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CLEAN COAL TODAY

A Newsletter about Innovative Technologies for Coal Utilization

News Bytes

The **U.S. Department of Energy FY 2006 budget request for $23.4 billion allocates $759.9 million for fossil energy activities**. Included is $286 million for the President's Coal Research Initiative, $50 million for clean coal demonstration projects, and $18 million for FutureGen, the world's first near-zero emissions hydrogen and electricity producing power plant. For details see: www.fe.doe.gov/news/techlines/2005/.

In mid-December 2004, **Universal Aggregates achieved a significant milestone in their Power Plant Improvement Initiative project**. Lightweight aggregate manufactured

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First Annual Sequestration Regional Partnership Meeting

The First Annual Meeting of the Carbon Sequestration Regional Partnerships was held in November 2004, in Pittsburgh, Pennsylvania, and reported significant progress since the U.S. Department of Energy (DOE) made the Phase I awards in September of 2003. The DOE Regional Carbon Sequestration Partnership Initiative is a network of 7 Partnerships that include 40 states, 4 Canadian provinces, 3 Indian Nations, and 244 organizations. Stakeholders come from government, the research community, industry, and academia, and are dedicated to developing the infrastructure and validating carbon sequestration technologies to mitigate carbon dioxide emissions, an important greenhouse gas. The Partnerships provide a critical link to the Administration's plans for FutureGen, an advanced coal-fired power plant that will produce both hydrogen and electricity, with near-zero emissions. Wide-scale deployment of FutureGen technology will depend on regulatory, infrastructure, and site-specific information derived from the Regional Partnerships.

Scott Klara, Technology Manager of the NETL Carbon Sequestration Program, delivers closing remarks on the first day

At the meeting, representatives of the seven Partnerships described efforts to date and noted that they are poised to move into Phase II field demonstrations if selected by DOE in September. The Phase I work has focused on identifying sources, sinks, and existing infrastructure; developing Geographic Information Systems (GIS); addressing regulatory compliance and environmental risks; identifying promising technologies and measuring, monitoring, and verification (MMV) protocols; and engaging in a dialogue with the public. The Interstate Oil and Gas Compact Commission spoke of its effort to evaluate the regulatory framework for geologic sequestration, and the Kansas Geological Survey provided an update on the NATCARB GIS system.

Overall, the Partnerships saw the need for using GIS and databases to filter through extensive data to identify promising sequestration opportunities and

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"Partnerships" continued...

CO_2 transportation options. Working with NATCARB, the partnerships have been able to build upon and share common models to estimate storage, costs for building pipelines, and matching sources and sinks using geospatial tools. In some states, many older data sets on abandoned oil wells and fields existed only in paper form. The Partnerships have worked to transfer this information into electronic databases for further analysis.

REGIONAL EFFORTS

The West Coast Regional Carbon Sequestration Partnership (WESTCARB) is led by the California Energy Commission and represents the geographic region along the Pacific coast from California to British Columbia. WESTCARB is using its GIS to screen potential sites, and in the process has eliminated 74 of 101 potential basins in California. The GIS contains geologic details such as reservoir thickness, porosity, and lateral extent, including risk assessment criteria such as location of faults and potential seismic activity, as well as proximity to population centers. WESTCARB is considering several field demonstrations that would integrate advanced power systems or capture technology with sequestration and enhanced oil or gas recovery. An integrated terrestrial sequestration project also is being considered that would demonstrate reforestation, reduce risk of fire, and utilize biomass for power.

The Midwest Geological Sequestration Consortium (MGSC) is led by the University of Illinois and the Illinois State Geological Survey. The partnership is assessing the storage potential in coal beds, oil reservoirs, and saline formations, with particular attention to the Illinois Basin. A comprehensive assessment of CO_2 transportation options, both pipeline and truck/rail, was completed to determine the costs of CO_2 transportation in a hypothetical 200-mile geologic sequestration fairway. A specific fairway will be identified during the second half of the project using a GIS-based decision support model.

Two-day meeting featured presentations by Regional Partnership stakeholders

The Plains CO_2 Reduction Partnership (PCOR) is led by the University of North Dakota - Energy & Environmental Research Center, and includes nine states and three Canadian Provinces. The Canadian Provinces offer significant opportunities for enhanced oil recovery coupled with CO_2 storage. The PCOR demonstrated that several formations in the region have enough capacity to accept CO_2 for storage over a several hundred year period. The PCOR also sees potential for terrestrial carbon sequestration in wetlands. Ducks Unlimited and the U.S. Geological Survey have determined that wetlands in the region have the potential to sequester up to 375 million metric tons over 10 years, while also offsetting emissions of methane and nitrous oxides. Compared to agricultural lands, wetlands can store significantly more carbon dioxide per hectare.

