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CLEAN COAL TODAY

A Newsletter About Innovative Technologies for Coal Utilization

News Bytes

Summer 2006 saw **major developments for FutureGen**, the $1 billion first-of-a-kind near-zero emissions coal-fueled power plant scheduled to come on line in 2012. In June, Korea became the second international participant in the project. In July, the FutureGen Industrial Alliance announced a short list of candidates still being evaluated from the 12 applications submitted in May 2006 (see *Clean Coal Today* Spring/Summer 2006). The short list includes two sites in Illinois — in Mattoon, and Tuscola — and two sites in Texas — one in Heart of Brazos near Jewett, and the other in Odessa. In August 2006, DOE held four local public scoping meetings in connection with the environmental impact statement under way.

DOE/NETL is partnering with the Internal Revenue Service to

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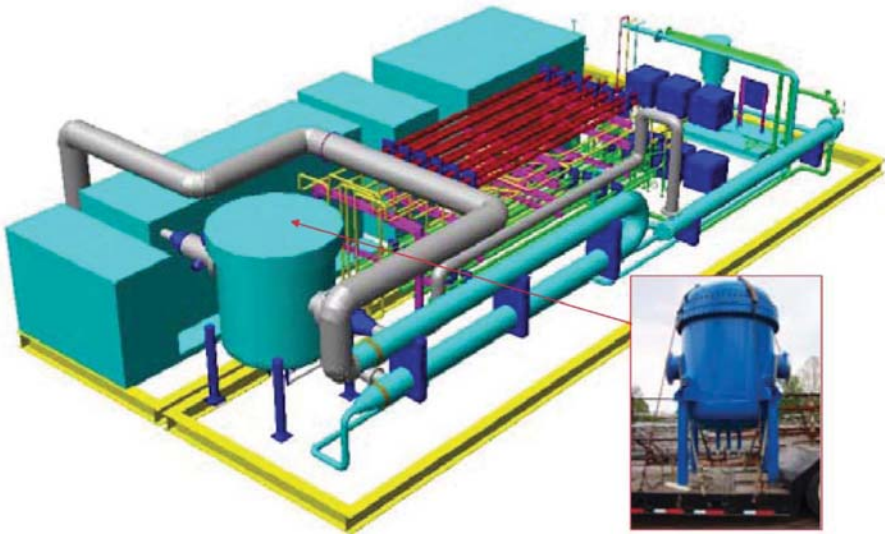
Inside This Issue

Innovative Oxygen Separation Membrane Prototype

Gasification systems offer coal-fired power plant operators a way to utilize coal — the nation's most affordable and abundant energy resource — more efficiently and cost-effectively, and in a more environmentally responsible manner. Yet many improvements still are needed to overcome remaining barriers to industry acceptance of full gasification systems, such as gas separation processes, components, and systems.

A key requirement for tomorrow's energy technologies is a continuous supply of nearly pure oxygen in industrial quantities. There are several major process advantages to using oxygen-blown gasifiers, and many existing and future gasification projects are or will be oxygen-blown, including the planned FutureGen integrated gasification combined-cycle (IGCC), near-zero-emissions power and hydrogen production plant. Since the air separation unit of a power plant typically can be 12 to 15 percent of the capital cost of the plant as a whole, improved oxygen separation technologies — like the Ion Transport Membrane technology being developed by the U.S. Department of Energy (DOE) and its partners — offer a substantial opportunity to lower overall plant cost and improve efficiency compared to conventional but expensive



Schematic of Ion Transport Membrane Oxygen Subscale Engineering Prototype, adjacent to the Air Products Air Separation Unit at Sparrows Point, Maryland; Inset: photo of the 6 ft. (diameter) pressure vessel during shipment from the manufacturing site

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..."ITM" continued

cryogenic distillation and pressure swing adsorption methods.

From 1998 to the present, DOE has worked with a team of industry and academic researchers to develop promising ceramic membrane oxygen separation processes to industrial scale, and bring them to pre-commercial acceptance by achieving costs that are at least a third lower than conventional cryogenic facilities. The first phase of this effort succeeded in proving project feasibility. The second phase is meeting program milestones, with the start-up of a Subscale Engineering Prototype (SEP) scaled to produce up to 5 tons-per-day (tpd) of oxygen. A third phase to demonstrate commercial viability extends to the end of the decade.

The New Technology

The new technology, known as Ion Transport Membrane (ITM) Oxygen, is based on a novel class of membranes composed of perovskite ceramic oxides. The electrochemical properties of these membranes make it possible to selectively separate oxygen ions from a stream of air at high temperature and pressure. Those ions are transported across the ITM, achieving high-purity, high-flow separation of the recombined oxygen on the permeate (or low-pressure) side of the ITM. This leaves a stream of hot, compressed, oxygen-depleted air on the non-permeate side. By integrating the non-permeate air stream with a fuel-fired gas turbine system, the overall process enables co-production of power and steam along with the concentrated, high-purity oxygen.

Compared to conventional air-injected combustion boilers, oxygen-enriched coal combustion and gasification processes are capable of achieving higher efficiencies with near-zero emissions through more complete fuel utilization. As the nation moves toward a hydrogen economy in which hydrogen becomes the preferred energy carrier, improved gas separation technologies will be needed to cost-effectively separate hydrogen from gaseous fuels such as synthesis gas (syngas). Syngas is a mixture of hydrogen and carbon monoxide that is derived from gasification of coal or other carbon-containing feedstocks. In addition, carbon dioxide will need to be separated from flue gas for long-term storage or sequestration. In addition to oxygen production, ITM technology also holds promise for both syngas processing and carbon management.

Project Phases & Scale-up

The overall objective of the first phase of DOE's ITM Oxygen research was to demonstrate basic feasibility of the technical approach, and to confirm expected commercial economic benefits. Between 1998 and 2001, the research team fulfilled all of the goals set for the first phase by selecting a material with the desired combination of electrochemical properties; designing and fabricating multi-layer, planar wafer structures using standard ceramic processing techniques; scaling these wafers to their full commercial dimensions; and producing them in volume on a pilot-production line using standard tape-casting technology. These activities established the feasibility of achieving the low-cost production required to meet overall economic targets.

