Office of Fossil Energy, U.S. Department of Energy • DOE/FE-0522 • Issue No. 76, Summer 2008

CLEAN COAL TODAY

A Newsletter About Innovative Technologies for Coal Utilization

News Bytes

Proposals are due October 8, 2008, under a Funding Opportunity Notice issued by the U.S. Department of Energy (DOE) for its restructured FutureGen Program. DOE is seeking proposals for multiple cost-shared commercial-scale Integrated Gasification Combined Cycle, or other clean coal power plants, with cutting-edge carbon capture and storage technology. DOE anticipates $290 million will be available for funding of selected projects through fiscal year 2009 (which ends September 30, 2010), and an additional $1.01 billion in subsequent years, subject to appropriation by Congress. Full details can be found by visiting the Office of Fossil Energy Web site at www.fe.doe.gov/news/techlines/2008/08023-FutureGen_FOA_Released.html ◆

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Inside This Issue

Regional Partnerships to Sequester CO_2 at Near-Commercial Scale

The Carbon Sequestration Regional Partnerships are essential to the path forward for carbon capture and storage, according to participants at the U.S. Department of Energy (DOE)-sponsored 7th Annual Conference on Carbon Capture and Sequestration, held May 5–8 in Pittsburgh, Pennsylvania. The theme of this year's conference, attended by over 700 members of the business, research, and academic communities, was closing the gaps — knowledge, policy, regulatory, and technology — to CCS deployment. The Regional Partnerships are doing their part to close these gaps. Their projects are entering the deployment phase, a 10-year span encompassing site characterization, permitting, near-commercial scale CO_2 injection, and post-injection monitoring. Almost 350 organizations now participate in this program, attesting to the validity of region-specific approaches to reducing greenhouse gases.

DOE's Acting Deputy Secretary Jeffrey F. Kupfer gives keynote remarks

Acting Deputy Secretary of Energy Jeffrey Kupfer, in a keynote speech, spoke on U.S. efforts to expedite deployment of carbon capture and storage (CCS), including not only the Regional Partnerships, but also the restructured FutureGen project, loan guarantees, and international cooperative efforts. He announced Regional Partnership Phase III awards totaling $126.6 million to the West Coast and Midwest Regional Carbon Sequestration Partnerships, which brings the total to six successfully negotiated agreements. The first agreements, finalized in October 2007, are with the Plains CO_2 Reduction Partnership, the Southeast Regional Carbon Sequestration Partnership, and the Southwest Regional Partnership for Carbon Sequestration. A fourth agreement was awarded to the Midwest Geologic Sequestration Consortium in December 2007. Phase III work follows earlier efforts in site characterization (Phase I) and validation/field testing (Phase II). Phase III (deployment) projects must be in areas where targeted geological sinks exist throughout the region, and contain at least 100 years of storage capacity. Multiple seals

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... "Partnerships" continued

must exist over each target sink, to ensure CO_2 stability and containment. Lastly, injection must be at near-commercial scale.

During Phase I, the Partnerships matched CO_2 sources with sinks (geological and terrestrial) and published a reference Atlas, which will be continually updated as more knowledge is gained. Phase II is half completed and is running concurrently with Phase III. In Phase II, three small-scale injections have been completed, three more are under way, and more than 10 are scheduled to begin by the end of 2008.

The conference provided the opportunity for Partnership sponsors, both at plenary and at technical sessions, to detail plans for Phase III, and provide important new results from Phase II field tests. While Phase II involved terrestrial as well as geologic sequestration, Phase III will focus on CO_2 injected in a total of seven deep saline formations, carbonates and sandstones ranging from 3,000 to 13,000 feet deep, as well as a depleted oil field in the Williston Basin. One million or more tonnes of CO_2 will be injected at each project site over a 3–4 year period. CO_2 will come from a variety of mostly man-made sources, such as natural gas processing facilities, ethanol plants, post-combustion capture technologies and an oxyfuel combustion power plant.

In one of the new agreements announced at the conference, the *West Coast Regional Carbon Sequestration Partnership (WESTCARB)*, led by the California Energy Commission, will co-locate CO_2 injection with a 50 MW Clean Energy Systems zero-emissions oxycombustion power plant in Kimberlina, California. The project will inject one million tonnes of CO_2 over four years into an over-7,000-ft.-deep formation. The plant uses either natural or synthesis gas in an oxyfuel system, which produces a relatively pure stream of CO_2 amenable to sequestration. During Phase II, WESTCARB completed a detailed study of the area to determine the potential for depleted oil and saline formations to receive and store CO_2.

Installation of seismic geophones at SWP's Aneth Phase II project

Under the other new agreement, the *Midwest Regional Carbon Sequestration Partnership (MRCSP)* will inject one million tonnes of CO_2 from the TAME ethanol production facility, located in Greenville, OH, into the Mount Simon Formation, which stretches from Kentucky through Ohio. MRCSP also reported important Phase II results. It is the first regional partnership to complete a saline injection project. In March 2008, it injected 10,000 tonnes of CO_2 — more than ten times that of any other U.S. project — at its Michigan field test site in Otsego County. The test site is close to both a gas processing plant (from which it gets its CO_2) and an enhanced oil recovery operation with pipelines in place. Post-injection monitoring is to continue through 2009, providing researchers with useful modeling data. Monitoring equipment has performed well, even under adverse winter conditions.

In another important agreement, the *Midwest Geological Sequestration Consortium (MGSC)* is also coupling its Phase III injection to an ethanol plant. Working with the MGSC's leader Illinois State Geological Survey, researchers will inject one million tonnes of CO_2 from Arthur Daniel Midland's ethanol plant in Decatur, Illinois. Injection will be at the plant site and into the Mt. Simon sandstone, a major saline reservoir. Drilling is scheduled to begin this October, and injection in December 2009. MGSC plans to test sophisticated measuring, monitoring, and mitigation (MMV) devices including satellite infrared and vertical seismic, which will transport geophones through tubing deep into injection wells. With 122 coal-fired plants in the Central Illinois

Basin area, there would be a ready source of CO_2 for geological storage in tested formations.

Two other negotiated projects — the *Plains CO_2 Reduction Partnership (PCOR)* and the *Southeast Regional Carbon Sequestration Partnership (SECARB)* — plan to inject CO_2 derived from post-combustion capture at power plants, a technology vital to achieving near-zero emissions. PCOR, which is led by the University of North Dakota's Energy and Environmental Research Center, has two large-scale projects in its region. PCOR plans to capture CO_2 from a coal-fired power plant and inject it into a depleted oil field in the Williston Basin for enhanced oil recovery. The second large-scale PCOR test will inject over one million tonnes of acid gas (CO_2 and hydrogen sulfide) from a natural gas processing plant into a deep saline formation in the Alberta Basin in British Columbia.

