies of scale provided by coal, is not economically feasible unless crude oil prices are very high, at least $170 to $240 per barrel depending on the carbon price.
- Adding CCS increases the product cost of CTL by only seven cents per gallon.

While CTL/CBTL fuels are not economically feasible when world oil prices are down, these fuels will be very profitable at predicted oil prices of $110/bbl (by 2015) and $130/bbl (by 2030), as forecast by DOE's Energy Information Administration's *Annual Energy Outlook 2009*. Under a carbon regulation scenario, CTL/CBTL diesel fuel would become more competitive with petroleum-derived diesel as carbon prices increase, since CTL/CBTL diesel

wt% Biomass	Life-Cycle GHG Emissions Relative to Petroleum-Derived Diesel
0	-5%
8	-20%
15	-33%
30	-63%
100	-322%

At a carbon tax between $0/mtCO$_2$E and $45/mtCO$_2$E, these fuels are economically feasible when...

- crude oil is above $80 to $95/bbl
- crude oil is above $95 to $110/bbl
- crude oil is above $175 to $225/bbl

Figure 1: Nexus of GHG Emissions, Economic Feasibility Price and Biomass Usage

has lower life-cycle GHG emissions. For example, CTL with CCS is economically feasible when crude oil is above $80/bbl when carbon is priced at $45/metric ton of CO_2 equivalent, whereas oil must be above $86/bbl when carbon the carbon price is $0/mt$CO_2$E.

Low-GHG Power

The U.S. power sector is responsible for some 80 percent of total GHG emissions, while coal-fired power plants account for approximately 50 percent of power generation in the U.S. Integrated Gasification Combined Cycle (IGCC) plants with carbon capture have shown great promise for providing low-carbon electricity at a more affordable price than conventional pulverized coal plants with carbon capture. *Conversion of Domestic Coal and Biomass Resources into Power with Net-Zero GHG Emissions* examines a dry-fed entrained flow IGCC system co-firing biomass along with coal as a strategy for carbon mitigation.

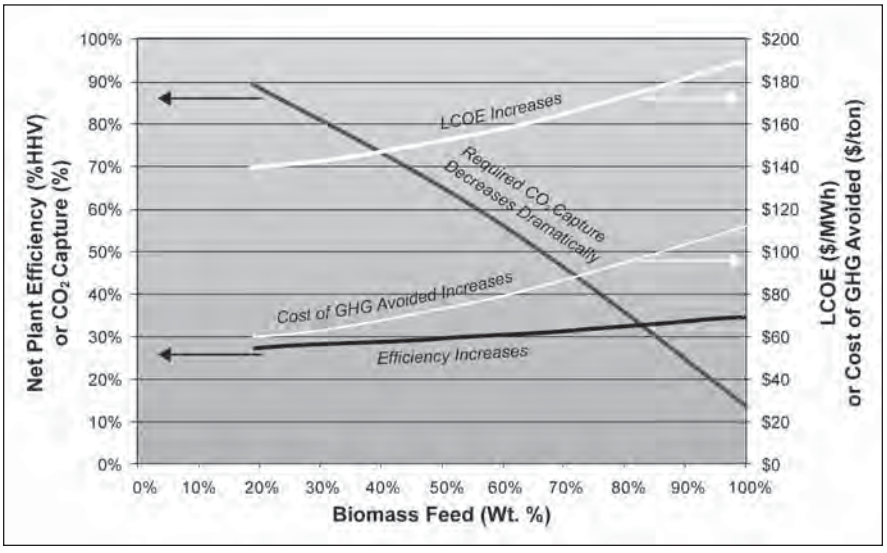
In the current power generation market, the most cost-effective way to capture CO_2 in an IGCC plant, on a dollars-per-ton-avoided basis, is to use conventional carbon capture while firing 100 percent coal as the feedstock. However, power generation with net-zero lifecycle GHG emissions requires the use of biomass, since capturing only CO_2 emissions from the plant itself could never offset the upstream lifecycle GHG emissions. Firing 100 percent coal while maximizing carbon capture in an IGCC plant can only reduce life cycle emissions to ~350 lbs GHG/MWh and costs approximately $40/ton of GHG avoided. Feeding 20% biomass with 90% CCS to reach net-zero emissions costs ~$60/ton of GHG avoided – which is similar to, or perhaps lower than, the cost of CO_2 capture in state-of-the-art pulverized coal plants using current post-combustion capture technologies.

While biomass co-firing has yet to be implemented in a system with CCS, NETL study results are promising. In addition to reducing GHG footprint, biomass/coal co-firing results in a significant reduction in auxiliary power required for CCS. For a given GHG target, increasing biomass feed percentage also increases net plant output, reducing the amount of power that must be generated by the neighboring plants in the power grid to compensate for the CCS auxiliary load penalty. If the cost of firing biomass to reduce GHG emissions can be reduced to less than the cost of state-of- the-art carbon capture/compression for an equivalent GHG reduction, the power industry will realize significant efficiency advantages.