The Southwest Regional Partnership for Carbon Sequestration is led by the New Mexico Institute of Mining and Technology. Data from thousands of oil and gas fields have been merged into a single database. The Gas Information System (GASIS) database platform was modified to accommodate additional information, and saline aquifers and CO_2 sources. The Partnership is completing an Integrated Assessment model that will evaluate scenarios for varying sequestration technologies and storage sites; regional economic and energy conditions; and effects of time frames for sequestration. The model ultimately will support candidate site and technology selections and help in providing public outreach and education. The Southwest Partnership features several sequestration opportunities that

include EOR and deep saline options. These validation projects could be coupled with separation/capture technology while taking advantage of the extensive pipeline infrastructure in the region.

Midwest Regional Carbon Sequestration Partnership (MRCSP), led by Battelle Memorial Institute, represents an area that generates over 21 percent of the United States' energy, mostly from fossil fuels. The MRCSP has an abundance of deep saline formations, oil and gas fields (active and depleted), coal seams, and organic shale. These sites have the potential to store several gigatons of CO_2. Many of the major CO_2 sources in the region are located over potential storage reservoirs. Terrestrial sequestration in agriculture and forestry sites has the potential to offset up to 20 percent of the region's CO_2 emissions. The MRCSP Website demonstrates the Partnership's commitment to public awareness and participation.

The Big Sky Regional Carbon Sequestration Partnership, led by Montana State University, has created a GIS out of thousands of well logs and hundreds of oil records. For geologic sequestration, the review has focused on the potential of mafic volcanic rocks to permanently sequester CO_2 in the form of mineral carbonates. A mineralization rate model developed to determine the fate of CO_2 injected into these formations shows that, after 150 years, mineralization dominates storage. During the coming year, a GIS will be used to identify candidate sites for field validation projects. Terrestrial sequestration accounting tools are being developed for both forestry and agriculture. These include user-friendly models to determine baseline carbon values and predict storage potential. The tools also provide methods for measuring and verifying carbon credits — including modeling, actual soil sampling, and third-party verification of land management compliance. It is expected that these guidelines will be rigorous enough for future carbon markets in the United States.

The Southeast Regional Carbon Sequestration Partnership (SECARB) is led by the Southern States Energy Board. Point sources in the region emit over 700 MMTCE of CO_2 each year. Opportunities for sequestration exist in a variety of oil, gas, and coal fields, and brine formations exist. Some specific areas of interest to SECARB are sequestration coupled with enhanced coal bed methane in the Warrior Basin, brine aquifer storage in the Southern Cincinnati Arch, and enhanced oil recovery in the Gulf Oil reservoir. Reforestation of agricultural lands for both carbon sequestration and use as a bio-energy feedstock also has potential in the region.

From the first annual meeting, it was evident that the Partnerships have made great strides in identifying potential validation sites for sequestration. The variety and distribution of energy resources, CO_2 sources, and potential sinks also is clearly shown in the options proposed as field validation projects for Phase II. To learn more about the Regional Carbon Sequestration Partnership Initiative, visit the website (http://www.netl.doe.gov/coal) and click on carbon sequestration, regional partnerships.

UPCOMING EVENTS

April 13, 2005
2005 Conference on Unburned Carbon in Utility Fly Ash
Location: Lexington, KY
Sponsor: NETL
Contact: Kimberly Yavorsky
Kimberly.yavorsky@netl.doe.gov
Phone: 412-386-4604

April 17–21, 2005
The Clearwater Conference – The 30th Annual Technical Conference on Coal Utilization & Fuel Systems
Location: Clearwater, Florida
Presented by: DOE, Coal Technology Association, and American Society of Mechanical Engineers, with NETL
Contact: Barbara A. Sakkestad
BarbaraSak@aol.com
Phone: 301-294-6080

April 18–21, 2005
Sixth Annual SECA Workshop
Location: Pacific Grove, CA
Sponsor: NETL
Contact: Karen Lockhart
karen.lockhart@sa.netl.doe.gov
Phone: 412-386-4763

May 2–5, 2005
Fourth Annual Conference on Carbon Capture & Sequestration
Location: Alexandria, VA
Sponsors: DOE, NETL, Exchange Monitor Publications, USDA, U.S. Climate Change Science Program, and EPA
Contact: Jose Figueroa
Phone: 412-386-4966