PCOR's Phase II work has also involved acid gas injection with CO_2 at another Canadian site, the Zama Field in Alberta. Injection began in December 2006, and a total of 42,000 tonnes of CO_2 and 18,000 tonnes of H_2S are to be stored at a depth of 5,500 feet. The project is providing insight regarding the impact of high concentrations of H_2S on sink integrity, monitoring, and EOR productivity within a carbonate formation. PCOR also plans to develop a best practices manual for use of acid gas with EOR and CO_2 sequestration operations.

SECARB, led by the Southern States Energy Board, also has two Phase III projects. These are to validate CO_2 storage in the Lower Tuscaloosa, a major geologic formation in the Southeast. The first stage of the project will inject one million tonnes of CO_2 per year from a natural CO_2 deposit into a deep sandstone formation near a commercial EOR operation. The CO_2 will be injected in the saline portion of the formation and monitored extensively both during and after injection. The second test will capture CO_2 from one of the large coal-fired facilities along the Gulf Coast. That CO_2 will also be injected into the Tuscaloosa formation several hundred miles from the first injection site. The second injection will determine whether or not the lessons learned are transferable between sites.

In a Phase II test, SECARB will inject 3,000 tonnes of CO_2 at an approximate depth of 8,600 feet at Mississippi Power Company's Plant Daniel, located near Escatawpa, Mississippi. SECARB has already obtained a UIC Class V Experimental Well permit from the Mississippi Department of Environmental Quality, finalized drilling permits, and installed monitoring and observation wells. Injection is scheduled to begin in late 2008.

Unlike the other projects, the *Southwest Regional Partnership*, led by the University of Utah, plans to obtain its CO_2 from a natural deposit at the Farnham Dome near Price, UT. The Phase III project will inject over two million tonnes of CO_2 into a deep brine formation in the area. SWP's Phase II work has involved a range of projects: CO_2 storage combined with EOR, enhanced coal bed methane production with carbon storage, geologic storage, and terrestrial tests. An intriguing ongoing SWP project involves EOR combined with sequestration in the Aneth Oil Field near Bluff, Utah. Project activities include injecting approximately 150,000 tonnes of CO_2 per year for two years at a depth of 5,600–5,800 feet. Injection began in August 2007 and is scheduled to continue through 2009. CO_2 for this project comes from the McElmo Dome, a natural CO_2 reservoir located in southwestern Colorado. Reservoir tracer tests and vertical seismic profiling are being conducted to identify the exact plume location.

Workers drill a CO_2 injection well in North Dakota as part of a PCOR project

The overall goal of DOE's Carbon Sequestration Program is to develop, by 2012, fossil fuel conversion systems that achieve 90 percent CO_2 capture with 99 percent storage permanence, at less than a 10 percent increase in the cost of energy services. The Regional Carbon Sequestration Partnerships will be key to testing and deploying essential technologies to achieve these objectives. ■

ACTIVATED CARBON INJECTION – A MERCURY CONTROL SUCCESS STORY

The U.S. Department of Energy (DOE) and its private sector partners, working through the National Energy Technology Laboratory's (NETL) Innovations for Existing Plants (IEP) Program, have brought mercury-specific control technologies to the point of commercial readiness. As of April 2008, almost 100 full-scale activated carbon injection (ACI) systems, a signature technology of the IEP Program, have been ordered by U.S. coal-fired power generators. These contracts include both new and retrofit installations and represent over 44 gigawatts (GW) of coal-based electric generating capacity. Approximately 33 GW of existing electric generating capacity (~10 percent of total U.S. coal-based capacity) will be retrofitted with ACI systems to control mercury (Hg) emissions. The ACI systems have the potential to remove more than 90 percent of the Hg in most applications, at a cost that can dip below $10,000 per pound of Hg removed.

EFFECTIVENESS OF MERCURY CONTROLS

Mercury's complex speciation adds to difficulties in designing effective controls. The trace amount of mercury present in coal is volatilized during combustion and converted to gaseous elemental mercury (Hg^0). Subsequent cooling of the coal combustion flue gas and interaction of the gaseous Hg^0 with other flue gas constituents, such as chlorine and unburned carbon, result in a portion of the Hg^0 being converted to gaseous oxidized forms of mercury (Hg^{2+}) and particulate-bound mercury (Hg_P). As a result, coal combustion flue gas contains varying percentages of Hg_P, Hg^{2+}, and Hg^0, and the exact speciation has a profound effect on the Hg capture efficiency of existing air pollution control devices. The Hg_P fraction is typically removed by a particulate control device such as an electrostatic precipitator (ESP) or fabric filter (FF). The Hg^{2+} portion is water-soluble, and therefore a relatively high percent can be captured in wet flue gas desulfurization (FGD) systems, while the Hg^0 fraction is generally not captured by any of these devices whose primary purpose is to remove other pollutants. As a result, the mercury-specific technologies developed by NETL and its partners are of significant importance.

TECHNOLOGY DEVELOPMENT

In the mid-1990s, NETL initiated an R&D program directed at two general approaches for controlling Hg: sorbent injection and oxidation enhancements. Sorbents injected into the flue gas include: conventional (untreated) ACI, chemically treated ACI, and other non-carbon sorbents. Mercury oxidation enhancements, where testing under NETL's program has also produced excellent results, improve the Hg capture efficiency of conventional ACI or downstream pollution control devices by converting elemental Hg to a more reactive oxidized state.

In 2000, following laboratory through pilot-scale development of these technology approaches, NETL launched a three-phase field testing program of the most promising Hg control technologies at operating coal-fired power plants. Phase I focused on short-term tests of untreated ACI and improving the capture of Hg across wet FGD systems. Results indicated a high effectiveness — 80–90 percent Hg capture for eastern coals and 60–70 percent for western coals — but also raised questions about sorbent cost and long-term performance. Phase II, which began in 2003 and ended in 2006, was expanded to include long-term testing of various sorbents to explore cost reduction possibilities. Phase III of the field testing program was initiated in 2006 for continued field testing of advanced Hg control technologies that could achieve 90 percent or greater capture at a 50 to 70 percent cost reduction. Most DOE-funded tests will be completed by the end of this year.