Among the study's specific conclusions:

- It appears technically feasible, if not currently profitable, to blend biomass with coal to reduce the GHG emissions from power generation. Capturing and sequestering CO_2 generated by a coal and biomass IGCC plant can realize net-zero lifecycle GHG emissions when firing ~20%wt biomass.

See "Systems Studies" on page 7...



Performance of an IGCC Plant Achieving Net-Zero Lifecycle GHG Emissions

NEW TURBINE MATERIALS FOR ADVANCED ULTRA SUPERCRITICAL COAL POWER PLANTS

As part of a collaborative effort joining the U.S. Department of Energy (DOE) with a team of energy research organizations and major equipment suppliers, the National Energy Technology Laboratory (NETL) has initiated a three-year project aimed at developing new turbine materials for Advanced Ultra Supercritical (A-USC) boilers. Work is being conducted under the Office of Fossil Energy's Advanced Research Program. Although A-USC steam cycles reduce carbon dioxide emissions through more complete fuel combustion and higher efficiencies, ultra supercritical steam conditions (1400 °F and 5,000 psi) are damaging to components. By developing new materials with the necessary fabricability, oxidization-, corrosion-, fatigue- and creep-resistance required to withstand A-USC conditions, the team members—including NETL, Energy Industries of Ohio, Electric Power Research Institute, Oak Ridge National Laboratory, GE Energy, and Alstom Power—hope to remove the existing barriers to implementing the cleaner, lower-emissions technology.

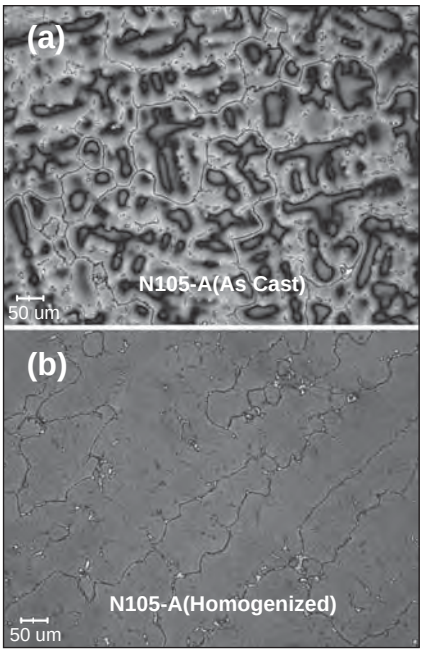
Inspection of a steam turbine rotor assembly

New materials technology for A-USC steam turbines to match the A-USC boiler conditions is clearly necessary and is a priority in order to support commercialization of A-USC power plants. As part of this development effort, modified cast versions of conventionally wrought high-temperature alloys are being developed and evaluated as to their resistance to creep and oxidation under the harsh steam conditions of the pulverized coal fired plants. Erosion and corrosion-resistant coatings are also being investigated. These materials will have the ability to be cast to form a finished product.

The overall approach is to identify high-potential candidate alloys for critical components for turbine casings and valve body applications. Two parallel efforts evaluate the mechanical and corrosion properties of the candidate materials and coatings to use for rotors, buckets, and bolting, as well as valves and cylinder body casing. The proposed steam inlet temperatures to the turbine are high enough (1400 °F) that traditional casing materials such as ferritic/martensitic steels are not an option. NETL's role is to identify alloy compositions capable of withstanding these harsh environments, while also meeting requirements for castability.

Examination of the as-cast microstructure of experimental castings showed them to be highly segregated. Many nickel (Ni)-based superalloy ingots are given a homogenization heat treatment prior to further processing by hot working in order to evenly distribute the alloying elements throughout the microstructure. Solute inhomogeneities can adversely affect the corrosion/oxidation resistance, strength (utilization of alloy additions), service temperature (resulting from artificially lowering the melting temperature in interdendritic regions), hot workability (from grain boundary liquation or cracking), and therefore induce formation of undesired topologically close-packed (TCP) phases. Alloys that are used in the cast form, such as those proposed for the turbine casing application, are not subjected to hot working. Thus, the homogenization heat treatment of cast Ni-base superalloys is especially critical, and can be viewed as the last "processing" step the component receives before being put into service.

Parameters for homogenization heat treatments for newly-developed alloys are often defined by trial and error, past practice on alloys of similar composition (parent alloys), or extensive experimental lab work. If a sample of the cast microstructure can be obtained, the segregation across a dendrite arm can be profiled, and the homogenization modeled with ther-



Microstructure of Nimonic 105 superalloy ingots before (a) and after (b) successful homogenization

modynamic modeling software. Such a homogenization treatment can be important for Ni-based superalloys, which are designed to be slow diffusing for high temperature mechanical and microstructural stability. While a traditional brute force approach to diffusion calculations may work to design a homogenization heat treatment for simple alloys, this approach is not practical for Ni-based superalloys. Typical Ni-based superalloys can contain in the neighborhood of 10-15 alloying elements.