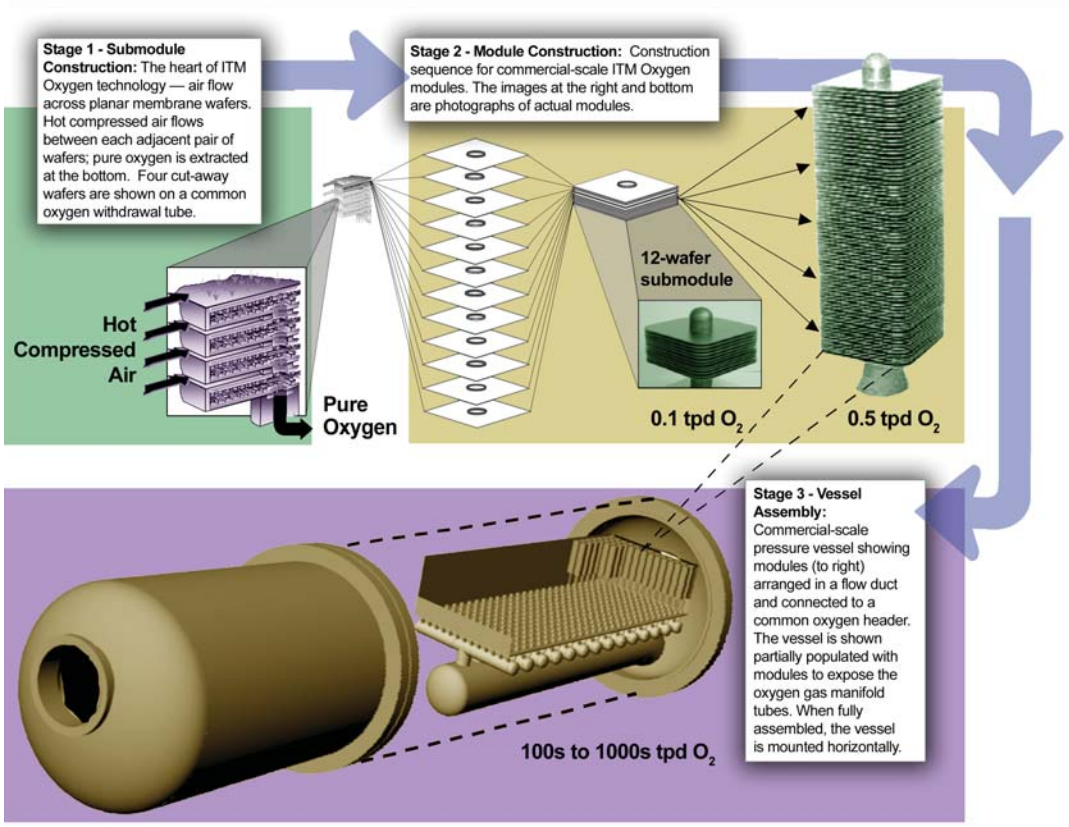
The second phase is under way. Its main objective is to scale up the ITM Oxygen ceramic devices to the targeted full scale in order to demonstrate the technology at the 1–5 tpd capability in the SEP facility.

To achieve scale-up, the ITM wafers fabricated and tested during the first phase have been combined into multi-wafer submodules of 12 wafers each. Fitted with a ceramic tube and cap for testing, such submodules have succeeded in producing on the order of 0.1 tpd oxygen each in pilot tests.

To make commercial-scale modules, multiple submodules are joined together so that they can undergo thorough testing at pilot scale to verify performance. Initially, 0.5 tpd modules have been constructed by mounting multiple 0.1 tpd submodules on a single ceramic tube with an end cap and conical base (see figure, next page). Ultimately, the research team aims to double the number of submodules in a single module to reach the goal of producing 1.0 tpd of oxygen.

As part of the performance testing, multiple modules are mounted into a common pressure vessel. All modules are installed in parallel rows in the vessel. Flow ducts for these banks are connected through a series of manifold tubes to a common oxygen header. The header collects and concentrates the flow of high-purity oxygen. The oxygen is withdrawn from the vessel by a blower/compressor, cooled by heat exchangers, and routed for storage or reuse.

The pressure vessel is designed to allow repetitive testing of various module and vessel configurations. These configurations make it possible to achieve the desired pilot plant



Scale-up of ITM module

production volume, *and* to enable testing and verification of vessel design concepts as well as module performance at high pressure (up to 300 psig) and temperature (up to 900 °C). The oxygen production from individual modules is monitored separately to establish module performance as a function of position in the module array.

The 1–5 tpd sub-scale engineering prototype entered test operation in the pilot facility in the Fall of 2005, with the initial goal of producing 1 tpd oxygen. The prototype is now successfully fulfilling test requirements and confirming earlier predictive studies as to expected economic benefits. To minimize compression costs, the prototype system is designed to recycle the pressurized air, and is capable of very high throughput to simulate commercial operation. The pressure vessel is oversized relative to commercial requirements, to enable numerous and rapid change-outs of internal equipment. To enable high-throughput experimentation, supporting equipment (such as heat exchangers) in the SEP is also much larger relative to the pressure vessel than would be the case in commercial facilities. Make-up gases for test purposes are supplied from an adjacent commercial-scale air separation plant.

Project Team

Key participants on the project team include Air Products and Chemicals, Inc. (principal technology partner); Ceramatec, Inc. (ceramics processing); Siemens Power Generation, Inc. (SPG) (gas turbine integration strategy); NovelEdge Technologies, LLC (integration strategy with steam systems); GE Energy Gasification division (process economic modeling and applications); Concepts/NREC, (gas turbine integration and pre-combustor design); SOFCo EFS (mechanical and vessel systems development); Pennsylvania State University (materials characterization); and the University of Pennsylvania (oxide materials science).

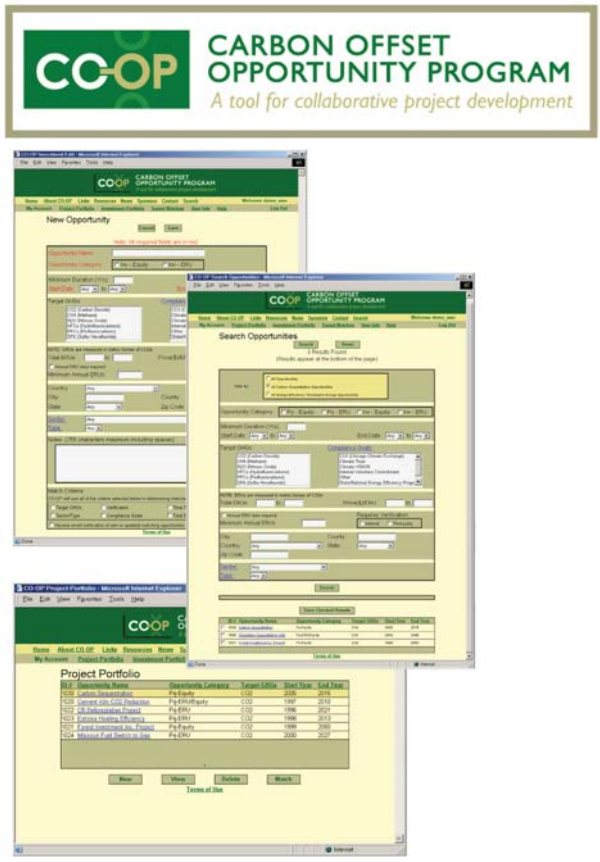
The team continues to attract interest from a variety of potential industry partners, and seeks those that will add expertise in needed areas as well as aid in developing early commercial pathways for the technology. In 2003, for example, SPG joined the team to help identify detailed requirements for integrating its large gas turbine machinery with the ITM Oxygen separation system. Preliminary studies confirm the suitability of SPG's existing SGT6-6000G (W501G) platform for use in supporting significant air extraction from the compression side of the gas turbine for feed to the ITM vessel. A high volume of air is a key parameter to reduce the amount of membrane required, and lower overall cost.

Toward the Future

Based on successes to date, DOE and its partners are planning further steps toward commercialization during a future third phase of the project. This phase is planned to culminate in a tonnage-quantity test facility that would start up by 2010, providing the necessary data to allow the team to meet the 2012 start-up date for a large-scale air separation plant. The plant would serve as an oxygen supply module for DOE's FutureGen initiative.

CARBON OFFSET OPPORTUNITY PROGRAM

As the debate on global warming intensifies in the United States and abroad, new greenhouse gas (GHG) reduction technologies and offset mechanisms can be facilitated by industry partnerships. The U.S. Department of Energy's National Energy Technology Laboratory (NETL) has developed the Carbon Offset Opportunity Program (CO-OP), an innovative online tool to assist utilities, coal companies, manufacturers, and other energy users to find greenhouse gas reduction opportunities through carbon sequestration, energy efficiency, and renewable energy use. CO-OP provides a searchable database for high-tech matchmaking, and links potential project developers and investors, as well as educational resources to help those new to greenhouse gas reduction methods.