MERCURY-SPECIFIC TECHNOLOGIES

The leading mercury-specific approach available today is injection of fine powder sorbent material (typically activated carbon) into the flue gas emitted from a boiler. A sorbent works by attracting and binding itself to gas-phase Hg, which then is captured by downstream particulate control equipment. Phase II successfully tested a wide range of sorbent injection technologies. These include chemically treated ACI, untreated ACI with and without chemical additives applied to the coal or flue gas, Electric Power Research Institute's (EPRI's) TOXECON™ and TOXECON II™ configurations that minimize spent sorbent/Hg mixing with fly ash, and concrete-friendly sorbents. Many of the sites were power plants firing lower rank Powder River Basin (PRB) and lignite coals, part of a concerted effort to reduce costs and improve effective-

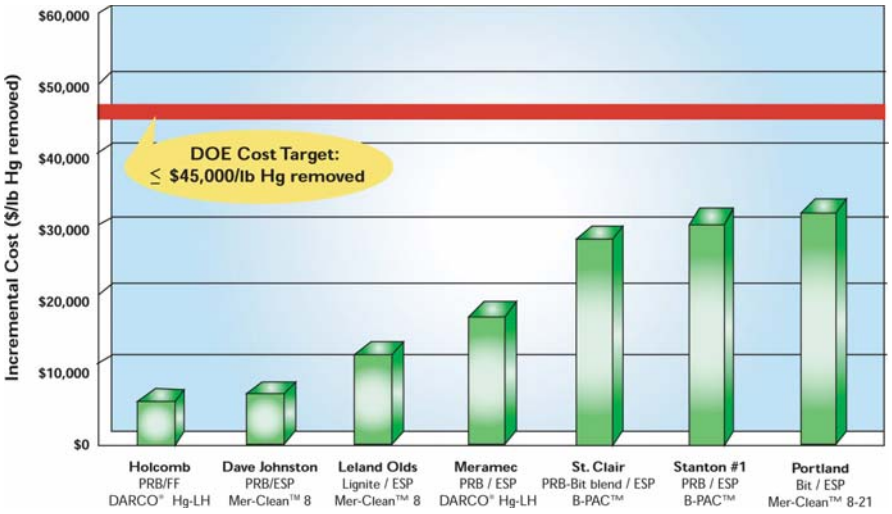
ness of removing the elemental Hg found in these coals.

PHASE II FIELD TESTS

Three test sites — Great River Energy's Stanton Station Unit 10 (lignite/FF), Basin Electric's Leland Olds Station Unit 1 (lignite/ESP), and Stanton Station Unit 1 (PRB/ESP) — showed a clear distinction in Hg removal when injecting untreated and chemically treated ACI. At least 90 percent Hg capture was achieved with chemically treated ACI at low injection rates (3 lb/MMacf). Hg capture using untreated ACI was limited to less than 80 percent at injection rates up to 10 lb/MMacf.

Two important brominated sorbents, a type of *chemically treated ACI*, are Norit Americas' DARCO® Hg-LH and Sorbent Technologies' B-PAC™. These sorbents have markedly reduced ACI rates (amount of sorbent required to achieve a given level of control) and lowered Hg control costs. They have consistently been top performers at test sites using lower-rank coals, and have helped accelerate commercialization of sorbent injection technology.

Another chemically treated ACI technology, ALSTOM Power, Inc. – U.S. Power Plant Laboratories' (ALSTOM-PPL) Mer-Cure™ process, is unique in that sorbent injection takes place upstream from the air preheater, allowing for greater residence (contact) time. The proprietary injection system prevents sorbent agglomeration and ensures uniform sorbent dispersion. Three 30-day, long-term field tests have been completed. Mer-Clean™ 8 injection rates of 0.63 and 1.4 lb/MMacf achieved average total Hg removals of 92 percent at Dave Johnston and 90 percent at Leland Olds. At Portland, 95 percent average total Hg capture was observed with Mer-Clean™ 8–21 injection at 8.5 lb/MMacf.



NETL's 20-year levelized incremental cost of 90 percent Hg control with chemically treated ACI

Another process uses Sorbent Technologies' chemically treated H-PAC™ and was designed specifically for hot-side ESP applications (ESP upstream of air heater), where the elevated flue gas temperature limits the Hg capture efficiency of ACI. A four-day trial conducted at Duke Energy's low-sulfur, bituminous coal-fired Buck Plant achieved approximately 70 percent total Hg removal with H-PAC™ injection at 10 lb/MMacf.

An economic analysis released by NETL in May 2007 (see chart above) indicates the 20-year levelized incremental cost of 90 percent ACI Hg control ranges from about $30,000 to less than $10,000/lb Hg removed.

As an alternative to using chemically treated sorbents, NETL has sponsored field tests using conventional sorbents supplemented with chemical additives (*sorbent-enhanced additives/SEAs*) applied to the coal or flue gas to enhance the performance of conventional sorbents in low-rank coal applications. The University of North Dakota Energy and Environmental Research Center (UNDEERC) conducted two successful 30-day field tests at full-scale units firing North Dakota lignite coal. During the 30-day trial at Basin Electric's Leland Olds Station Unit 1, 58 percent average total Hg capture was observed with DARCO® Hg injection (the untreated variety of DARCO sorbent) at 2.7lb/MMacf, coupled with the addition of an aqueous $CaCl_2$ solution at a rate of 2.9 lb/MMacf. At Basin Electric's Antelope Valley Station Unit 1, total Hg removal averaged 92 percent across the SDA/FF configuration, with the addition of SEA at a rate of 0.033 lb/MMacf and DARCO® Hg injection at 0.81 lb/MMacf.

Still another important area of study involves processes to minimize impacts of ACI on fly ash utilization. Foremost is the *TOXECON*™ first-of-a-kind commercial Hg control technology demonstration at WeEnergies' Presque Isle Power Plant in Marquette, Michigan. TOXECON™, developed by EPRI, delays sorbent injection into flue gas until

after the fly ash has been collected in a plant's ESP; the Hg-sorbent mixture is then captured in a fabric filter installed further downstream. Currently operational, with an installed capital cost of approximately $128 per kilowatt for the retrofit fabric filter, the TOXECON™ configuration has achieved about 90 percent total Hg removal with untreated DARCO® Hg and brominated DARCO® Hg-LH injection at about 3 and 2 lb/MMacf, respectively. During an extended testing period, greater than 90 percent total Hg removal was maintained for 48 consecutive days with both DARCO® Hg and DARCO® Hg-LH injection.

TOXECON II™ requires no retrofit fabric filter. Tests were conducted by ADA-ES at Entergy's PRB-fired Independence Station Unit 1 in February 2007. DARCO® Hg-LH injection at 5.5 lb/MMacf achieved 90 percent total Hg removal with redesign of the injection lances.

As NETL's mercury control program reaches a successful conclusion, government and industry can point to a number of successes in their partnership – technologies that can now be confidently deployed to the fleet of U.S. coal-fired plants. ■

NETL LICENSES MERCURY CONTROLS PROCESSES

Over the past several years, NETL has licensed three trace metal capture technologies that are now in commercial demonstration. The *Thief* process was licensed to Nalco-Mobotec in May 2005; the *Photochemical Oxidation (PCO) Process* was licensed to Powerspan in March 2004, and a *palladium sorbents* process was licensed to Johnson-Matthey in June 2007. *Thief* and *PCO* work with the existing fleet of pulverized coal power plants, while *palladium sorbents* can survive in high-temperature environments of coal-based integrated gasification combined cycle plants.