Researchers at NETL developed a patent-pending technique to model the as-cast segregation and optimize the homogenization heat treatment process (see p. 6). Castings given this homogenization heat treatment performed comparably to conventional wrought materials in terms of creep. Improvements are also anticipated in corrosion and other critical performance criteria. ■

... "News Bytes" continued

the Clean Coal Power Initiative, $800 million will provide broader commercial-scale experience by expanding the range of technologies, applications, fuels and geological formations to be tested. For Industrial CCS, $1.52 billion will fund large-scale projects, as well as innovative concepts for CO_2 re-use and CO_2 capture from the atmosphere. ◆

Three Notices of Intent (to issue FOAs) include $50 million for Geological Sequestration Site Characterization, and $20 million for both Regional Sequestration Technology Training, and Geological Sequestration Training and Research. For more information: http://www.fe.doe.gov/aboutus/budget/stimulus.html. ■

... "Systems Studies" continued

- For a target GHG emission rate, efficiency tends to increase as biomass feed is increased in a coal and biomass IGCC plant. Increasing the proportion of biomass feed causes a decrease in the total amount of non-renewable CO_2 emitted for a given power output. This reduces the required level of CO_2 capture/sequestration and associated auxiliary load, thus raising efficiency.
- For a net zero GHG emission rate, increasing biomass feed percentage from 19%wt to 100%wt raises efficiency by nearly seven percentage points (HHV basis) overall. This represents nearly a 20 percent decrease in heat rate, compared to a 15 percent heat rate increase with state-of-the-art CCS capturing 90 percent of CO_2 in a coal-only IGCC plant.
- Despite the large increase in efficiency, when capital and operating costs are considered, the LCOE normalized on a $/MWh basis increases as the biomass feed percentage is increased. This is due largely to the cost of biomass production and transportation. R&D to reduce the cost of production and delivery of switchgrass could help reduce these costs.

The GHG reduction benefits of Coal Biomass IGCC plants may extend to the transportation industry if plug-in hybrid electric vehicles, recharged with the carbon-neutral power, become a substantial component of the automotive industry. Together, the power generation and transport industries comprise two-thirds of the total CO_2 footprint of the United States. Pending adequate feedstock availability, integrating biomass-generated power with the transportation sector has enormous potential for GHG reduction. ■

... "CCS Conference" continued

conflict-of-law issues" relating to CO_2 long-term storage.

A number of speakers felt a government role was either desirable or unavoidable. Theodore Roosevelt, IV, of Barclay Capital, indicated the government would need to issue loan guarantees, government indemnification, or even become an equity partner for an initial pool of large-scale products. He recommended six CCS projects, managed by an Electric Power Research Institute (EPRI)-type entity and joint ventures in China and India. It is necessary, Roosevelt said, to employ a full portfolio of technologies/energy sources, and lack of one key element (such as CCS) would put pressure on other key components of the mix.

Attendees were hopeful for CCS as long as there is policy action. The EPRI roadmap considers CCS viable. If used in conjunction with other technologies, including measures like demand-side management and "smart grid," EPRI's analysis indicates CO_2 levels can be brought to 1990 levels by 2025. The Natural Resource Defense Council's Hawkins emphasized the need to move quickly. "By next year we will need to have a lot done or Congress will become mired in climate policy, Wall Street will be averse, and the dash to gas will have begun," concluded Hawkins. ■

REGIONAL PARTNERSHIPS ADVANCE CARBON STORAGE MVA

Robust techniques for monitoring, verification, and accounting (MVA) of CO_2 stored in geological formations are critical to commercial success of projects and acceptance of CO_2 storage as a safe, effective, and environmentally acceptable method of climate change mitigation. Lack of uniformity across the U.S. in terms of geology, energy use, and population distribution, dictates a regional approach to carbon capture and storage (CCS). To this end, the U.S. Department of Energy (DOE) has spearheaded a network of seven Regional Carbon Sequestration Partnerships (RCSPs) across North America, spanning 43 states and four Canadian provinces. Small-scale field testing (< 1 million tons of CO_2 injection) is currently underway. Large-scale field testing (> 1 million tons of CO_2 injection) will begin soon in a variety of geological formations.

Pinnacle tiltmeter array. These devices are placed over CCS formations to monitor subsurface fluid movement and caprock integrity

Sophisticated MVA packages are being devised for these large projects, to assess physical and chemical phenomena associated with geologic storage of CO_2. These research-based MVA protocols greatly exceed minimum regulatory requirements for injection wells under the United States Environmental Protection Agency's (EPA) Underground Injection Control (UIC) Program. The MVA effort builds on and complements work carried out by the DOE/NETL in several early projects under its core R&D program, as well as through cooperation with international partners. These and other efforts are described in the recently issued NETL publication on MVA "best practices." (see p. 10).