CO-OP was developed in consultation with a group of West Virginia stakeholders close to NETL's Morgantown campus. Stakeholders include Appalachian Power, CONSOL Energy, the West Virginia Coal Association, and the West Virginia Department of Environmental Protection, among others. Users of the system, however, are nationwide.

With the CO-OP matching system, companies or organizations searching for partners in carbon offset and reduction projects can do so at no cost. For example, a power generator that is seeking to reduce its GHG emissions to meet internal corporate goals may want to invest in a reforestation project. A coal company engaged in reforestation could post, on the CO-OP website, its desire to seek investors for its tree-planting projects. In linking the coal company project developer with the power generator project investor, CO-OP could help the coal company to subsidize its reforestation activities, and the power generator to meet its environmental targets. Project developers can post listings describing either existing or contemplated projects. Investors can post descriptions of the type of projects in which they would like to invest. In both cases, users have the option of posting either specific or general descriptions on projects of interest. Users must register with CO-OP in order to post opportunities so that those searching the CO-OP database can contact them regarding collaboration. However, in order to search the CO-OP database, users do not need to register.

Since launching the website in 2004, significant interest has been expressed by smaller organizations new to the area of GHG offset and reduction. Therefore, efforts have focused on expanding the educational resources component of CO-OP, which includes fact sheets providing an explanation of the basics of carbon sequestration, and an overview of the different types of GHG offset and reduction projects. Additional resources include a list of common frequently asked questions and a glossary of terms. The website also offers links to information on various GHG programs, GHG research activities, and carbon sequestration. These include the U.S. Department of Agriculture (USDA) Global Change Program Office, U.S. Environmental Protection Agency Climate Leaders program, International Energy Agency Climate Change site, and the Energy Information Administration Voluntary Reporting of Greenhouse Gases program.

As CO-OP continues to evolve and meet the needs of users, upcoming enhancements are likely to include changes to increase the user-friendliness of the site, expanding the database to include additional resources beyond project investors, as well as augmenting educational resource material.

To access the CO-OP website, visit www.offsetopportunity.com

The Carbon Sequestration Newsletter Via Email

Tired of searching newspapers, magazines, and peer review journals for the latest news in carbon sequestration? Getting trigger finger from searching the web for relevant news?

The National Energy Technology Laboratory's ***The Carbon Sequestration Newsletter*** does the work for you, providing summary information, together with web links, for key news and journal articles of the preceding month. Carbon sequestration has become an increasingly vital research area for the U.S. Department of Energy, which is partnering with the FutureGen Industrial Alliance, the Carbon Sequestration Regional Partnerships, and — internationally — with the Carbon Sequestration Leadership Forum and the Asia Pacific Partnership. ***The Carbon Sequestration Newsletter*** includes sequestration news about NETL and these joint efforts, as well as other public and private sector activities related to such areas as technology, science, policy, legislation, and carbon markets. Calls for papers, conference announcements, and job listings are also regular features.

The newsletter is free of charge and is delivered in pdf, with full color graphics, and text format. To subscribe, please enter your e-mail address at: http://www.netl.doe.gov/publications/carbon_seq/subscribe.html. Back issues are available at this site as well.

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evaluate 49 applications received in response to an Energy Policy Act of 2005 program of tax credits to spur investments in advanced clean coal facilities, including advanced gasification projects. The projects are valued at $57.7 billion, with $5 billion eligible for tax credits.

A new **cooperative agreement under the Clean Coal Power Initiative was signed in May 2006 with MEP-I LLC**, a project company of Excelsior Energy, to develop the Mesaba Energy next-generation IGCC project. In July, the **last cooperative agreement under the Power Plant Improvement Initiative was signed with CONSOL Energy, Inc.** for development of the Greenidge Multi-Pollutant Control Project, to pioneer control technology applicable to smaller power plants. Watch for further details on these and other demonstration projects in later issues of *Clean Coal Today.*

The **Dakota Gasification Company announced the return of $79 million to DOE in revenue-sharing gas sales from the Great Plains Synfuels Plant** near Beulah, North Dakota. Dakota bought the plant from DOE in 1988 and has returned a total of $241 million. The Great Plains Plant is the only commercial U.S. plant producing synthetic natural gas from coal. Dakota also participates with DOE and others in the Weyburn Enhanced Oil Recovery Project transporting CO_2 from the synfuels plant to Weyburn for both enhanced oil recovery and CO_2 sequestration.

UPCOMING EVENTS

September 25–28, 2006
23rd Annual Pittsburgh Coal Conference
Sponsor: University of Pittsburgh School of Engineering
Location: Pittsburgh, PA
Phone: 412-624-7440
Fax: 412-624-1480
E-mail: pcc@engr.pitt.edu

October 24–26, 2006
20th Symposium on Western Fuels — International Conference on Lignite, Brown, and Subbituminous Coals
Location: Denver, Colorado
Sponsors: EERC, DOE/NETL, EPRI
Registration Information:
La Rae Foerster
Phone: 701-777-5246
E-mail: lfoerster@undeerc.org

November 13–17, 2006
Fuel Cell Seminar
Location: Honolulu, Hawaii
Organizing Committee: DOE/NETL, and many others
Contact:
fuelcell@courtesyassoc.com
Phone: 202-973-8671
Fax: 202-331-0111

November 14–16, 2006
Workshop on FGD Byproducts at Coal Mines and Responses to the National Academy of Sciences Final Report "Managing Coal Combustion Residues in Mines"
Location: Columbus, OH
Contact: William Aljoe
Phone: 412-386-6569
E-mail: aljoe@netl.doe.gov

December 11–13, 2006
DOE Mercury Control Conference
Location: Pittsburgh, PA
Contact: Charles Miller
Phone: 412-386-5745

HIGH-FIDELITY PROCESS CO-SIMULATION OF ADVANCED POWER GENERATION SYSTEMS

The R&D 100 award-winning Advanced Process Engineering Co-Simulator (APECS), developed at the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), enables design engineers to better understand and optimize power plant performance with respect to coupled fluid flow, heat and mass transfer, and chemical reactions. APECS is a suite of software tools providing a powerful co-simulation capability by facilitating, for the first time, the efficient and systematic integration of process simulation with computational fluid dynamics (CFD) models of key equipment items, such as combustors, gasifiers, syngas coolers, steam and gas turbines, heat recovery steam generators, and fuel cells. By coupling process/CFD co-simulations with advanced visualization and high-performance computing, APECS also offers opportunities for using virtual plant simulation to reduce the time, cost, and technical risk of developing high-efficiency, zero-emissions power plants such as the DOE's FutureGen plant.

FEATURES AND ANALYTICAL CAPABILITIES

APECS builds on the computational framework developed in 2000–2004 by NETL through its Aspen Plus®/FLUENT® integration project (see *Clean Coal Today*, Fall/Winter 2003). In March 2005, U.S. Secretary of Energy Samuel Bodman announced that Fluent and Reaction Engineering International were awarded $1.9M and $0.5M APECS projects, respectively, as part of a portfolio of $62.4 million for 32 clean coal research projects. The ongoing APECS projects are focused on providing the high-fidelity modeling and simulation capabilities required for next-generation power systems.