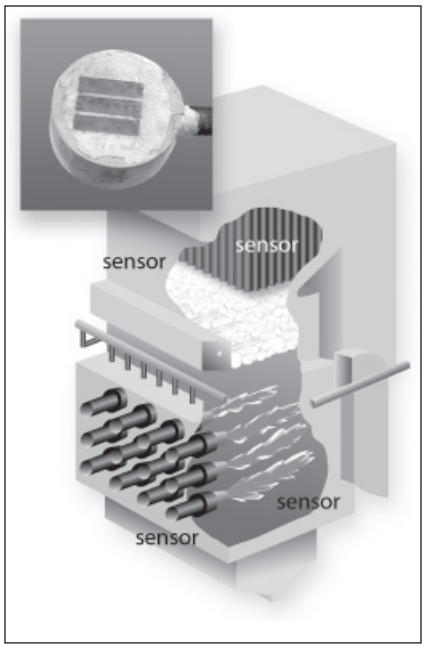
May 10–12, 2005
Second Int'l Conf. on Clean Coal Technologies for the Future
Location: Sardinia, Italy
Sponsors: SOTOCARBO, IEA Clean Coal Centre, DOE, Assessorato all'Industria Regione Autonoma della Sardegna
Contact: Eugenio d'Ercole
(info@cct2205it)

MATERIALS RESEARCH AT ALBANY RESEARCH CENTER

The Albany Research Center (ARC), a government owned and operated Office of Fossil Energy (FE) materials R&D Laboratory, has been focusing on key materials research in order to improve service life for the components of advanced clean coal plants. ARC was first established in 1942 and was part of the U.S. Bureau of Mines, earning global recognition for expertise in materials development, wear, and corrosion, as well as melting and casting. Since closure of the Bureau in 1995, ARC has been providing its unique materials competencies to FE.

SENSING CORROSION PRESENT UNDER ASH DEPOSITS

Corrosion is a key factor limiting the service life of materials. ARC researchers are investigating sensors to monitor the corrosion of key power plant components, with a view to incorporating sensors as an essential part of new and existing fossil energy plants. Corrosion-resistant materials (and corrosion-detecting sensors) for key components, such as waterwalls and superheaters, are critical for existing power plants and even more so for supercritical and ultrasupercritical power plants. ARC plans to enable monitoring every seven minutes using commercially available technology that is being validated and further developed for specific applications.



High-temperature electrochemical corrosion rate sensor and proposed sensor location in a coal-fired boiler

Power plants of the future will need to be as completely instrumented as possible in order to fully control all processes and maximize efficiency while reducing environmental impacts. Corrosion sensors could detect the onset of corrosion and reduce downtime. The sensors are planned to be used as a process determinant for power plant operators who would then be able to control corrosion rates of key components by varying the coal feed rate, composition, or temperature. For example, accumulated metal wastage data could be used to cost-effectively schedule downtimes. Low costs of electricity could be maintained by extending the time required between replacing key components and reducing the need for excessive or unscheduled downtimes.

ARC is taking an approach that focuses on an electrochemical-based sensor, while the other leading design of a corrosion sensor for this type of application is based on electrical resistance. Validation and continued design of both types of sensors are the primary focuses of boiler corrosion work being carried out by the United States as part of the U.S.-UK Collaboration on Energy R&D, an effort begun in 2004, in which ARC collaborates. Other participants in the U.S.-UK research include Alstom Power, Covanta Energy, InterCorr International, Reaction Engineering, Tennessee Valley Authority, University of Alabama at Birmingham, Cranfield University, Mitsui Babcock, The National Physical Laboratory, and RWE Innogy.

Research on corrosion sensors based on electrochemistry has thus far produced positive results. In some cases, sensors have accurately shown equipment corrosion rates, or corrosion rates that could be calibrated based on some factor of the actual corrosion rate. Research to be conducted this year will test the sensors in a wider range of environments such as more complex gas mixtures (including sulfur dioxide and hydrochloric acid) and ash from varying coal types. Upon research completion, field tests will be conducted.

DOE also has funded parallel sensor R&D outside the power generation industry. A project funded by the National Energy Technology Laboratory demonstrated that corrosion sensor technology could be used successfully to monitor both internal and external corrosion in gas pipeline environments. The Oregon Department of Transportation has also funded a project using the same technology coupled with cathodic protection to control the corrosion of a steel-reinforced concrete bridge. All three efforts are contributing to critical aspects of the safety and security of the U.S. energy, pipeline, and transportation infrastructure.