MVA includes monitoring the impact of CO_2 injection on the geology of a site, verifying that the CO_2 is permanently stored, and accounting for the total amount of CO_2 that has been stored. As part of the selection process, potential storage sites would first be scrutinized for the proper surface and subsurface characteristics. These features include sufficient storage potential, an intact confining formation above the target storage area, favorable porosity and permeability, and site access to necessary infrastructure. The initial mechanisms for containment of CO_2 in deep geological formations are structural and stratigraphic trapping. Ideally, impermeable caprock overlays the intended target formation. The best geologies contain additional continuous impermeable layers acting as secondary seals above the initial caprock formation. The RCSPs are attempting to define sites where these sealing units are on a regional scale and separate the target formation from both the surface and underground sources of drinking water.

MVA begins in a project's pre-operational phase and continues through operation, closure, and post-closure. MVA improves understanding of storage processes and trapping mechanisms, evaluates the interactions of CO_2 with formation solids and fluids, and follows the movement of the CO_2 plume. Data obtained help to assess environmental safety and health impact, provide input to regulatory bodies, and assure the public as to project safety and proper mitigation strategy.

REGIONAL PARTNERSHIP FIELD TESTS

The MVA packages developed by the RCSP field tests are intended as research-based monitoring tools for use across a geological regime – that may be applied to other sites with similar geology – as opposed to tailoring a site-specific suite of MVA tools. The RCSPs are employing an array of tools that range from basic technologies that have been proven viable in multiple scientific applications, to more cutting-edge technologies that show promise, but require additional demonstration. Proven techniques (including monitoring for injection and formation pressures, injection flowrate, and assessing well integrity) are in wide use in the oil and gas industry for enhanced oil recovery (EOR). The challenge is to ensure that these methods are transferable to non-EOR sites.

Target monitoring zones for the field tests include: atmospheric, above-ground, gas-phase phenomena; near-surface, including surface water and shallow groundwater, and deep-subsurface, depths below the vadose zone (the area extending from the surface to the water table).

ATMOSPHERIC AND NEAR-SURFACE MONITORING

Atmospheric sensing tools are intended to detect gaseous CO_2 above background levels that may indicate leakage. One atmospheric method being used by the RCSPs is eddy covariance, or eddy correlation. An infrared gas analyzer takes high frequency measurements of atmospheric CO_2 concentration at a specific height above the ground, along with measurements of micrometeorological variables such as wind velocity, relative humidity, and temperature. Integration of these measurements allows derivation of the net CO_2 flux over the upwind footprint, typically m^2 to km^2 in area, depending on tower height. Eddy covariance assumes a horizontal and homogeneous surface, and researchers are working to apply the technique to natural systems.

Near-surface monitoring tools can be used to characterize shallow site geology and detect elevated levels of CO_2 that point to leakage pathways. These tools monitor soil gas and shallow groundwater to detect short-term rapid loss or long-term intermittent leakage of CO_2. All RCSPs are conducting some form of groundwater quality analysis at their field tests to ensure that drinking water sources remain intact and free from CO_2 contamination.

Several RCSPs are employing flux accumulation chambers at their large-scale injection test sites to measure soil CO_2 flux. In this technique, a chamber with an open bottom is placed directly on the soil surface or on a collar installed on the ground surface, and the contained air is circulated through the chamber where an infrared gas analyzer performs continuous CO_2 measurements. The rate of change of CO_2 concentration in the chamber is used to derive the flux of CO_2 across the ground surface at the point of measurement. This technique can detect CO_2 fluxes at discrete locations, but is unable to detect fluxes over large areas.

Eddy covariance tower manufactured by LICOR. Lawrence Berkeley National Laboratory leads this aspect of MVA work for the Midwest Geological Sequestration Consortium

In another method of shallow site characterization, two RCSPs are using shallow 2-D seismic surveying with closely spaced geophones along a seismic line. This technology can provide high-resolution images of the presence of gas-phased CO_2. Seismic tools are critical to site characterization and time-lapse evaluations over the various project phases. Magnetotelluric surveys (soundings), are another, and high-tech tool. This method utilizes variations in the earth's magnetic field to image subsurface structures, including abandoned wells.

MONITORING THE SUBSURFACE

Monitoring in the subsurface at depths from the saturated zone to slightly below the target formation is crucial to characterizing the injection site, tracking the CO_2 plume, and ensuring that injection operations are not threatening the integrity of the target formation. One of the most important purposes of monitoring is to confirm that the project is performing as expected based on predictive models or simulations. This is particularly valuable in the early stages of a project when there is the opportunity to alter operations if the project is not performing as originally planned. Site characterization and geologic property data collected early in the project can be used to refine and calibrate the predictive model.

Wireline logging, through a suite of devices lowered down a well or borehole, is used to quantify physical properties, measuring such parameters as temperature, noise, density, and cement bonding both before (to establish a baseline) and after injection. These measurements give an indication of structural integrity of the well, composition of pore fluids, and the mineralogy of the formation. Regardless of the storage formation type, capacity, or location, the well itself must not provide a leakage pathway. While wireline logging is limited to the area immediately around the borehole, it has been crucial to site characterization and operational-phase time-lapse monitoring (monitoring changes in geologic conditions over the duration of the project) at CCS projects worldwide.