The APECS integration framework uses the process industry-standard CAPE-OPEN software interfaces, developed through international collaboration of more than 50 organizations from the process industries (*e.g.*, petroleum, chemical, pharmaceutical), academic institutions, and software vendors. Application of APECS culminates in plug-and-play interoperability between process simulation and equipment models. The hierarchy of equipment models used by APECS ranges from high-fidelity CFD models, to custom engineering models (CEMs), to fast reduced-order models (ROMs). The CFD models provide detailed and accurate representations of a wide variety of process equipment items, while CEMs are typically engineering models that calculate mass and energy balances, phase and chemical equilibrium, and reaction kinetics. ROMs are a class of equipment models that are based on pre-computed CFD solutions over a range of parameter values, but are much faster than CFD models.

The APECS system drastically reduces the time and effort required to couple CFD-based equipment models into plant-wide simulations. Today, design engineers can use APECS to integrate CFD models into a process simulation in a matter of an hour or two using the CAPE-OPEN software interfaces and easy-to-use configuration wizards. APECS also offers parallel execution of CFD models on high-performance computers. The APECS integration controller allows process simulations running under the Windows operating system to use equipment models running locally/remotely and serially/in parallel on Linux clusters and/or supercomputers.

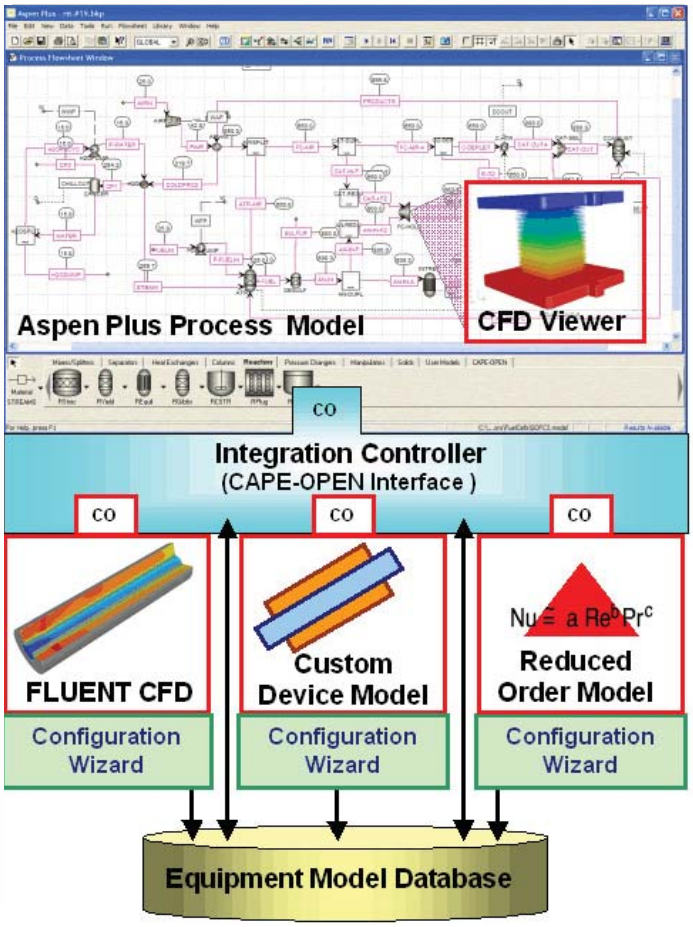
The APECS system also provides a wide variety of powerful analysis tools for optimizing overall power plant performance. Design specifications are used to calculate operating conditions or equipment parameters to meet specified performance targets. Case studies are used to run multiple simulations with varying input. Sensitivity analysis shows how process performance varies when selected equipment specifications and operating conditions change. Optimization is used to maximize plant efficiency, energy production, and process economics. For process optimization in the face of uncertain variables — such as coal feed flow rates, or fluctuating prices of raw materials — APECS offers stochastic modeling and multi-objective optimization capabilities.

Visualization coupled with co-simulation enhances the power plant engineering process, by linking analysts who use high-fidelity modeling techniques, such as CFD, to power plant engineers, designers, and operators. Advanced 2-D and 3-D visualization tools available in APECS enable design engineers to display, within the process simulator, the results of a process/CFD co-simulation, including contours of velocity, temperature, pressure, and species mass fractions for specified surfaces in the equipment models. Ongoing collaborative efforts aimed at integrating APECS with VE-Suite (www.vesuite.org), an open-source virtual engineering software toolkit,

will enable users to explore co-simulation results in a context-based, user-centered interface, including walking through a 3-D representation of the power plant.

APECS APPLICATIONS

Systems analysts at NETL are applying APECS to a wide variety of advanced power generation systems, including potential FutureGen plant configurations. In a recent demonstration case, the FutureGen co-simulation combined a plant-wide Aspen Plus® simulation with two FLUENT® CFD-based equipment models, one for the entrained-flow gasifier where fluid dynamics strongly affect syngas quality and carbon conversion, and another for the gas turbine combustor where the blending of air and fuel is vital to gas turbine combustor performance and efficiency. Using APECS, Aspen Plus® controls the co-simulation and automatically executes the gasifier and combustor CFD models as needed to converge the tail gas recycle loop and a design specification on the gas turbine inlet temperature. The design specification is met by manipulating the synthesis gas split between power production and hydrogen production. This co-simulation typically requires several hours of CPU time to converge on a single-CPU workstation. The turnaround time for the co-simulation is improved by running the computationally intensive CFD models in parallel on 2–8 CPUs of the Linux clusters at NETL and/or Pittsburgh Supercomputing Center.



Other work on advanced systems has ranged from applications for small fuel cell systems to commercial-scale power plants. Using APECS, the overall performance of solid oxide fuel cell auxiliary power units for transportation applications was optimized with respect to the local fluid flow, heat and mass transfer, electrochemical reactions, current flow, and potential field in simulated fuel cell stacks. The process/CFD co-simulations are performed over a range of fuel cell currents to generate a voltage-current curve, and analyze the effect of current on fuel utilization, power density, and overall system efficiency.

Elsewhere, NETL put in place a technology transfer partnership with Fluent Inc. to offer software and services designed to help industry customers deploy coupled CFD and process simulation, as part of a complete engineering solution. In the chemical industry, process engineers are using APECS to optimize plant performance by analyzing the impact of complex reactor mixing and fluid flow phenomena on overall plant product quality and yield. In the power industry, Alstom Power cycle engineers are routinely employing the APECS technology to design and optimize commercial-scale power plants including coventional pulverized coal-fired steam plants and natural gas-fired, combined-cycle power plants.

Participants in the U.K.'s Virtual Plant Demonstration Model program are leveraging APECS to integrate high-fidelity FLUENT CFD equipment models into overall power plant models developed with the Process Systems Enterprises gPROMS simulator. In the research community, APECS is used by Carnegie Mellon University for developing optimization-based ROMs based on CFD results. Iowa State University and Ames National Laboratory are coupling process/CFD co-simulation to immersive 3-D virtual engineering software, and the Vishwamitra Research Institute is using stochastic analysis and multi-objective optimization capabilities for process/CFD co-simulation.