IMPROVING REFRACTORIES FOR COAL GASIFIERS

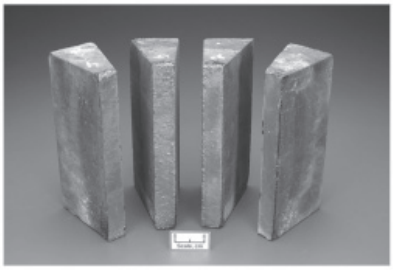
Gasifiers, as part of an Integrated Gasification Combined-Cycle (IGCC) system, are crucial to the success of the FutureGen zero-emission fossil fuel plant of the future. Severe slag attack of high temperature materials that line coal gasifiers, used in the production of chemicals, liquid fuels, and/or electricity, makes them unacceptably short lived. The refractory liners for IGCC gasifiers can require replacement in as little as three months, and usually last no longer than 24 months. Lengthening this short service life to increase gasifier reliability and increase on-line availability is viewed as critical for greater technology acceptance and utilization. ARC is focusing on identifying the failure mechanisms of high-chrome oxide refractories used to line gasifiers in order to develop an improved refractory with a lifetime increase of at least 50 percent.

A phosphate-containing, high-chrome oxide refractory has been developed by the ARC and scaled up for plant trials by an industrial producer of refractories. Tests of the physical and thermal properties of the ARC-developed refractory indicate comparable, or in many cases superior, properties when compared to several commercially available high-chromium oxide refractory materials.

As a result of these laboratory tests, the ARC-developed refractory has been installed in a test panel for placement in a commercial coal gasifier. A field test began at Eastman Chemical Company in late 2003. Initial observations of this refractory indicate improved service, although the test duration was too short to evaluate long-term performance. Because of this preliminary test, longer and expanded testing is under way at Eastman, as well as with Conoco Phillips Company. Results from these and other field tests should lead to the production of longer-life, commercially available refractories.

ARC continues to conduct research that is vital to the success of many FE programs and objectives. These research activities are providing information on performance characteristics of materials that are required for the current generation of power systems, and will be used to develop cost-effective materials for inclusion in future clean energy systems. ARC research also continues to provide solutions to environmental emission problems related to fossil-fired energy systems.

Conventional refractory after rotary slag testing.



Phosphate modified high-chrome oxide refractory material developed at ARC after rotary slag testing.

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with spray dryer ash from the adjacent Birchwood Power Station was shipped for the first time to a concrete block material distributor. The plant operation was fully integrated, and embedding material and screened fines were recycled back into the process input silos. The initial shipments consisted of a combination of manufactured lightweight aggregate and Solite startup aggregate that was initially loaded into the curing vessel.

Tampa Electric Company has successfully completed the **PPII-funded *Neural Network Sootblower Optimization Project*** at its 445-MW coal-fired unit at Big Bend Station, Apollo Beach, Florida. The sootblowing system, which monitors soot buildup in real time, is the subject of a recent invention disclosure by Pegasus Technologies. Results show that boiler efficiency can be increased by 0.5–1 percent, and NO_x levels reduced by 10–20 percent by integrating the new technology with state-of-the-art sootblower controls.

Great River Energy has successfully completed a prototype dryer design for the Lignite Fuel Enhancement Project, only six months after receiving an award under the Clean Coal Power Initiative, Round I (see article page 6). Cooperating in the effort are Barr Engineering Company of Minneapolis, and Heyl & Patterson of Pittsburgh, Pennsylvania. The dryer, a two-stage fluidized-bed design, reduces lignite coal moisture by 10 percent and utilizes low-temperature waste heat.

NEW PROJECTS JOIN CCPI

Since the summer of 2004, three new projects have been added to the U.S. Department of Energy's Clean Coal Power Initiative (CCPI) program. These projects expanded the program's technology portfolio to include important work in coal by-product and waste pile utilization, as well as the use of lower-heating-value coals. The first two CCPI projects awarded (see Summer 2004 *Clean Coal Today*) investigate integrated pollution controls and innovative power plant optimization software. All five projects were selected under Round 1 of the CCPI, which was intended to foster technologies offering improved efficiency, economics, and environmental advantages over existing state-of-the-art methods.

NEXT-GENERATION BY-PRODUCT TECHNOLOGY

The most recent project, with a cooperative agreement signed in November 2004, is the **UKRF Advanced Multi-Product Coal Utilization By-Product Processing Plant**, in Ghent, Kentucky. In this project, the University of Kentucky Research Foundation, in partnership with CEMEX USA and Kentucky Utilities, will demonstrate an advanced coal-ash beneficiation processing plant to treat waste pond ash from the 2,200-MW Ghent Power Plant. The plant represents the next-generation of coal utilization by-product beneficiation in that it extends processing capability to the entire coal utilization by-product stream. DOE is providing about $4.5 million of the $9 million cost for the 4-year project.

The plant utilizes hydraulic classification and froth flotation technology developed at the UKy Center for Applied Energy Research, and will produce several high-quality marketable products. The technology also has the capability to process ash directly from the power station. The primary product is pozzolan, a material that can be used to replace up to 30 percent of the Portland cement in mixes, while achieving superior strength and performance characteristics. Portland cement is the cementitious material that, when combined with water, forms a paste to flow over and coat both coarse and fine aggregate, which then hardens into concrete. The use of pozzolan in mixes also will result in a reduction in CO_2 emissions due to a decrease in the use of conventional cement manufacturing processes. In fact, one ton of CO_2 is released per ton of Portland cement produced.