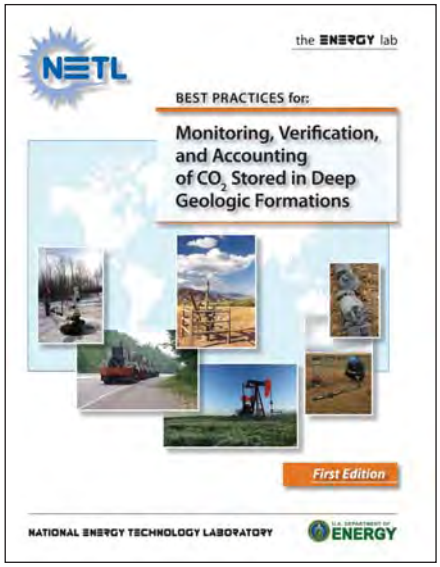
Cutting Edge MVA

A number of novel technologies are being employed in the RCSP field tests. Among them are advanced laser systems for detecting surface and atmospheric CO_2 fluxes, and light detection and ranging (LIDAR). LIDAR is an optical remote sensing technology for detecting atmospheric CO_2 concentrations over a wide area. Isotope tracers "fingerprint" injected CO_2, so that it can be differentiated from background CO_2 in the event it seeps to the atmosphere. Aerial photography and hyperspectrial imaging are also new techniques for assessing site topography and changes in the plant population over the course of the injection. Tiltmeters, a mature oil field technology for mapping small changes in elevation, are being adapted to detect surface changes that may be due to CO_2 injection.

Lessons learned from MVA activities of the RCSPs will ensure that effective and economic monitoring tools are available for future commercial CCS practices. ■

New Report on Monitoring "Best Practices"

DOE's National Energy Technology Laboratory's comprehensive report, *Monitoring, Verification, and Accounting of CO_2 Stored in Deep Geological Formations (DOE/NETL-311/081508)* has just become available at the NETL Reference Shelf http://www.netl.doe.gov/publications/refshelf.html. The comprehensive survey addresses MVA activities at DOE's seven Regional Partnerships nationwide and in Canada, at early DOE pilot tests, and at international projects in which DOE participates. Reliable and cost-effective MVA is crucial to making geological sequestration a safe, effective, and publicly acceptable method of greenhouse gas control. The report incorporates MVA experience obtained over a period of ten years and addresses: objectives and goals of monitoring, monitoring techniques, EPA permitting requirements, and MVA development in large-scale tests in a variety of geological settings. The handbook is intended for project developers, regulatory organizations, and national and state policymakers.



Upcoming Events

July 14 – 16, 2009
10th Annual Solid State Energy Conversion Alliance (SECA) Workshop
Sponsor: DOE-NETL
Location: Pittsburgh, PA
Contact: Wayne Surdoval
Phone: 412-386-6002
E-mail: wayne.surdoval@netl.doe.gov
Web site: http://www.netl.doe.gov/events/09conferences/SECA/index.html

August 11 – 14, 2009
10th Annual Small Business Conference
Sponsor: DOE
Location: Long Beach, CA
Contact: Larry Sullivan
Phone: 412-386-6115
E-mail: larry.sullivan@netl.doe.gov
Web site: http://www.netl.doe.gov/events/09conferences/sm-business/index.html

Clean Coal Today

Published quarterly by:
The Office of Fossil Energy
U.S. Department of Energy
(FE-24)
Washington, DC 20585

Editor: Phoebe Hamill
Phone: 202-586-6099
Fax: 202-586-7085
E-mail:
phoebe.hamill@hq.doe.gov
Web site:
http://www.netl.doe.gov/technologies/coalpower/cctc/newsletter/newsletter.html

Comments are welcome and may be submitted to the Editor.

INTERNATIONAL INITIATIVES

U.S. AND UK ADVANCED MATERIALS COLLABORATION

Participants in a U.S.-UK advanced materials collaborative effort held a meeting in March 2009, in Washington, DC, to mark the fifth anniversary of the cooperative research and report on its results. The collaboration was launched in 2003 under an Implementing Arrangement (IA) between DOE's Office of Fossil Energy headquarters and the former UK Department of Trade and Industry, now the UK Department of Energy and Climate Change. The IA takes advantage of specialized research facilities and the skills of scientists in both countries, and calls for joint project planning, integrated work tasks, scientist exchange, and workshops. New and advanced materials capable of surviving high-temperature and high-pressure environments are central to next-generation power plants with high efficiency and low emissions.

L to R: Phillip Sharman of Alstom Power, NETL's Bob Romanosky, and Bronwen Northmore confer

Bronwen Northmore, Director of Cleaner Fossil Fuels Policy at the UK Department of Energy and Climate Change, heads the collaboration on the UK side. She spoke of UK policy initiatives in carbon capture and storage, policies in which ultra-efficient coal plants, constructed with advanced materials, have a definite place. DOE officials provided the equivalent U.S. picture. Technical presentations reported on team achievements in the major research areas.