NETL's Evan Granite (foreground) and post-doctoral student Albert Presto perform experiments at NETL's bench-scale packed bed reactor, used for evaluating promising sorbents and catalysts

The *Thief* process is a cost-effective alternative to activated carbon injection (ACI) for mercury removal from flue gas. Laboratory, bench, pilot-scale, and field tests demonstrate that carbon sorbents are as effective as activated carbons for mercury capture. Activated carbons range from $500 to $3,000/ton compared to $90-to-$200/ton for *Thief* carbon sorbents. In the *Thief* process, partially-combusted coal, or char, is removed by a lance from the combustion section of a pulverized coal power generation plant and injected into the ductwork downstream of the air preheater. This char has properties similar to activated carbon, but is available at much lower cost. The technology is being further tested at larger scale by Nalco-Mobotec.

The Photochemical Oxidation (PCO) introduces a 254-nm ultraviolet light into flue gas, leading to oxidation of mercury and facilitating mercury removal in a downstream SO_2 scrubber, wet electrostatic precipitator, or baghouse (fabric filter). Field tests demonstrate greater than 90 percent of oxidation and capture achieved in simulated flue gas streams containing elemental mercury. NETL researchers received the 2005 Award for Excellence in Technology Transfer from the Federal Laboratory Consortium (FLC) for the PCO method.

Another NETL-developed process to remove mercury uses palladium sorbents, and has received two important awards: the 2008 FLC award, and a 2008 R&D 100 award. *Palladium (Pd) sorbents* can remove mercury, arsenic and selenium from fuel gas at temperatures above 500 °F, as compared with conventional sorbents that only function at ambient temperatures. These sorbents have more than twice the capacity of other sorbents to capture mercury, which together with high efficiency acts to lower costs. NETL is collaborating with Johnson-Matthey to evaluate effects of surface area and loading upon palladium's capacity for adsorbing mercury. Johnson-Matthey will be responsible for commercial development and application of the sorbents, including larger-scale testing of the palladium sorbent at a gasification facility.

DOE EXPLORES CO-FEEDING BIOMASS WITH COAL

In fiscal year 2008 Congress provided funding for a DOE-sponsored coal-biomass-to-liquids (CBTL) R&D effort. While coal-to-liquids (CTL) technology has existed for years, co-feeding of coal and biomass in a gasifier to produce liquid fuels is a relatively new concept. The process, when combined with carbon capture and storage, is expected to result in lower greenhouse gas emissions than conventional petroleum fuels.

An Air Force Boeing C-17 Globemaster III on a nonstop, coast-to-coast flight using a 50-50 blend of synthetic fuel and jet fuel

To date, not much is known about how co-feeding biomass with coal will affect a gasifier, gas cleanup, or catalyst systems. Moreover, various coal/biomass combinations will produce different raw syngas compositions. To better understand the process and products of co-feeding coal and biomass in a gasifier, the Department of Energy (DOE) recently issued a Funding Opportunity Announcement (FOA) soliciting proposals for research in three key CBTL process areas: feeding coal/biomass mixtures across a pressure gradient to a high-temperature, high-pressure gasifier; characterization of the synthesis gas products from gasifying coal/biomass mixtures, and optimization of the Fischer-Tropsch and water-gas shift processes.

DOE anticipates awarding five R&D projects to be conducted over 2–3 years, with DOE providing over $4 million in cost-sharing. Project selections are expected to be announced in September 2008.

The Air Force, meanwhile, has set a goal to supply 50 percent of its continental U.S. fleet with domestic synthetic fuel sources, such as CTL and CBTL, by 2016. It has already certified the B-52 bomber to fly on synthetic fuel, has performed test flights on the C-17 and the B-1 bomber, and plans to certify all its aircraft on 50-50 blends of synthetic fuel and conventional jet fuel by 2011. The Air Force has also offered land at Malmstrom Air Force Base in Montana to industry for the purposes of constructing a CTL or CBTL facility.

The recently-enacted Energy Independence and Security Act of 2007 states that a government entity, such as the Air Force, cannot purchase alternative fuels, other than for research purposes, that have lifecycle greenhouse gas emissions greater than conventional petroleum-based fuels. CTL technology, when coupled with carbon capture and storage, can limit CO_2 emissions to a level approximately equivalent to that of an existing petroleum-based fuel supply chain. Co-feeding coal with biomass in a gasifier, along with capturing and storing the CO_2 from the process, could reduce the carbon footprint of the process below that of a conventional petroleum refinery, providing a way to accommodate the federal mandate. ■

UPCOMING EVENTS

August 25 – 28, 2008
Power Plant Air Pollutant Control "Mega" Symposium
Sponsors: DOE/NETL, EPA, EPRI, and the Air and Waste Management Association
Location: Baltimore, MD
Contact: Andrew O'Palko
Phone: 304-285-4715
E-mail: andrew.opalko@netl.doe.gov
Web site:
www.megasymposium.org

September 29 – October 2, 2008
25th Annual International Pittsburgh Coal Conference
Host: University of Pittsburgh Swanson School of Engineering
Location: Pittsburgh, PA
Phone: 412-624-7440
E-mail: pcc@engr.pitt.edu
Web site: www.engr.pitt.edu/pcc

CLEAN COAL TODAY

Published quarterly by:
The Office of Fossil Energy
U.S. Department of Energy
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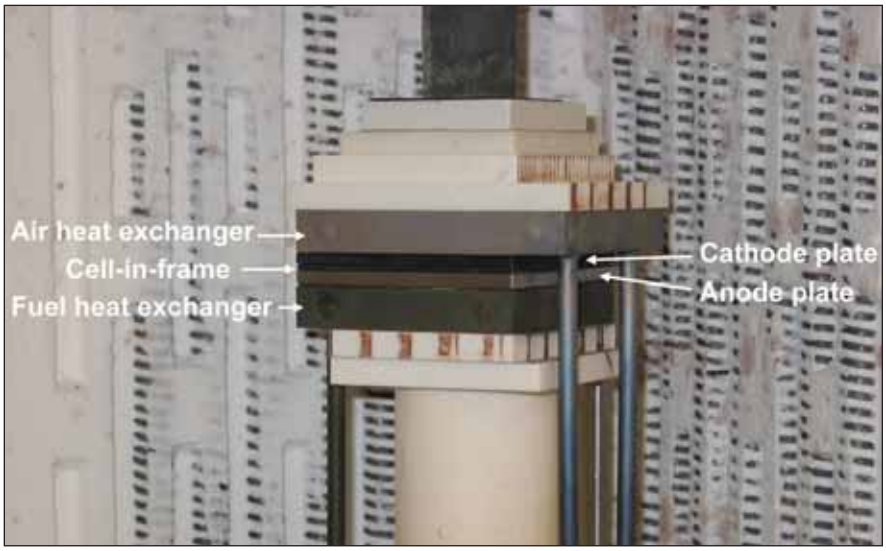
http://www.netl.doe.gov/technologies/coalpower/cctc/newsletter/newsletter.html

Comments are welcome and may be submitted to the Editor.