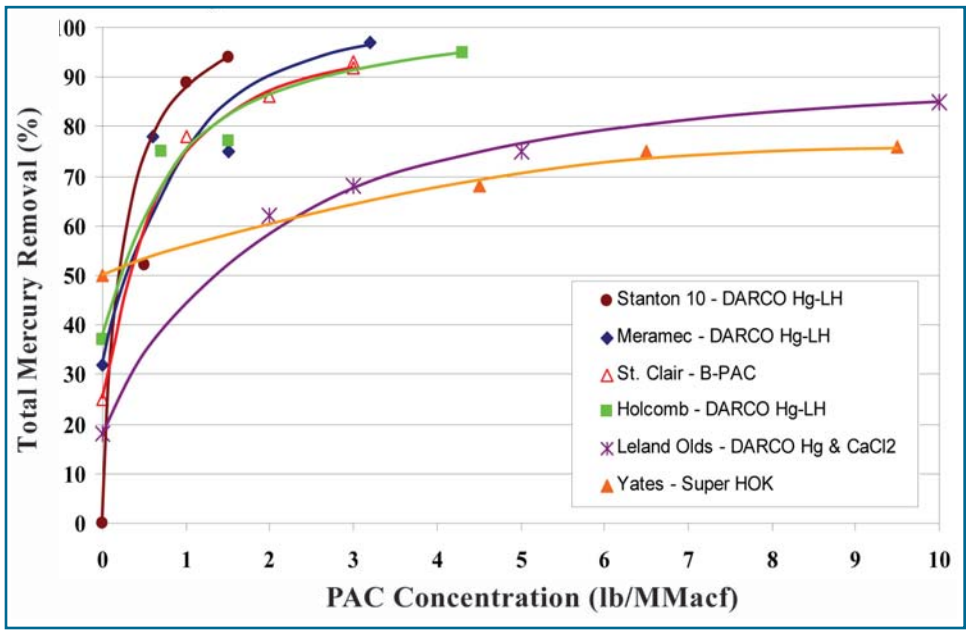
COST AND PERFORMANCE OF ACTIVATED CARBON INJECTION FOR MERCURY CONTROL

The clock is ticking for U.S. coal-fired power plants as they prepare to comply with final regulations for controlling mercury emissions, issued May 18, 2005, by the U.S. Environmental Protection Agency. The Clean Air Mercury Rule requires coal-fired power plants to reduce their total mercury emissions from current levels of 48 tons per year (tons/yr) to 15 tons/yr by 2018 — a reduction of almost 70 percent. Because coal-fired power plants burn a broad range of coals and employ a variety of air pollution control devices, one size does not fit all when considering technologies for controlling mercury. Consequently, as they develop their individual mercury control plans, coal-fired power plant owners must closely evaluate the results of ongoing tests of several promising control technologies. One such technology is activated carbon injection (ACI), in which the powdered activated carbon (PAC) is injected into the combustion flue gas upstream of a particulate control device — either an electrostatic precipitator or fabric filter. The PAC adsorbs the mercury and is subsequently captured, along with the fly ash, by the particulate control device. Assessing the preliminary performance and cost of ACI technologies from various field tests provides valuable input to guide research efforts and utility compliance planning.

MERCURY CONTROL FIELD TESTING

The U.S. Department of Energy's National Energy Technology Laboratory (DOE/NETL) initiated comprehensive mercury research under the DOE Office of Fossil Energy's Innovations for Existing Plants Program in the early 1990s. The research was to ensure that effective control technologies would be available as needed for the existing fleet of coal-fired plants. The near-term goal has been to develop technologies that can achieve 50–70 percent mercury capture at costs 25–50 percent less than baseline estimates of $50,000–70,000 per pound of mercury ($/lb Hg) removed. These technologies would be available for commercial demonstration by 2007 for all types of coal. The longer-term goal is to develop advanced mercury control technologies to achieve 90 percent or greater capture, which would be available for commercial demonstration by 2010.

In 2003–04, DOE/NETL selected 14 projects to test and evaluate various mercury control technologies. The projects focus on long-term, large-scale field testing at plants burning various coal types and equipped with a variety of air pollution control configurations. While field testing is still ongoing, DOE/NETL recently completed a preliminary economic analysis of mercury control for six test sites spanning three ACI variations — conventional PAC, brominated PAC, and conventional PAC combined with a sorbent enhancement additive (SEA) applied to the coal. The brominated PAC and SEA are used to enhance ACI performance for low-rank coals such as lignite and subbituminous. Field testing included a baseline period followed by parametric tests and a 30-day long-term continuous ACI trial.



ACI performance data from Phase II field tests

While the preliminary field testing results are encouraging, both in terms of the level of mercury removal achieved and the cost of control, they represent relatively short-term testing at optimum conditions. Such testing provides a basis for estimating performance and cost, but the limited duration of testing does not allow for

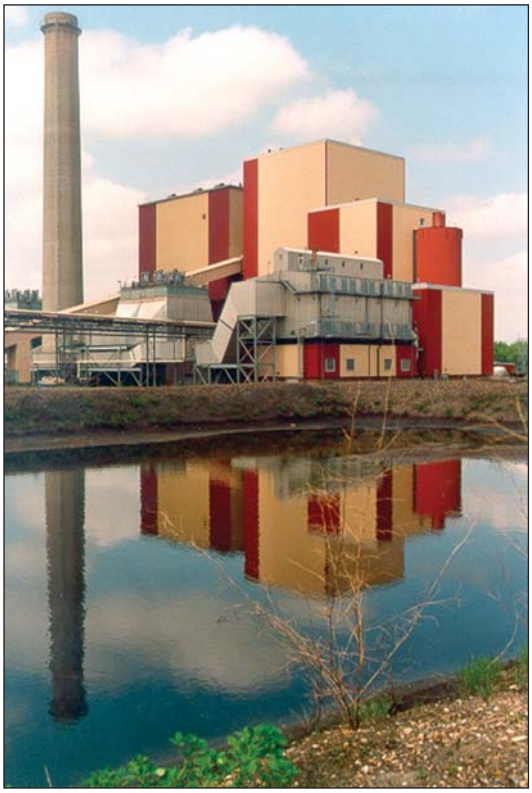
a comprehensive assessment of operational and balance-of-plant issues.

PRELIMINARY COSTS

The ACI performance curves shown in Figure 1 display total mercury removal as a function of PAC injection concentration. Baseline mercury removal corresponds to a PAC concentration of 0 lb/MMAcf. To evaluate the progress of DOE/NETL's mercury control field testing program and discern the performance of ACI, a data adjustment methodology was developed that accounts for baseline mercury capture. The resulting ACI data were used to perform economic analyses that show the cost required to achieve low (50 percent), mid (70 percent), and high (90 percent) levels of mercury control above and beyond baseline mercury removal. The levels of mercury control used for the economic analyses are directly attributable to ACI. If baseline capture was 33 percent and total capture during PAC injection 80 percent, then the capture attributed to ACI would be approximately 70 percent.

20-Year Levelized Cost of Mercury Control without By-Product Impacts

ACI Hg Removal, %	50%		70%		90%	
20-Year Levelized Costs (Current$)	COE, mills/kWh	$/lb Hg Removed	COE, mills/kWh	$/lb Hg Removed	COE, mills/kWh	$/lb Hg Removed
Holcomb Unit 1 DARCO® Hg-LH	0.14	$4,220	0.18	$3,810	0.37	$6,060
St. Clair Unit 1 B-PAC™	0.36	$16,200	0.48	$15,200	1.06	$26,200
Meramec Unit 2 DARCO® Hg-LH	0.37	$11,800	0.47	$10,800	0.99	$17,700
Stanton Unit 10 DARCO® Hg-LH	0.82	$19,500	1.02	$17,400		
Leland Olds Unit 1 DARCO® Hg & $CaCl_2$	0.83	$20,600	1.25	$22,200		
Plant Yates Unit 1 Super HOK	0.97	$54,600	1.72	$69,500		



Great River Energy's Stanton Station is using brominated PAC injection for mercury control

Estimated operation and maintenance (O&M) costs and fixed capital costs for the ACI technologies were provided by project sponsors, and were used to calculate the total cost for mercury control on an amortized, current dollar basis. Using a three percent escalation rate for O&M costs and a 20-year book life for capital costs, levelized costs for the incremental increase in cost of electricity (COE), expressed in mills/kWh, and the incremental cost of mercury control ($/lb Hg removed), were calculated for each level of mercury control. The levelized cost estimates for the six projects are presented in the table above, and show that the increase in COE varied from 0.14 mills/kWh to 1.72 mills/kWh, and the incremental cost of mercury control ranged from $3,810/lb Hg removed to $69,500/lb Hg removed. The table does not show cost estimates for 90 percent mercury control for Stanton, Leland, and Yates because this level of performance was not achieved during testing.