Over the day's program, speakers addressed the problem of materials "creep" (deformation under stress), the behavior of materials under steam oxidation conditions, and models developed to evaluate the oxidation process. The group also noted progress in understanding boiler corrosion, developing special oxide dispersion-strengthened (ODS) alloys, and overcoming problems specific to gas turbines fired by syngas.

Material creep is a particular problem in boiler steam tubes under *steam oxidation* conditions. Thus, understanding oxidation mechanisms of conventional and candidate new materials in steam environments is critical. Oxide scales build up and form an insulating layer on the inside of the boiler steam tubes. This acts to increase the local temperature of the metal, as the heat from the boiler can no longer be effectively transferred to the cooling steam. The material then creeps at a faster rate and component life is shortened. The oxide can also spall away from the waterwall side of the tube, exposing fresh materials to oxidize. As this continues, the wall thickness is reduced, leading to further reductions in component life.

One of the important results of U.S.-UK work has been the development of models based on the mechanistic behavior of oxides to help forecast how oxidation will progress over the service life of the materials. Oxidation research is taking place at several high-pressure steam test facilities in the U.S. and the UK. In total, over 1 million hours of steam oxidation data have been accumulated in these laboratory tests, with some 30 alloys tested at varying temperatures.

U.S.-UK researchers are also studying *boiler corrosion* in cases where a range of fuels (e.g. waste and biomass) are combined with coal. New fuels added to the feed coal expose tube surfaces to different particulates and gaseous compounds that can shorten boiler tube life. Work has emphasized oxidation kinetics and accumulation of scale on boiler tubes exposed to steam, air, and water vapor. Electrochemical techniques are being used for on-line monitoring at high temperatures. Laboratory studies have also investigated potential effects of oxyfuel firing on corrosion rates.

Progress has also been made in field testing of prototype corrosion probes, with the goal of improving durability and reliability in harsh environments. Probes allow measurements of tube corrosion in-situ, avoiding the need for unplanned, costly shutdowns.

In terms of *gas turbines fired by syngas*, contaminants from coal, waste products and biomass necessitate corrosion-resistant, thermal barrier coatings for blades, vanes, and combustor cans. Turbine materials also have to be optimized for specific gas streams using different gasifiers, syngas systems, and pre-combustion CO_2 capture/H_2 enriched syngas production. Researchers have worked to quantify the effects of contaminants and rank alloys and coatings that could be used in future high-temperature power plants. Four 1000-hour burner rig tests have been carried out on candidate materials, including single crystal and conventionally cast materials.

Oxide dispersion-strengthened (ODS) alloys have excellent creep strength, but cannot be effectively joined by conventional welding techniques. Work has focused on developing non-fusion joining methodologies, evaluating tube-to-tube, butt- and flanged-joint welding configurations as required for the high temperature sections of the boiler. Friction-stir welding, inertia welding, and plasma-assisted diffusion bonding were shown to be promising methods of joining ODS alloys, with the latter producing joints with creep strength of 75 percent of the parent metal. Another joining method, hot tube torsion welding, also showed promise.

Collaborative efforts will continue in these same materials study areas, developing data to improve understanding of degradation mechanisms, improving predictive models, and establishing standardized test methods to make more effective use of research data.

NETL Assists Turkey in Developing Lignite Proposal

A team of U.S. energy consultants, including a representative of the U.S. Department of Energy's National Energy Technology Laboratory (NETL), visited Turkey in January 2009 under the auspices of a U.S. Trade and Development Agency (USTDA) mission. NETL's role was to provide technical expertise in the area of lignite utilization. As a large user of natural gas (mostly imported from Russia), Turkey wants to diversify its energy supply and at the same time reduce its overall carbon footprint as part of its application for entry into the European Union.

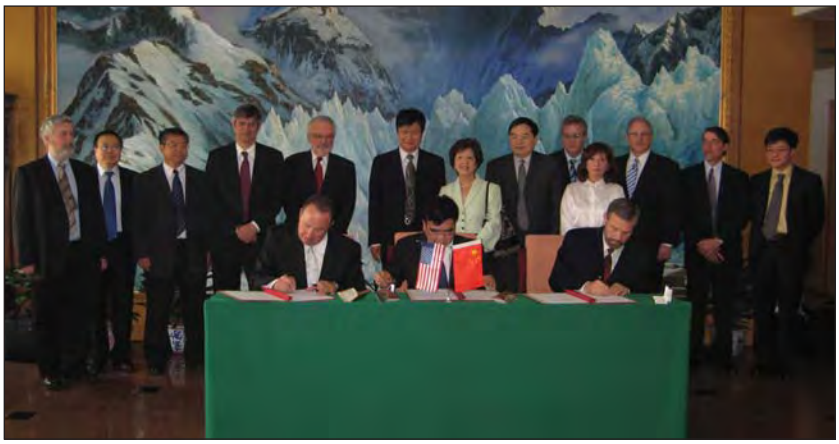
NETL estimated that a single, large lignite gasification facility, similar in capacity to the existing Great Plains Gasification Plant in North Dakota, could displace a significant percentage of the projected future annual growth of Turkey's natural gas imports. NETL worked closely with USTDA to develop an internal document on the need and rationale for a feasibility study on such a facility. As a result of the January mission, and in advance of President Obama's visit, USTDA and Turkey's Ministry of Energy and Natural Resources signed a Memorandum of Agreement (MOA) on April 4, 2009. The MOA includes funding for a lignite gasification feasibility study by Turkish Coal Enterprises, the state-owned lignite mining company. The lignite study, together with other MOA cooperation in energy efficiency and renewable energy, will advance key objectives of the Obama Administration by reducing carbon emissions, investing in clean energy, and creating U.S. jobs associated with the deployment of advanced clean energy technologies.