The plant also will produce lightweight aggregate suitable for use in concrete masonry blocks, or as graded fill sand for construction applications. A uniform and very fine-sized material (~ 3 to 4 μm median particle sizes) will be produced, suitable for use as a polymer filler for plastics or for specialized pozzolan. Unburned carbon product will be concentrated for use as a supplemental fuel.

Since November 2004, an assessment of the ash pond at Ghent Power Station has been completed, including a statistical core sampling, analysis and characterization, and iso-grade mapping of the pond. Initial product testing has begun at CEMEX, the commercialization partner.

Overall, the project is expected to result in fewer new ash storage ponds, since harvesting of pond ash extends the useful life of existing ponds. Nationwide, preliminary information suggests the pozzolan market could sustain 6–7 plants somewhat larger than the Ghent demonstration.

ECO-PARK ANCHOR TENANT

Another project is the **Western Greenbrier Co-Production Demonstration Project**, an 85- to 90-MW clean coal co-production facility planned for Rainelle, West Virginia. The Western Greenbrier Co-Generation, LLC, is a newly formed public service entity serving three municipalities (Rainelle, Rupert, and Quinwood) in Greenbrier County, West Virginia. The grassroots nature of the project, and the prospect of providing an initial 100 long-term jobs, have given rise to considerable community support. The project will utilize waste coal from local waste refuse piles — a source of considerable environmental degradation — as a fuel source and will turn new power plant ash into cement substitutes or structural bricks (Woodbrik™). Fly ash also will be returned to the waste coal refuse sites to neutralize acid runoff, thereby enhancing land restoration, returning it to productive use. The novel power plant is envisioned as the "anchor tenant" in a new environmentally balanced industrial park.

The project brings together a highly qualified team, including Parsons E&C, Hazen Research, and Alstom Power. Parsons will serve as the turnkey systems contractor for the municipalities involved, and Alstom will provide an innovative circulating fluidized-bed (CFB) boiler system incorporating an advanced inverted

cyclone for capture and recirculation of solids. Because of its configuration, the design decreases the boiler footprint by 40 percent. Construction time and costs would also be reduced compared to existing CFB systems. A state-of-the-art multipollutant control system for SO_x, NO_x, particulate, and mercury emissions would be included.

Successful demonstration at Greenbrier has the potential to be replicated — with vast regional impacts. The project, and successor plants, could eliminate nearly 400 million tons of waste coal refuse at several West Virginia sites. That refuse carries an estimated cleanup cost of $2–3 billion and is considered to be West Virginia's premiere environmental hazard. Similar waste piles in the Eastern U.S. also could be candidates for application of the technology.

Great River Energy's Coal Creek Station, Underwood, North Dakota

Conceptual design of a majority of Greenbrier's facility subsystems was completed in February 2005, and construction is expected to begin in 2006. The DOE role is to end in 2009. DOE is providing over $107 million, or 50 percent of total costs.

LIGNITE FUEL ENHANCEMENT

A third CCPI project, successfully negotiated last summer, is **Great River Energy's Power Plant Efficiency – Lignite Fuel Enhancement Project.** Great River Energy (GRE), the prime participant, is collaborating with Barr Engineering Company, Heyl & Peterson, Falkirk Mining, and Couteau Properties, as well as EPRI, to demonstrate moisture reduction of lignite coal, thereby increasing its value — and that of other high-moisture coals — as a fuel in power plants. The project will be conducted at one of the two 546-MW units at GRE's Coal Creek Station in Underwood, North Dakota and will demonstrate the use of plant waste heat from the power plant condenser to lower moisture content in lignite coal from 40 percent to 30 percent. This moisture reduction translates into a power plant efficiency improvement of 3–5 percent, due to improved heating value of the coal. Since less coal is required to produce the same amount of electricity, SO_2 emissions at Coal Creek Station could be reduced by 25 percent, and emissions of NO_x, carbon dioxide and ash by seven percent. The drying process could also be modified to remove and capture mercury-containing waste coal. Installation of the dryers could save the 546-MW unit $3 million in annual operating costs due to higher availability, lower maintenance costs, lower parasitic power, and reduced ductwork erosion.

A full-scale prototype dryer module, now under construction, is designed to supply one-sixth of the dry coal required by a unit at Coal Creek. Following successful demonstration of the prototype, GRE will carry out full-scale, long-term operational testing on a complete set of dryer modules needed to produce the feedstock for full power operation of the 546-MW unit.