The mercury control costs shown also do not include the potential cost of by-product impacts associated with PAC injection. The three ACI technologies included in the economic analysis are designed to inject PAC upstream of the particulate control device. This configuration results in commingling of the PAC and fly ash, which could affect the marketability of the fly ash as a partial substitute for Portland cement in concrete. Consequently, a parallel economic analysis of mercury control

See "Mercury" on page 10...

...*"Mercury" continued*

via ACI was conducted that included additional costs for fly ash disposal and loss of fly ash sales revenue. Based on this analysis, the incremental increase in COE varied from 0.86 mills/kWh to 3.92 mills/kWh and the incremental cost of mercury control ranged from $18,000/lb Hg removed to $166,000/lb Hg removed.

The complete economic analysis and other technical reports on the mercury control field testing program are available on the DOE/NETL web site at: http://www.netl.doe.gov/technologies/coalpower/ewr/mercury/index.html.

ACTIVATED CARBON INJECTION TEST SITES

ADA Environmental Solutions (ADA-ES) tested conventional PAC, brominated PAC, and conventional PAC with SEA at Sunflower Electric's 360-MW **Holcomb Station Unit 1**, which burns subbituminous coal and is equipped with a spray dryer absorber and fabric filter. Baseline mercury capture was approximately 37 percent across the absorber-filter. Parametric testing achieved 75 percent total mercury removal with brominated PAC (DARCO® Hg-LH) injection of 0.7 pounds per million actual cubic feet (lb/MMacf) of flue gas. During the 30-day long-term trial, total mercury removal averaged 93 percent with an average PAC injection of 1.2 lb/MMacf.

ADA-ES evaluated the same three technologies at AmerenUE's 140-MW **Meramec Station Unit 2**, which burns subbituminous coal and is equipped with a cold-side electrostatic precipitator (CS-ESP). Baseline mercury capture was approximately 32 percent across the CS-ESP. Parametric testing achieved 75 percent total mercury removal with brominated PAC (DARCO® Hg-LH) injection of 1.5 lb/MMacf. During the 30-day long-term trial, total mercury removal averaged 93 percent using 3.3 lb/MMacf of the brominated PAC.

URS Group, Inc. (URS) conducted testing at Southern Company's 100-MW bituminous coal-fired **Plant Yates Unit 1**, which is equipped with a relatively small cold-side ESP. Baseline mercury capture averaged approximately 50 percent prior to ACI testing. For the 30-day long-term test, a conventional PAC (Super HOK) achieved average total mercury removals of approximately 68, 75, and 76 percent for injection rates of 4.5, 6.5, and 9.5 lb/MMacf, respectively.

The University of North Dakota Energy & Environmental Research Center (UNDEERC) conducted testing at Basin Electric's 220-MW **Leland Olds Station Unit 1** to evaluate conventional PAC (DARCO® Hg) injection when lignite coal is treated with an SEA. Baseline mercury capture was approximately 18 percent across the cold-side electrostatic precipitator. During parametric tests with a PAC injection of 10 lb/MMacf, total mercury removal increased from 64 percent to 85 percent with addition of the sorbent-enhanced additive. The 30-day long-term test, conducted with the additive and PAC injection of 3 lb/MMacf, resulted in an average total mercury removal of 63 percent.

URS also conducted testing at Great River Energy's 60-MW **Stanton Station Unit 10**, which burns North Dakota lignite. No baseline mercury capture was observed across the spray dryer absorber/fabric filter configuration. A brominated PAC (DARCO® Hg-LH) injection of 1.5 lb/MMacf achieved 94 percent total mercury removal during parametric testing. For the 30-day long-term trial, total mercury removal averaged 60 percent with average PAC injection of 0.7 lb/MMacf.

Sorbent Technologies Corporation evaluated brominated PAC (B-PAC™) at Detroit Edison's 145-MW **St. Clair Station Unit 1**, which fires a blend of 85 percent subbituminous and 15 percent eastern bituminous coal. Baseline mercury capture was approximately 25 percent across the cold side-ESP. A PAC injection of 1.0 lb/MMacf achieved 78 percent total mercury removal during parametric testing. During the 30-day long-term trial, total mercury removal averaged 94 percent with an average PAC injection of 3.0 lb/MMacf.

INTERNATIONAL INITIATIVES

CHINA GASIFICATION AND LIQUEFACTION WORKSHOP

The China–U.S. Coal Gasification and Liquefaction Technology Workshop was held in Beijing, People's Republic of China, June 15–16, 2006, as an activity under Annex II of the Protocol for Cooperation in the Field of Fossil Energy Technology Development and Utilization, between the U.S. Department of Energy (DOE) and the Ministry of Science and Technology, People's Republic of China. The Protocol was first signed in April 2000, and extended for another five years in April 2005. Annex II focuses on cooperation in clean fuels, including coal conversion, advanced separation processes/innovative coal preparation, co-production of chemicals and power, and ultra clean liquid fuels from coal (such as hydrogen). The National Development and Reform Commission (NDRC) is the Chinese coordinator for Annex II. The June workshop, attended by 150 representatives from government organizations, the private sector, and research institutions, was sponsored by the NDRC and DOE, and organized by the Shenhua Group Corporation, Ltd. and West Virginia University.

Opening addresses were given by Wu Yin, the Director General of the Energy Bureau, NDRC; Biting Chen, Chairman of the Shenhua Group; and Justin Swift, DOE Office of Fossil Energy's Deputy Assistant Secretary for International Activities. The agenda featured four keynote speeches and papers on such technical topics as direct and indirect liquefaction, coal gasification for utility and industrial purposes, and co-production. Eight U.S. corporations doing business in China participated: Headwaters Energy Service Corporation, Rentech, Inc., Syntroleum, Inc., Shell–China Corporation, General Electric, Air Products, Inc., the Sud-Chemie Group, and Peabody Coal Co.

The Shenhua Group is a leading industrial group in China exploring coal liquefaction, and the workshop provided key information about Shenhua's development strategy and ongoing projects. Shenhua is one of the largest coal producers in China, accounting for over 6 percent of the total coal production and one-third of coal exports. It operates the Shendong coalfield, one of the eight largest coal fields of the world. Shenhua is pursuing both direct and indirect liquefaction, as well as chemicals from coal. The responsible subsidiary is the China Shenhua Coal Liquefaction Corporation.