SECA FUEL CELL TEST DEVICE ADVANCES TECHNOLOGY TRANSFER

A new fuel cell stack testing device developed in a collaboration among Lawrence Berkeley National Laboratory (LBNL), the National Energy Technology Laboratory (NETL) and the Pacific Northwest National Laboratory (PNNL), will help to validate fuel cell materials and designs under conditions similar to large industrial-size stacks and at a fraction of the cost. Unlike laboratory-scale experiments under idealized conditions, the new standardized intermediate testing device provides real-world data from fuel cell components that actually come into contact with one another. Thus, it will no longer be necessary to make an immediate leap from the simplified laboratory scale to the full complexity of industrial-scale stack testing – a great benefit for technology transfer.



Assembled stack test fixture pictured in the open test furnace

Research is being conducted under the Solid State Energy Conversion Alliance (SECA), a partnership of NETL, national labs and academia engaging in fuel cell research with a variety of private partners. The SECA industry teams compete with one another as they endeavor to develop fuel cells for power generation, an approach which has been successful in reducing production costs. Teams also provide feedback to the Core Technology Program as to crosscutting research needs. SECA's focus is on solid oxide fuel cells (SOFC), which lend themselves to integration with coal gasification combined-cycle power plants achieving efficiencies up to 60 percent. Besides being inherently fuel-efficient devices, SOFCs keep fuel and oxidant streams separate, thus enabling efficient CO_2 capture and near-zero net water usage. Such new technologies are vital in helping DOE achieve goals for coal-fired power systems, such as 60 percent efficiency by 2015, and 90 percent CO_2 capture by 2012.

The stack test fixture was initially designed by NETL and Lawrence Berkeley National Laboratory in 2006, and since early 2007 has been further developed by PNNL to meet specific test needs. The device is an assembly for up to three fuel cells. It can be put together easily and its hardware is reusable. The assembly is sealed and placed in a dedicated test stand that consists of a furnace, heat exchangers, a gas handling system, and an electrical characterization unit. Electrochemical performance of the cells is measured under both isothermal and thermal cyclic conditions. After the completion of the tests, the assemblies are analyzed by using optical and electron microscopy, chemical analyses, and X-ray diffraction in order to evaluate the stability of components or to troubleshoot any performance degradation. The fixture assembly is only two square inches, but provides data comparable in complexity to that of 30–60 cell stacks.

The photo (left) shows a single cell mounted in a stack test fixture. The fuel cell is attached to the metallic frame by glass seals which hermetically seal the perimeter. The seal operates as a gasket preventing ambient air from mixing with the air and fuel streams flowing through the cell. The test fixture is designed to be flexible and can accommodate many different gas flow geometries.

The fixture allows for the simultaneous testing under realistic conditions of virtually all components typically found in industry stacks. These components include the cell-to-frame and stack perimeter seals, anode and cathode contact materials, interconnect and gas separator plate materials, and the primary cell components (cathodes, electrolytes, and anodes). In addition to its use by PNNL, the fixture is also being used by LBNL and will be used by NETL

and Oak Ridge National Laboratory. Test stand availability is a key issue in R&D progress, and SECA management has worked to ensure that the standardized test fixture is employed widely to provide consistent results and cross-validation of technology.

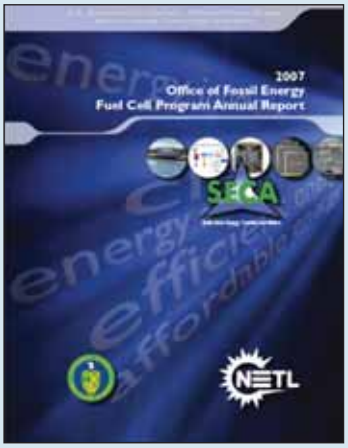
Early Successes – Refractory Seals

In the Fall of 2007, researchers began to evaluate new refractory glass seals to replace softer glass sealed at lower temperatures. Sealing glass at higher temperatures (>900 °C) has the potential to improve stability in terms of thermal expansion, chemical compatibility, interfacial strength, and reactivity during long-term operation. When this glass is sealed within the stack, the higher sealing temperature also sinters the contact materials to a higher density providing a mechanically-robust support for the ceramic fuel cell components while enhancing electrical connectivity, both of which reduce performance degradation.

The cell frame, cathode plate, and anode plate were fabricated from a candidate SOFC interconnect steel (AISI 441, provided by Allegheny Technologies, Inc). The refractory glass cell-to-frame seal was fabricated prior to test fixture assembly at 950 °C (2 hours hold). The test fixture components (cell/frame, anode plate, cathode plate, contact and perimeter seal materials) were then assembled and heated to 930 °C in air (2 hours hold) to form the stack perimeter seals and electrical contacts. The open-circuit voltage (OCV) of the cell was then measured during thermal cycling (room temperature to 750 °C) using air and moist hydrogen as the oxidant and fuel, respectively. A stable cell voltage of 1.1 V at 750 °C was recorded for over 25 cycles indicating effective sealing of the cell. During the post-test analysis, the refractory glass cell-to-frame seal showed no observable fractures or cracks, which was consistent with the high OCV observed throughout the test. Overall this test provided an encouraging demonstration of the ability of the refractory glass seals to withstand thermal cycling.

The next high-priority testing activity will be isothermal testing, 1,000 hours or more of low-cost steel interconnects, protected by a promising (Manganese Cobalt Oxide spinel) ceramic coating that reduces steel oxidation and Chrome volatilization. Validation of other new Core Technology Program components, such as interconnect coatings, cathodes, and composite seals, will follow. ■

SECA Spurs Competitive Innovation



Across the United States, SECA Core Technology participants are working on dozens of fuel cell projects, led by the brightest minds from leading universities, national laboratories and businesses. These competitively selected projects work together to provide vital R&D and testing in support to the Industry Teams.

Findings and inventions under the Core Technology program are made available to all Industry Teams under unique intellectual property provisions that serve to accelerate development.