Natural gas accounts for 29 percent of Turkey's total primary energy consumption. Coal accounts for 25 percent. Most of Turkey's energy comes from oil (35 percent), with a small portion (11 percent) derived from hydro and renewable energy. Recent estimates show Turkey's proven oil reserves to be 300 million barrels, with natural gas reserves at 300 million cubic feet. As of 2005, Turkey's recoverable coal reserves (mostly lignite), stood at 9.3 billion short tons. Of this total, some 2 billion tons are minable, mostly from open-pit mines supplying mine-mouth power plants.

LAB-TO-LAB COOPERATION WITH CHINA

NETL and China's Academy of Sciences have taken the first steps toward formal laboratory-to-laboratory R&D by signing two Memoranda of Understanding (MOU) in Beijing, on May 11, 2009. In one agreement among NETL, the Chinese Academy's Research Center for Energy and Power, and DOE's Pacific Northwest National Laboratory, joint research will be undertaken in advanced coal conversion carbon capture and storage (CCS) technologies. The other MOU, between NETL and the Academy's Institute of Processing Engineering, centers on computational modeling and virtual simulation related to advanced coal utilization.

The CCS-related MOU has several areas of emphasis. It calls for joint work in high-volume carbon capture and storage, including impacts of mineralization on CO_2 storage and phase behavior. Advanced gasification technologies will also be pursued, including the impact of coal rank on syngas product distribution. Oxygen separation technologies, advanced materials, and sensors for gasification are other areas of study. Syngas conversion to gasoline, oxygenated products, chemicals and natural gas will also be researched jointly. The modeling-focused MOU addresses multi-phase and multi-scale modeling of carbon capture and storage processes, gasification, combustion, and other processes.



Signing Ceremony for CCS-related MOU. Left to right: Michael Kluse, Director of Pacific Northwest National Laboratory; Xiao Yunhan, Director of the Research Center for Energy and Power, Chinese Academy of Sciences, and NETL Director Carl O. Bauer

While in China, NETL Director Carl O. Bauer and the NETL team met with key government agencies and the private sector. DOE's Office of Fossil Energy already has an R&D protocol with the Chinese Ministry of Science and Technology (MOST), which was reviewed with MOST Vice Minister Cao Jianlin. During the meeting, Mr. Cao elucidated a clean energy future for China with coal as the mainstay of its primary energy supply. He also foresees increasing contributions from renewable sources, such as wind, solar, and biomass, and more emphasis on energy conservation in all sectors. Director Bauer and his team also met with Shenhua Corporation, the largest single coal producer in China and operator of the world's only direct coal liquefaction facility, to discuss potential R&D cooperation. Shenhua and Tsinghua University are establishing a National Low-Carbon Energy Research Institute in Beijing, and expressed interest in formal cooperation with NETL and other U.S. laboratories. NETL plans to participate in Shenhua's symposium later this year on low-carbon energy development strategies and technologies.

The visit of NETL representatives to China helped the laboratory to identify a number of near-terms goals for cooperation on coal and CCS-related areas. One important goal is to help China develop a Carbon Sequestration Atlas similar to that published for the United States. This effort would build on recent analyses coordinated by the U.S.-China Energy & Environmental Research Center (EETC) and clean cooperative activities under the Asia Pacific Partnership's (APP) Cleaner Fossil Energy Task Force.

ACTIVE PPII AND CCPI PROJECT STATUS

PPII STATUS

CONSOL Energy Inc. – *Greenidge Multi-Pollutant Control Project*. The Final Technical Report for the Greenidge Multi-Pollutant Control Project was approved and has been posted on the NETL Clean Coal Technology Compendium website. The Final Technical Report is a comprehensive overview of the project, including concept and goals, design, construction, operations, testing, results, and conclusions. This highly successful project concluded on October 18, 2008, having achieved all of its emissions reduction goals. The demonstration project was conducted at the 104 MWe coal-fired AES Greenidge Unit 4 near Dresden, NY. The multi-pollutant control system includes a hybrid selective non-catalytic reduction (SNCR) / in-duct selective catalytic reduction (SCR) system to reduce NO_x emissions, followed by a circulating fluidized bed dry scrubber system to reduce emissions of sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrochloric acid (HCl), and hydrofluoric acid (HF). Mercury (Hg) removal was also achieved via the co-benefits afforded by the in-duct SCR, dry scrubber, and baghouse. Performance targets included NO_x reduction to ≤0.10 lb/mmBtu, ≥95 percent removal of SO_2, SO_3, HCl, and HF, and Mercury removal ≥90 percent. Actual measured results were a NO_x emission rate of 0.10 lb/mmBtu, SO_2 removal of 96 percent, Hg removal of 94–98 percent, SO_3 removal in the range of 95 to 97 percent, and HCl removal of 97 percent. HF concentrations were typically at or below the detection limit, precluding the determination of removal efficiency. (Dresden, NY)