Representatives of the conference organizing/sponsoring committees visited Shenhua's Direct Liquefaction Plant under construction near Erdos, Inner Mongolia. Construction is proceeding on schedule, with preliminary start-up of the first of three trains (processing units) expected by the end of 2007. The facility will function as a "hybrid" direct liquefaction process that includes a product upgrading as well as a gasification section. When integrated, these units can produce a wide range of products at a greater efficiency than would otherwise be achieved. The first of three trains is expected to produce over one million tons per year of liquid products (approximately 20,000 barrels per day). The product slate is reported to be approximately 102,000 tons of liquefied petroleum gases, 250,000 tons of naphtha, 714,000 tons of diesel fuel and

See "International" on page 12...

INTERNATIONAL INITIATIVES (CONTINUED)

gasoline, and 3,600 tons of hydroxybenzene. A successful start-up of this first train will support a decision to proceed with the remaining two trains in Phase I. Phase II of the project would include construction of the additional seven trains needed to achieve the project's planned production goal of 10 million metric tons of oil products by 2010.

Over the two-day workshop, Shenhua brought attendees up to date on the status of their other coal-related projects, where they are engaged in indirect liquefaction as well as deriving chemicals from coal. The Yulin Project (indirect liquefaction) was started in August 2004 in the Shaanxi Province, about 100 kilometers south of the direct coal liquefaction plant. When operational, the first phase of the facility is designed to produce about 3 million tons per year of products, (*e.g.,* LPG, naphtha, diesel oil, wax, and some chemicals). Another indirect liquefaction plant under development — the Ningxia Project — is also designed to produce some 3 million tons per year of similar products in its first phase.

In the area of coal-based chemicals and polygeneration, Baotou Coal Chemical Project began construction in October 2005. The goal is to convert coal from the Erdos Coal Field into 1.8 million tons per year of methanol, 300,000 tons per year of ethylene, and 300,000 tons per year of propylene. Another chemical facility, the Ningdong Energy and Heavy Chemicals Base, in the province of Ningxia, is in the planning phase. When operational, it is to produce 4.0 million tons per year of methanol and 1.2 million tons per year of dimethylether (DME).

Elsewhere under Annex II, DOE and China are conducting an ongoing survey study of long-term environmental and economic impacts of commercial coal liquefaction.

NETL EDUCATING FOREIGN SERVICE OFFICERS TO MEET ENERGY CHALLENGES

Major power system failures, rapidly rising fuel costs and supply issues, natural and manmade threats to grid reliability and security are energy issues that figure prominently in today's headlines around the world. One way U.S. government employees gain an understanding of these interrelated technological, environmental, economic, and security challenges is through the U.S. Department of State Foreign Service Officers Coal and Power Training Course.

During the week of July 17–21, 2006, for the seventh consecutive year, the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) conducted a training course for the State Department. Offered through the Foreign Service Institute (FSI) of the State Department, the course provides an overview of electricity generation, transmission, and distribution; introduces current and emerging technologies in the coal and power generation sectors; and discusses how technologies are increasing efficiency, reducing emissions, and driving down costs. Advances through DOE coal and power RD&D are emphasized, as is the varying applicability of clean coal technologies to developing countries. The 20 participants become familiar with the structure of the energy and power sectors, and the trend toward worldwide regulatory reform. Through the course, officers become better prepared to represent a wide range of U.S. government commercial, economic, and environmental interests. They also are better able to facilitate U.S. exports of energy and related environmental technologies, products, and services.

Established in 1947, the FSI is the primary federal government training institution for officers and support personnel of the U.S. foreign affairs community, preparing American diplomats and other professionals to advance U.S. foreign affairs interests overseas and in Washington, D.C. Training is provided to more than

50,000 enrollees from the State Department and over 40 other government agencies and the military. FSI programs include training for the professional development of Foreign Service administrative, consular, economic/commercial, political, and public diplomacy officers; for specialists in the fields of information management, office management, security, and medical practitioners and nurses; for Foreign Service nationals who work at U.S. posts around the world; and for Civil Service employees of the State Department and other agencies.

The Coal and Power curricula is guided by NETL's ongoing analysis of issues and developments in the coal and power industries, as well as changes in the international energy picture. The program is fine tuned based on feedback from the State Department, and student evaluations. This year's training program continued to emphasize technology developments from research, development, and demonstration efforts of DOE and its partners, such as progress toward FutureGen plants, with hydrogen and electricity co-production, coupled with the sequestration of carbon dioxide.

Dr. Mildred B. Perry (left end, middle row), DOE/NETL Coordinator, shown with course participants in front of a huge water cooling tower at FirstEnergy Generation Corporation's Bruce Mansfield Power Plant

Thirty experts from industry, academia, and government delivered presentations on a wide variety of coal-related topics including mining, coal preparation, combustion, gasification, and by-product utilization. Presentations also included natural gas-based power generation using various distributed generation technologies, such as fuel cells and microturbines. Site visits were a highlight of the instructional week. This year, course participants visited the Warrior Run Power Plant of AES Corporation in Cumberland, Maryland, and the nearby Carlos Coal Mine owned by Vindex Energy Corporation. Students also toured the coal-fired Bruce Mansfield Power Plant in Shippingport, Pennsylvania, owned and operated by FirstEnergy Generation Corporation, and the adjacent wallboard manufacturing plant of National Gypsum Company. They visited the solid oxide fuel cell manufacturing facility of Siemens Power Generation in Pittsburgh, Pennsylvania, and the gas-fired Springdale Power Plant of Allegheny Energy Corporation in Springdale, Pennsylvania. The tour included NETL's own test facilities, as well as the Safety Research Mine operated by the National Institute of Occupational Safety and Health, at the nearby Bruceton Research Center in South Park.

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Editor: Phoebe Hamill ***Fax:*** 202-586-1188

Phone: 202-586-6099 ***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.

ACTIVE CCT DEMONSTRATION, PPII, AND CCPI PROJECT STATUS

CCT DEMONSTRATION STATUS

Kentucky Pioneer Energy (KPE), L.L.C. – *Kentucky Pioneer Energy Project.* The Cooperative Agreement has expired. The Draft Final Report is in progress. (Trapp, KY and West Terre Haute, IN)

TIAX, LLC (formerly Arthur D. Little, Inc.) – *Clean Coal Diesel Project.* The Cooperative Agreement has expired. The Draft Final Report is in progress. (Fairbanks, AK and Beloit, WI)

PPII STATUS

Otter Tail Power Company – *Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector (AHPC) Technology*. The project has been completed. The Final Report has been submitted and approved. (Big Stone City, SD)

Sunflower Electric Power Corp. – *Demonstration of a 360-MWe Integrated Combustion Optimization System*. Due to larger than anticipated costs for installation of new low-NO_x burners and overfire air systems, Sunflower has withdrawn the continuation application to DOE for proceeding to Phase III Budget Period 2 of the project, and DOE has accepted Sunflower's withdrawal position. The project is now in closeout. A final report has been received and approved. (Garden City, KS)

Universal Aggregates, LLC – *Commercial Demonstration of the Manufactured Aggregate Processing Technology Utilizing Spray Dryer Ash.* The project is in the operations phase. Universal Aggregates has successfully run the entire plant process including mixing, extrusion, curing, crushing, screening, and recycling screened fines. The plant has shipped finished product to its distributor on a limited basis. Design, fabrication, and installation of equipment modifications are ongoing in an effort to produce a consistent product using the spray dryer ash removed from the Birchwood Power Generation Facility. Universal Aggregates has requested and been granted a no-cost extension until December 31, 2006, to allow time to make those modifications and improvements intended to increase throughput capacity and extend the continuous run time of the plant. (King George, VA)