Participants include Barr Engineering Company, providing engineering design and specifications; Heyl & Patterson, performing dryer design and construction; EPRI, conducting a technology selection and fleet extendibility study; and Falkirk Mining and Couteau Properties, providing lignite coal.

Currently, coals with high moisture content are used in approximately 100 GW of installed capacity in the United States, indicating a large potential nationwide benefit should the application of the new drying method become widespread. According to a DOE study, economic benefits of $84 million could be realized if the process were applied to all U.S. lignite-fired facilities, and $840 million if applied to all Powder River Basin (also high-moisture) coal-fired units. DOE is providing $11 million, some 43 percent of total project costs. The project is expected to be completed in 2008.

For more information on these and other CCPI projects, consult the CCPI Website at: www.netl.doe.gov/coal/CCPI/index.html/. Negotiations also are under way to finalize cooperative agreements under Round 2 of the CCPI.

COMPUTATIONAL METHODS FOR HYDROGEN MEMBRANES

The Administration's Hydrogen Fuel Initiative recognizes that a number of technical barriers must be resolved before large-scale, cost-effective production of hydrogen can occur to move the nation toward a hydrogen economy. To address those barriers, the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) and Carnegie University (CMU) are collaborating in a research effort to apply a combination of computational and experimental methods to produce hydrogen.

DOE is developing a suite of technologies to produce hydrogen from sources such as fossil fuels, water, or renewable energy sources at a reduced cost of production — one of hydrogen's major barriers. Hydrogen, unlike gasoline and natural gas, has no large-scale supportive infrastructure, and building one would be tremendously costly. Although chemical and refining industries commercially use hydrogen production, storage, and delivery technologies, existing facilities and conversion technologies still remain too uneconomical for widespread use in energy applications.

One promising method for hydrogen production is hydrogen gas separation. DOE has focused on testing a variety of hydrogen separation membranes to cost-effectively remove hydrogen from mixed gas streams, while eliminating the impurities in the resulting hydrogen product.

A mounted 3/4-inch diameter Pd-Cu alloy membrane for hydrogen separation

Researchers at NETL have had recent success with a new hydrogen membrane material made of a palladium and copper (Pd-Cu) alloy. The studies to date have demonstrated the membrane's ability to allow pure hydrogen to pass through without the membrane becoming contaminated by other gas impurities during the separation process, such as hydrogen sulfide.

NETL and CMU are collaborating on improved methods to develop optimum compositions of membranes. They have devised a process to use advanced computing techniques, coupled with ongoing laboratory experiments, to predict which compositions might contain the most effective properties.

Both NETL (through its fuels and gasification activities) and CMU have long histories in conducting computational modeling studies. NETL, in fact, has a focus area of Computational and Basic Sciences. A major thrust of the focus area is application of advanced simulation techniques to facilitate cleaner, more efficient energy processes. In the membrane area, by adding the predictive capability of computation to laboratory experiments, NETL and CMU researchers have developed an effective method for screening complex alloys. Instead of having to produce a large suite of alloys and test all of them, researchers were able to predict in advance which alloys were better suited for membranes.

The specific approach of the research team has been to compare model predictions with extensive experimental measurements to assess hydrogen permeation through the Pd-Cu alloy. The predictive model describes the flux of hydrogen through the flat disc Pd-Cu membrane, while studying alloy composition, temperature, and pressure; surface chemistry; and resistance to sulfur impurities. By comparing models with laboratory findings, researchers have been able to validate their findings. Data from the studies also can lead to development of other alloys to serve as hydrogen membranes.

The development of high-flux membranes that can resist contamination represents a major step forward in manufacturing pure hydrogen in a cost-effective manner. Validating results through a combination of computational and experimental methods reduces costs associated with identifying the most effective membranes. A hydrogen economy of the future would find its place in the transportation sector, including emission-free hydrogen-driven cars; central power stations; and distributed power generation. The end result could be a decrease in reliance on imported fuels concurrent with virtually no pollutant emissions or greenhouse gases.

LOW NO_x FROM IGCC TURBINES

The U.S. Department of Energy (DOE) and industry have worked for many years to develop the concept of integrating coal gasification with clean, efficient gas and steam turbines to create Integrated Gasification Combined-Cycle (IGCC) power plants. This development program, the DOE Fossil Energy (FE) Turbine Program, has been sparked by the need for more efficient and lower cost coal-based power generation with near-zero (< 3 ppm) emissions of oxides of nitrogen (NO_x). In addition to cost effective power generation, the synthesis gas produced by coal-based IGCC power systems makes hydrogen production possible for use in fuel cell systems, providing additional efficiency improvements and emissions reduction. Ultimately, the DOE goal is to enable the use of hydrogen in large frame gas turbines and FutureGen-type applications.