In the same spirit of healthy competition, the Industry Teams leverage the collective ingenuity of the Core Technology participants to independently pursue innovations in fuel cell design that can be mass produced at lower cost.

Focusing on cost reduction and larger coal-based systems, the Industry Teams are working to solve the challenges of fuel cell technology, each using different design and manufacturing approaches. As a result, the SECA program is rich in innovation, allowing it to reach its goals much faster.

The *FY 2007 Office of Fossil Energy Fuel Cell Program Annual Report* provides a compilation of abstracts of all fuel cell projects managed under the SECA Program. A copy of the report can be found at: http://www.netl.doe.gov/technologies/coalpower/fuelcells/seca/refshelf.html

GREENIDGE MULTI-POLLUTANT PROJECT ACHIEVES EMISSIONS REDUCTION GOALS

Performance testing at the Greenidge Multi-Pollutant Control Project has met or exceeded project goals, indicating that the technology being demonstrated can be an economical way to achieve deep emission reductions in small, difficult-to-retrofit power plants. The project was awarded in 2006 to CONSOL Energy Inc. under the Department of Energy's Power Plant Improvement Initiative, and is now in the operations phase at the 107 MWe AES Greenidge Unit No. 4, on the western shore of New York's Seneca Lake. Participants include AES Greenidge LLC, the host site owner, and Babcock Power Environmental Inc. (BPEI), the engineering, procurement, and construction contractor and technology supplier. DOE is providing some 44 percent of the near-$33 million project costs, with AES Greenidge contributing the remainder.

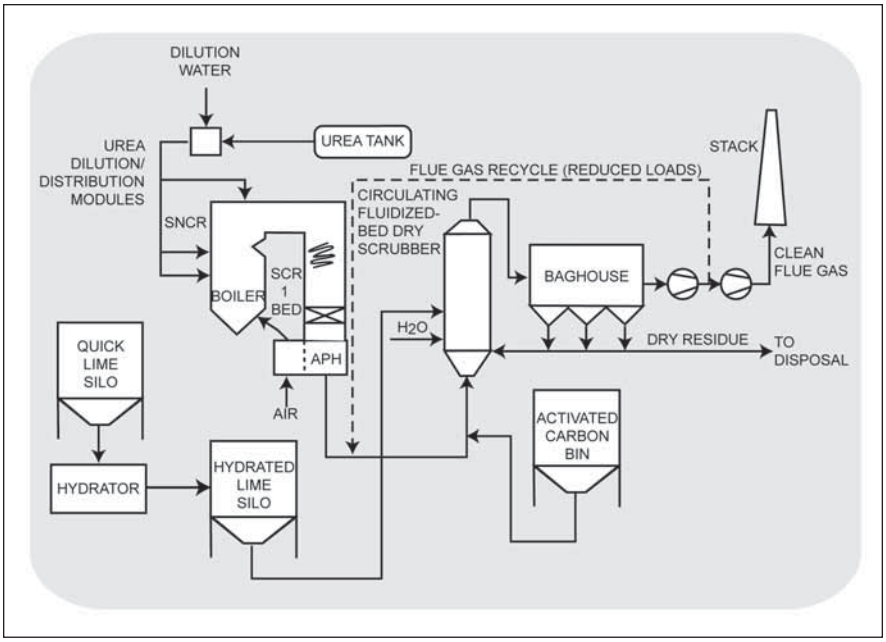
View of Greenidge scrubber and baghouse

There are approximately 420 small coal-fired electric generating units in the U.S. rated between 50 and 300 MWe that, due to space constraints and high capital costs of retrofitting, lack key pollution controls. Many of these plants have no FGD systems for SO_2 removal, no SCR systems for NO_x removal, and no mercury control systems. In total, these smaller plants represent almost 60 GW of generating capacity. Due to progressively more stringent environmental regulations, these units are increasingly vulnerable to retirement or fuel switching.

The compact technology at AES Greenidge is designed to meet the needs of these smaller units. Greenidge is demonstrating a NOxOUT CASCADE® hybrid selective non-catalytic reduction / selective catalytic reduction (SNCR/SCR) system for NO_x control and a Turbosorp® circulating fluidized bed dry scrubber (CFBDS) system for sulfur dioxide (SO_2), mercury (Hg), sulfur trioxide (SO_3), hydrochloric acid (HCl) and hydrofluoric acid (HF) control. A baghouse, integral to the CFBDS, provides particulate control. Baghouse ash is recycled to the CFBDS to improve sorbent utilization. An activated carbon injection (ACI) system is provided to permit tests of Hg removal with and without such injection. Project goals include reducing NO_x emissions by 60 percent to 0.10 pounds per million Btu (lb/mmBtu); reducing SO_2, SO_3, HCl, and HF emissions by at least 95 percent; and reducing Hg emissions by at least 90 percent while the unit fires 2–4 percent sulfur eastern U.S. bituminous coal and co-fires up to 10 percent biomass.

As shown in the schematic on the following page, in the hybrid SNCR/SCR process, urea is injected into the upper furnace, where it reacts with NO_x to form nitrogen, carbon dioxide, water vapor, and some ammonia. The flue gas then passes over BPEI's Delta Wing® static mixing technology to ensure thorough mixing before the gas enters the compact SCR reactor. The remaining ammonia reacts with NO_x in the SCR to further lower NO_x emissions and to minimize ammonia slip. The SCR consists of a single catalyst bed located in an expanded section of ductwork between the unit's economizer and air heaters. Downstream of the air heaters, the flue gas enters the CFBDS where water and dry hydrated lime are separately injected to cool the flue gas and remove SO_2, Hg, SO_3, HCl and HF. The gas then passes through a baghouse where fly ash and partially reacted sorbent are removed before the cleaned flue gas is discharged. A majority of the solids captured in the baghouse are recycled to the CFBDS to enhance lime utilization and pollutant capture. If ACI is required to meet Hg removal goals, it is injected between the SCR and the CFBDS.

During the guarantee tests in 2007, NO_x emissions were measured at 0.10 lb/mmBtu (60 percent removal) for short durations, although NO_x emissions have typically varied between 0.10 lb/mmBtu and 0.15 lb/mmBtu in the longer term. Hg removal was >94 percent with ACI, one percent lower than Hg removal without ACI. Thus, the unit routinely operates without ACI. SO_2 removal was 96 percent, and SO_3 and HCl



Schematic of the Greenidge multi-pollutant control process

removal rates were each 97 percent. HF emissions at the stack were below detection limits.

The multi-pollutant control system has also reduced the unit's particulate emissions by more than 98 percent relative to baseline levels. A problem, however, occurred with accumulation of large particle ash in the SCR catalyst bed. Hence, a screen, soot blowers, and vacuum ports were installed to filter the ash from the flue gas and remove it from the system. This has reduced ash accumulation, but monitoring continues and further improvements may be pursued.