CONSOL Energy Inc. – *Greenidge Multi-Pollutant Control Project.* Construction of the integrated multi-pollutant control system at the coal-fired, AES Greenidge 107-MW Unit 4 in Dresden, NY, is under way. The project includes a unique "hybrid" non-catalytic (SNCR) and in-duct catalytic (SCR) system for NO_x reduction; a circulating dry scrubber for SO_2, SO_3, and acid gas reduction; activated carbon injection for mercury control; and a baghouse for particulate control. This combination of technologies will demonstrate advanced emissions control at a lower cost than traditional retrofits at a plant of this size and age. (Dresden, NY)

CCPI STATUS

MEC-I LLC (Excelsior Energy Inc.) – *Mesaba Energy Project.* Public scoping meetings were held on August 22–23, 2006 at Taconite and Hoyt Lakes, Minnesota concerning the preconstruction Joint Permit Application filed by Excelsior Energy with the Minnesota Public Utilities Commission (MPUC). The application includes requests for a large electric power generating plant site permit and routing permits for a high voltage transmission line and natural gas pipeline. Also attached to the filing were Excelsior's applications for air and water-related permits. The Environmental Impact Statement (EIS) is being jointly prepared by the Minnesota Department of Commerce and U.S. Department of Energy, with a draft expected to be available in December 2006. Excelsior has also filed a petition with the MPUC for approval of a 603-MWe Power Purchase Agreement with Northern States Power, as required by the Minnesota state Innovative Energy Project and Clean Energy Technology statutes. The Project Definition and Development phase runs through April 2008. (Itasca & St. Louis Counties, MN)

NeuCo, Inc. – *Integrated Optimization Software*. The project at Dynegy's Baldwin Energy Complex has completed the planned efforts in Budget Period 1 within budget and on schedule. The Combustion Optimization module achieved the NO_x reduction goal of 5 percent along with improvements in cyclone stability. NeuCo has shown that by using their SCR Optimization module, they are reducing ammonia consumption by 18 percent. NeuCo has installed the Sootblowing Optimization module on two separate units, with and without an intelligent sootblowing control system. This dual approach allows NeuCo to address a wide range of sootblowing issues. An initial draft of user documentation for the CombustionOpt system on Unit 1 has been issued. The PerformanceOpt model has been running smoothly on both Unit 1 and Unit 2. (Baldwin, IL)

University of Kentucky Research Foundation – *Advanced Multi-Product Coal Utilization By-Product Processing Plant.* UK's Center for Applied Energy Research (CAER) has evaluated four equipment configurations and corresponding ash by-products in the field tests conducted at the 2,200-MW Ghent Generating Station. Secondary classification of the primary classification overflow was effective for producing an ultra-fine ash product (smaller than 5 μm). The ultra fine ash, produced using lamella

plates for settling the coarser particles, finds application as a high performance additive in concrete preparation and as a polymeric filler. Use of ultra fine ash would provide increased resistance in situations where concrete is exposed to chloride compounds, such as salt. Tests also were performed by varying the ultra fine ash substitution levels in concrete. These tests showed that although higher substitution levels delay early strength development, the control strength was surpassed after 28 days. In mortar tests, when ash byproducts were used to replace 20% cement, up to 7% less water was required to retain the mortar flow properties of the control material. Reducing the water content increases the mortar strength. The reduced water requirement was attributed to smaller particle size of the ash by-products. The various tests conducted demonstrate superior properties of selectively prepared ash by-products compared to the starting material, *i.e.*, pond ash. (Ghent, Carroll County, KY)

We Energies – *TOXECON™ Retrofit for Mercury and Multi-Pollutant Control.* Project operation began in January 2006 when activated carbon was injected into the flue gas stream. Baseline testing was performed to characterize the flue gas. Parametric testing to establish a correlation between activated carbon injection was initiated in February 2006. Initial mercury control results were promising, but further testing was delayed when hot glowing embers were found in all the baghouse hoppers. Several hundred bags were damaged and had to be replaced. The ongoing investigation has revealed that powdered activated carbon (PAC) will glow-smolder and eventually spontaneous combustion will occur if the PAC-ash mixture generates heat faster than it can be liberated. Guidelines that include additional temperature monitoring, lower hopper heater temperature controls, and more frequent hopper discharge rates were developed. Particulate removal baghouse operation without PAC injection resumed in June. PAC injection and mercury control parametric testing resumed in August. The TOXECON™ project has continued to successfully demonstrate, under full scale power plant conditions, reliable mercury continuous emission monitors (CEM). (Marquette, MI)

Western Greenbrier Co-Generation, LLC – *Western Greenbrier Co-Production (WGC) Demonstration Project.* WGC continues to work to develop key project areas including the waste coal resource plan, coal upgrading processes, and arrangements for sale of power to support a public tax-exempt bond sale to fund the project. The preliminary process design is completed. The project received its air permit from the State of West Virginia, and a Draft Environmental Impact Statement is expected in early September 2006. Transmission and interconnection agreements are expected to be finalized in late September 2006. WGC has requested a six month extension of the cooperative agreement until the end of April 2007 to complete their Phase 1 milestones, particularly with respect to project financing and bond sales. (Rainelle, WV)

Great River Energy (GRE) – *Lignite Fuel Enhancement.* In Budget Period 1, GRE has successfully designed, constructed, and demonstrated the first coal dryer at the Coal Creek Station. More than 100,000 tons of lignite coal was processed reducing the moisture from about 38.5% to 29.5%. Early estimates show that with just one pulverizer using dried coal, the stack flow rate from the Coal Creek unit decreased 1 percent, boiler efficiency increased 0.3 percentage points, pulverizer power consumption decreased 4.5 percent, sulfur oxide emissions fell 2.0 percent, nitrogen oxide emissions decreased 8.5 percent, and carbon dioxide emissions decreased 0.34 percent. GRE will be continuing the demonstration tests to obtain additional operating and performance data for a 546-MW unit. Overall, the first dryer operation and performance have been satisfactory. From September 1, 2006, GRE will be proceeding to Budget Period 2 to design and construct two commercial dryers, which will supply 50% of the coal needed for the 546-MW unit. (Underwood, ND)

Pegasus Technologies – *Mercury Specie and Multi-Pollutant Control.* Since the cooperative agreement was signed in April 2006, work has progressed on installation of sensors and other neural-network data acquisition and control software and hardware. The project will demonstrate non-intrusive advanced sensors and neural network-based optimization and control technologies for enhanced mercury and multi-pollutant control on an 890-MW tangentially fired boiler at the project host site in Jewitt, Texas. The $15.6M project is 38 months in duration with DOE cost share at 39% ($6.1M). The Pegasus technology provides plant operators the ability to assess detailed plant operating parameters which affect mercury capture efficiency as well as overall heat rate, and particulate removal and flue gas desulfurization efficiencies. The technology, once demonstrated, should have broad application to existing coal fired boilers and provide positive impact on the quality of saleable by-products such as fly ash. Performance testing will begin in October 2008. (Jewett, TX and Cardon, OH)

Southern Company Services, Inc. – *Demonstration of a 285-MW Coal-Based Transport Gasifier.* The Draft EIS has been issued and is currently available for public comment. The public hearing on the draft EIS is scheduled for September 13, 2006. Work is continuing on preparing the comprehensive Front End Engineering Design (FEED) package. By preparing a FEED package prior to detailed design, any process issues can be identified and resolved. This approach results in reduced engineering and construction costs, more effective project controls, and a plant with fewer start-up issues to resolve. (Orlando, FL)

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