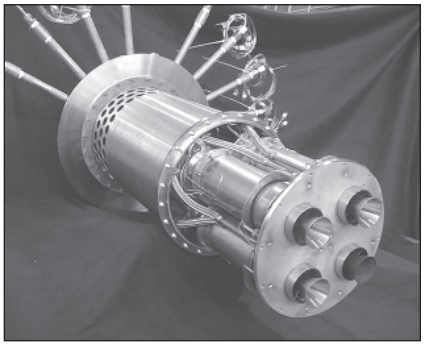
More specifically, the DOE Turbine and Gasification programs have the goal of providing a commercial design for a coal-based power system at 45–50 percent efficiency (HHV) and a capital cost < $1,000/kW with near-zero emissions by 2010. There are several approaches to achieving this goal. One of the more promising approaches includes a new catalytic combustion technology that has been developed through the Small Business Innovation Research (SBIR) process by Precision Combustion, Inc. (PCI) and currently is being assessed and developed for large-scale commercial turbines applicable to IGCC processes.

Under contract to DOE, PCI is testing a new method of catalytically combusting coal-derived syngas fuel for ultra-low NO_x IGCC applications. PCI's catalytic combustion system is especially well-suited for these syngas fuels, since it is designed to operate robustly and with constant performance using a wide range of fuel types. The system offers the potential for breakthrough technology with coal-derived fuels, achieving ultra-low NO_x emissions as low as 0.01 lbs/MMBtu, and equivalent to <3 ppmv @ 15 percent O_2.

PCI initially developed its catalytic combustor technology for natural gas fuel under DOE's SBIR program, with both DOE and gas turbine manufacturer support. Natural-gas-fired tests at large frame turbine conditions have demonstrated the robustness of the technology, as well as stable combustion with NO_x emissions as low as 2 ppm and low combustion dynamics. Engine tests in a modified industrial engine, using the cluster of four catalyst modules, were equally successful (see photo). The present project is directed toward adapting and moving the pictured natural gas technology toward a similar level of development for syngas fuels.

Tests to date have shown excellent results. For simulated Tampa Electric syngas fuel, catalyst lightoff temperature is below 200 °C. Thus, no preburner is required to activate the catalyst, since combustor inlet temperatures are greater than these values across the entire engine load range. Following lightoff, catalyst temperatures for syngas operation are similar to those for natural gas. Thus, PCI's basic catalytic reactor design is applicable to syngas operation, with design changes for syngas fuel being primarily directed toward handling of high-volume syngas flows, mixing of high-hydrogen content fuels, and minimizing NO_x emissions during final combustion downstream of the catalyst. On this basis, a sub-scale syngas catalytic reactor was designed and fabricated, and tested in PCI's mid-pressure (10 atm) combustion rig. The heat release from the catalyst stage provides flame stability to the downstream gas-phase combustion stage, allowing stable combustion of very low-Btu fuels (< 90 Btu/SCF successfully tested to date).

Emissions performance for a simulated Tampa Electric syngas fuel from sub-scale mid-pressure testing at PCI have produced favorable results. At



Set of PCI's Rich-Catalytic Lean-burn (RCL®) injectors tested in a modified industrial engine with natural gas fuel

10 atm pressure baseline NO_x emissions were 0.011 lbs/MMBtu (corresponding to 2.0 ppm NO_x corrected to 15 percent O_2 dry) with near-zero CO emissions. These "baseline" emissions levels were achieved at scaled (10 atm, sub-scale) conditions corresponding to Tampa Electric's Polk Power Station base load operation on 100 percent syngas (no co-firing of natural gas). CO emissions remained near zero for flame temperatures as low as 2,250 °F, providing a wide 300 °F turndown from the 2,550 °F baseline operating condition.

With a successful sub-scale demonstration of emissions performance

in hand, the project will now continue with technology evaluation and development directed toward meeting commercial requirements for IGCC applications, and toward full-scale demonstration in partnership with an OEM gas turbine manufacturer. This work will include evaluation of catalyst response to contaminants in syngas fuels, evaluation and development of materials and catalysts for syngas and hydrogen, design for syngas fuel handling and mixing, scale up, and testing.

Currently, Pratt & Whitney has completed Phase I design work to successfully demonstrate that the PCI-based concept could be implemented into a 25-MW engine. Siemens Westinghouse is progressing into a 22-month Phase II program. The goal of this work is to conduct the development, verification, and engineering testing to apply a PCI-like system into the 180-MW 501FD gas turbine. GE Power Systems is also working with PCI to assess deployment issues in large frame engines under coal-derived synthesis gas applications. Besides the IGCC application, it often goes unnoticed that this catalytic combustion technology has huge retrofit opportunities for large frame natural gas fueled turbines to reduce NO_x and CO emissions, and reduce combustion dynamics while eliminating the need for expensive power consuming selective catalytic reduction.