Additional tests were recently conducted to establish the effects of unit load, biomass co-firing, and variations in plant operating conditions on performance. These tests showed at least 95 percent SO_2 removal, more than 90 percent mercury removal (with no activated carbon injection), and very low emissions of SO_3, HCl, HF, and particulate matter.

Testing at Greenidge thus far has demonstrated that emission goals can be achieved or exceeded by a technology that is substantially less expensive than conventional technologies when applied to smaller power plants. Capital costs are estimated to be approximately 40 percent lower and annualized costs are estimated to be about 25 percent less than those for a conventional SCR and wet FGD when retrofitted to a 100 MW unit. Moreover, the entire retrofit at AES Greenidge required less than 0.5 acre of land. Having a compact, economical retrofit option will present the electric power industry with a viable alternative to retirement or fuel switching while avoiding the cost of replacing the retired capacity. ■

... "News Bytes" continued

The International Energy Agency has published an expert review of DOE's Carbon Sequestration Regional Partnerships. Before undertaking Phase III of the program, DOE asked IEA's Greenhouse Gas R&D Program to assess the partnerships in general and the Phase III proposals. IEA found the Phase III large-scale tests to be the world's most ambitious, and said they were both realistic and achievable. The Office of Fossil Energy's National Energy Technology Laboratory has also published its Annual Accomplishments report, which can be found at www.netl.doe.gov/publications/others/accomp_rpt/accomp_fy07.pdf ◆

Australia has launched the first carbon sequestration project in the Southern Hemisphere with the help of technology developed by researchers at DOE. Scientists will inject and monitor carbon dioxide (CO_2) in a depleted gas field in the Waarre Formation of the Otway Basin. DOE developed the cutting-edge instrumentation that will be used to track the CO_2 plume during and after the injection. The $36 million Otway Basin Pilot Project is one of 19 sequestration projects endorsed by the international Carbon Sequestration Leadership Forum. ◆

DOE has selected two projects for the Department's Solid State Energy Conversion Alliance program portfolio. The projects will be led by UTC Power, a United Technologies Corporation, in partnership with Delphi Corporation, and Rolls-Royce Fuel Cell Systems (U.S.) Inc. Both teams will research, develop and demonstrate fuel cell technologies that can support power generation systems as large as several hundred megawatts capacity. ■

INTERNATIONAL INITIATIVES

U.S. HOSTS ASIA PACIFIC PARTNERSHIP PEER REVIEW

The Power Generation and Transmission Task Force of the Asia Pacific Partnership on Clean Development and Climate (APP) held its third peer review meeting April 28 – May 2, 2008, in Sheboygan, Wisconsin. The event was hosted by Alliant Energy Corporation. DOE's Office of Fossil Energy and China's National Development and Reform Commission act as co-chairs of the Task Force. The APP which first met in January 2006, is a seven nation public-private partnership designed to build on existing lateral and multi-lateral agreements to accelerate deployment of cleaner, more efficient technologies and practices. The Power Generation Task Force, one of the eight APP task forces, is promoting adoption of best practices in power generation in order to improve operational and environmental performance of existing coal-fired plants. The effort includes capacity building, site visits, workshops, and peer reviews. Two peer reviews have already been held: in Japan in April 2007, and in India in February 2008.

APP delegates discuss checklist results

Some 90 delegates participated in the Wisconsin event, which included attendees from the U.S., Japan, South Korea, India, and China. Since the first peer review, delegates have been fine-tuning a coal-fired power plant efficiency checklist. With these lists in hand, attendees visited two of Alliant's coal-fired power plants. The Edgewater station in Sheboygan consists of three units which came on line in 1951, 1969, and 1995. Two are cyclone fired boilers sized at 70 MW and 340 MW, and one is a 400-MW pulverized coal wall-fired boiler. Alliant's Columbia station in Portage, Wisconsin, dates to the early 1970s and has two 500-MW pulverized-coal tangential fired boilers. At the plants, participants formed three groups depending on area of interest, whether boilers, condensers, or auxiliaries. Knowledgeable plant personnel, along with representatives from American Electric Power, Progress Energy, and Southern Company Services, were available to answer questions on specific equipment. Attendees studied each plant component and held group discussions to identify specific operating parameter variations and make recommendations for improvement.

As part of the peer review, participants heard a number of technical talks in such areas as: application of neural networks to Distributed Control Systems; combustion optimization utilizing data mining techniques; computational fluid dynamics (CFD) boiler modeling to optimize over-fired air system design; mercury reduction using carbon injection; computerized maintenance planning and cost tracking; and, condenser air in-leakage.

APP is unique in its private sector participation, intended to ensure that actual research efforts and projects come to fruition. The seven APP countries — Australia, Canada, China, India, Japan, Republic of Korea, and the United States — represent more than half of the world's economy, population and energy use. They produce about 65 percent of the world's coal, 60 percent of its steel, 52 percent of its aluminum, and 62 percent of its cement. Partner nations also are responsible for 54 percent of global CO_2 emissions from fossil fuel consumption, 54 percent of the world's electricity production, and 39 percent of global renewable energy electric power production.

U.S., INDIA OFFICIALS PROMOTE CLEAN ENERGY COOPERATION

The U.S. Department of Energy's Under Secretary of Energy, Bud Albright, and Indian Foreign Minister Shivshandar Menon co-chaired the fourth meeting of the US-India Energy Dialogue in New Delhi, India, on March 31–April 4, 2008. The Dialogue, launched in May 2005, is designed to promote increased trade and investment in India's energy sector via government-industry cooperation. The week-long series of working group meetings (coal, oil and gas, power and energy efficiency, and new technology) focused on cooperation in energy security, promotion of increased trade and investment, and the deployment of clean energy technologies. Meetings were held with a number of senior Indian officials, including Dr. Montek Ahluwalia, Deputy Chairman of the Planning Commission (co-founder of the Energy Dialogue along with U.S. Energy Secretary Bodman); Secretary of Coal, Harish Chandra Gupta; Minister of Petroleum and Natural Gas, Murli Deora; Minister of Power, Sushilkumar Shinde; and Secretary of New and Renewable Energy V. Subramanian.

DOE's Office of Fossil Energy Deputy Assistant Secretary Justin Swift and Dr. S.P. Seth, Additional Secretary, Ministry of Coal, co-chaired the Coal Working Group (CWG) meeting. The CWG has been instrumental in facilitating important joint projects involving India's vast coal reserves. India is the world's third largest producer of coal, but is troubled by inefficient production, aging infrastructure, and low-quality, high-ash coal. The week's agenda included discussion of three joint R&D proposals where funding is expected from Coal India Ltd (CIL). Projects would involve joint CIL and U.S. private sector/university work in cost-effective technology for beneficiation of thermal and low-volatile coking coal, and recovery of fine coal. The CWG is also considering cooperation in underground coal gasification and waste coal utilization for power generation.