CCPI STATUS

Great River Energy (GRE) – *Lignite Fuel Enhancement*. GRE has installed four dryers on Unit 2 as part of the Clean Coal Power Initiative project. Due to success obtained in the prototype phase of this project, GRE has installed four more dryers on Unit 1 with its own funds. Thus, the entire Coal Creek Station has been retrofitted with lignite coal dryers. To date, GRE has completed the construction of three floors in the dryer building and installed the major pieces of equipment, i.e., four dryers on the bottom floor, four baghouses on the middle floor, and four fans on the top floor, for each of the two 546-MW units at the Coal Creek Station in North Dakota. The major dryer internals, such as water coils, air sparger, fire protection system, and explosion protection system, have also been installed. The dryer building is now enclosed, and equipped with electrical cables, lights, and heating systems. The construction of the coal crusher building is in progress. (Underwood, ND)

MEP-I LLC (Excelsior Energy Inc.) – *Mesaba Energy Project*. Excelsior's application for pre-construction site environmental permits—including requests for a large electric power generating plant site permit, routing permits for a high voltage transmission line and natural gas pipeline, and air and water appropriation permits—continues to proceed through the Minnesota Public Utilities Commission (MPUC) approval process. The Administrative Law Judge recommendation and subsequent MPUC site decision will come after the public release of the Final Environmental Impact Statement (EIS). Release of the Final EIS is expected before the end of 2009. In a separate action, the MPUC deemed the docket on Excelsior's Power Purchase Agreement petition closed as of May 1, 2009. In closing the docket, the MPUC acknowledged that Excelsior could pursue other off-take arrangements. These could include agreements with municipal utilities or operating the project as a merchant facility. (Itasca & St. Louis Counties, MN)

NeuCo Inc. (formerly Pegasus Technologies) – *Mercury Specie and Multi-Pollutant Control*. The project is in the final budget period (BP3), which represents the actual demonstration phase. All optimization subsystems with the exception of FGDOpt (Flue Gas Desulfurization optimizer) have been released to the project host site (NRG Texas Limestone Plant). FGDOpt release is pending final shakedown of the recently installed upgrade (not part of the DOE project scope) to the plant wet SO_2 scrubber system. Upon release of the FGDOpt subsystem, and a brief period of specific neural network training, plant-wide optimization demonstration for mercury will begin. The project is already demonstrating functional dependencies of mercury emissions with boiler operating parameters and with other controllable plant functions. Long term plant-wide optimized operation will be demonstrated by comparison of optimized test results (with emphasis on mercury reduction optimization) with baseline data and with the targets established for the project. (Jewett, Texas)

We Energies – *TOXECON™ Retrofit for Mercury and Multi-Pollutant Control*. In February 2009, Wisconsin Electric Power Company (WE Energies), was granted a six-month no-cost extension which extended the project end date until September 30, 2009. The extension was granted to al-

low WE Energies to evaluate solutions to corrosion issues in the TOXECON ductwork. The corrosion issues result from the unique geometry of the plant ductwork and not from the TOXECON technology itself. Several remediation options are under consideration. These include use of duct coatings, installation of additional dampers or bypasses, additional insulation, and upgrade of ductwork material. Recent focus has been on low-cost, operational procedure changes during outages. A test was performed during a recent outage to evaluate the safety and effectiveness of the proposed solution, and results were encouraging. To date, average mercury removal has been (with the exception of specific test periods) greater than 90 percent. This level of removal was obtained by using both neat and halogenated powdered activated carbon (PAC) at injection rates nominally between 1.0 and 1.5 lb/mmacf. (Marquette, MI)

Southern Company Services, Inc. – *Demonstration of a Coal-Based Transport Gasifier*. Southern Company, through its affiliate Mississippi Power, plans to develop an air-blown Integrated Gasification Combined Cycle (IGCC) power plant demonstration project utilizing a coal-based transport gasifier. The demonstration plant will generate electricity using Mississippi lignite. The preparation of the Environmental Impact Statement is currently under way. This project will incorporate 50 percent CO_2 capture and sequestration via enhanced oil recovery. A Certificate of Public Convenience and Necessity was filed with the Mississippi Public Service Commission in January 2009. (Kemper County, MS)

U.S. Department of Energy
FE-20
1000 Independence Avenue
Washington, DC 20585-1290

Printed with soy ink on recycled paper