FE's Dr. Craig Zamuda and plant managers at tree planting ceremony at Dadri Power Plant ash mound. The specially landscaped ash mound, as well as a system to recycle ash for construction purposes, are part of a showcase project under USAID's Greenhouse Gas Pollution Prevention Program.

To date, CWG has sponsored the exchange of researchers and facilitated several U.S. Trade and Development Agency (USTDA) grants to improve coal mining operations. India is particularly interested in best practices and new technology as they relate to beneficiation of its high-ash coal resources; waste coal utilization; improving efficiency in surface and underground mining operations; coal mine safety; overburden slope stability; steep seam extraction; and mine reclamation.

Outreach is an important focus of the CWG. The group helped to establish the Coal Bed Methane (information) Clearinghouse and organized workshops on coal beneficiation, "reject" (waste) coal use, and underground coal gasification. Future plans include business development conference for U.S. clean coal technology providers and the Indian market, tentatively scheduled for late 2008 in New Delhi. ■

ACTIVE PPII AND CCPI PROJECT STATUS

PPII STATUS

Universal Aggregates, LLC – *Commercial Demonstration of the Manufactured Aggregate Processing Technology Utilizing Spray Dryer Ash*. The Cooperative Agreement for this project expired on December 31, 2006. The Final Report and Post Project Assessment have been approved and posted on the NETL Clean Coal Compendium website. The project is in close-out. (King George, VA)

CONSOL Energy Inc. – *Greenidge Multi-Pollutant Control Project*. Testing of the emissions control systems installed in Unit 4 of the AES Greenidge plant has verified that all of the performance targets of the project have been met. Additional performance tests are being conducted to measure the longer-term effectiveness of the emissions control systems under a variety of operating conditions. The project team has made significant progress toward resolving a recurring problem of ash deposits fouling the selective catalytic reduction system and forcing premature outages to clean the catalyst. (Dresden, NY)

CCPI STATUS

MEP-I LLC (Excelsior Energy Inc.) – *Mesaba Energy Project*. Excelsior's application for pre-construction site environmental permits continues to proceed through the Minnesota Public Utilities Commission (MPUC) approval process. The permit application included 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. The U.S. DOE and the Minnesota Department of Commerce are currently addressing comments made on the draft Environmental Impact Statement (EIS). Minnesota has an EIS-equivalent requirement associated with the site environmental permitting process under the State Power Plant Siting Act. The final EIS is expected by the end of 2008. The MPUC is also considering Excelsior's petition for approval of a Power Purchase Agreement (PPA) with Xcel Energy, under the State Innovative Energy Project and Clean Energy Technology statutes. The MPUC has not issued a final ruling, but has directed Excelsior and Xcel to enter into a dialogue with other Minnesota utilities to determine their interest in participating in the PPA. (Itasca & St. Louis Counties, MN)

NeuCo, Inc. – *Integrated Optimization Software*. NeuCo has successfully completed its operational phase. Project goals included reducing NO_x and increasing efficiency and availability. NO_x and ammonia consumption have been reduced to a point significantly below the target values. Substantial heat rate and availability benefits were also attained. An analysis is currently being done to determine more precisely the magnitude of those benefits. A final project technical report is in preparation. (Baldwin, IL)

We Energies – *TOXECON™ Retrofit for Mercury and Multi-Pollutant Control*. Mercury removal average for 2007 was 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 1.2 lb/mmacf. ESP optimization and PAC milling testing were completed. Initial results indicate some level of additional mercury removal, but with little overall benefit. Complete data analysis and reporting are expected by late summer 2008. An effort was initiated to better correlate PAC properties with real-life performance. This effort should result in better specification and analysis methodologies for *a priori* knowledge of PAC performance. WE Energies and United Conveyor Corp. continue to investigate the potential for further reduction in fugitive dusting during the ash unloading process. A pressure transmitter was installed in order to monitor the silo inlet, so as to control inlet pressure and reduce dusting. The level of dusting has decreased dramatically since project inception. (Marquette, MI)

Western Greenbrier Co-Generation (WGC), LLC – *Western Greenbrier Co-Production Demonstration Project*. The preliminary process design is complete. WGC has nearly finalized the key project areas including the plant engineering/procurement/construction, and operations and maintenance contracts. Arrangements are in progress for sale of power to support a public tax-exempt bond sale in September 2008. A National Environmental Policy Act (NEPA) Record of Decision (ROD) was signed on April 23, 2008, based on the final EIS released last November. WGC has received all permits and was scheduled to start preliminary site work in July 2008. (Rainelle, WV)

Great River Energy (GRE) – *Lignite Fuel Enhancement.* GRE is installing four dryers on Unit 2 as part of the Clean Coal Power Initiative (CCPI) project, and four more on Unit 1 with its own funds. Thus, the entire Coal Creek Station is being retrofitted with lignite coal dryers. GRE has completed fabrication of the eight full-scale dryers for both units. Dryer shells have been assembled on the ground and lifted to the respective dryer floors. They will be fitted with internal systems, such

as heating coils and air distributions systems. Unit 1 outage was completed in May 2008, and the dryer system construction on that unit has resumed. (Underwood, ND)

NeuCo Inc. (formerly Pegasus Technologies) – *Mercury Specie and Multi-Pollutant Control.* A novation has been signed by DOE acknowledging the change of ownership from Pegasus Technologies, Inc. to NeuCo, Inc. Pegasus Technologies was acquired by NeuCo in May 2006, and is now a division of NeuCo, Inc. The Zolo combustion analysis instruments are performing well. Improved instrument signal reliability means more high-quality data is available for neural network analysis. Plant-wide release of MaintenanceOpt is complete including operator training. The multiple process controller functional matrixes are almost fully commissioned. Operators now have functional interactive screen views in the control room. The project team has begun neural net development for combustion optimization (CombustionOpt). A subsystem for soot blowing (SootOpt) is expected to be placed in closed loop after July 4th. Data collection is continuing for all neural network subsystems. Full closed loop operation of all optimization subsystems, except for the SO_2 scrubber (FGDOpt) subsystem, is expected by August 2008. (Jewett, TX)

Southern Company Services, Inc. – *Demonstration of a Coal-Based Transport Gasifier*. On November 14, 2007, Southern Company and Orlando Utilities Commission announced cancellation of the Orlando Gasification Project due to State regulatory uncertainties. Southern Company requested DOE provide them the opportunity to evaluate other potential demonstration sites for the Transport Gasifier technology.

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