Through the PCI catalytic combustion technology, as well as other approaches, the Turbine Program is well along in efforts to meet performance goals for NO_x reduction. Meeting this goal will make coal-based IGCC power systems more marketable by offering the cleanest and potentially most cost effective way to utilize coal for power generation.

R&D MILESTONES

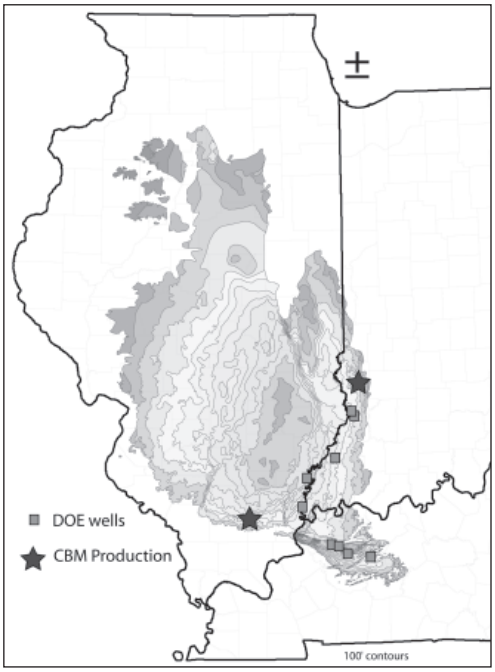
The North Dakota Energy and Environmental Research Center, under contract with NETL, has made advances in real time infrared thermography (IR), an effective non-invasive technique to detect deviations from normal thermal signatures of power plant equipment and components. The digital IR radiometer measures apparent surface temperatures and thermal gradients to detect conditions that impact heat and mass flows. Changes in temperature could be caused by insulation degradation, alloy failure, heat transfer line blockage (convective pass), or flow maldistribution. The thermal imaging allows development of optimal control system designs and operating parameters to improve power plant output and operating efficiency.

Using the H-class turbine technology developed by GE under the U.S. Department of Energy Advanced Turbine Systems Program, GE Energy and Calpine are to build the world's first power plant based on the 60-Hertz design. The new facility will be based on two GE 7H combined-cycle systems, and provide a total plant output of more than 775 megawatts. As a result of FE's R&D program, this new generation of advanced turbines will leapfrog existing technology and demonstrate 60 percent combined-cycle efficiency, together with the potential of NO_x emissions as low as 9 ppm. The first 50-hertz H system, a 9H combined cycle unit, operating in Wales, has compiled over 5,000 hours of successful operation. The new plant is expected to begin operating in the spring of 2008.

Researchers at NETL's high pressure test combustion facility, in collaboration with Ramgen Systems, have completed testing of a fuel-flexible Advanced Vortex Combustion (AVC) concept (see *Clean Coal Today* Spring 2002) that can achieve NO_x emissions of less than 3 ppmv, and combustion efficiencies of over 99 percent. The Advanced Vortex Combustor is dynamically stable over a wide range of operating conditions. This makes the approach significantly more attractive than other lean premixed combustion approaches. In addition, the pressure drop associated with this combustion approach is significantly lower than a conventional gas turbine combustor, which translates into an improvement in the overall cycle efficiency. The relatively high velocities and low pressure drops achievable with this technology make the AVC approach an attractive alternative for hydrogen fuel applications. The project is sponsored by the California Energy Commission's Public Interest Energy Research Group.

COALBED METHANE FORUM DISCUSSES DOE RESOURCE ASSESSMENT

Over 100 participants from industry and state organizations attended the First Annual Illinois Basin Coalbed Symposium, November 16–17, 2004, in Evansville, Indiana. The Symposium was sponsored by the Midwest Petroleum Technology Transfer Council, and the States of Kentucky, Illinois and Indiana. The results of a project entitled "Resource Assessment & Production Testing of Coalbed Methane Development in the Illinois Basin," sponsored by the U.S. Department of Energy (DOE), National Energy Technology Laboratory, were the subject of widespread discussion at the meetings. Participants heard detailed presentations by the three states and several industry groups who are successfully developing coalbed methane. New resource characterizations have replaced old data that indicated low, uneconomic coalbed methane resources. The new surveys, co-funded by DOE, the three states, and industry, are based on a more detailed geoscience assessment than has been done in the past. This assessment makes use of core data tested for gas content, gas chemistry and isotopes, and coal isotherms. The three-state coalbed methane resource is also located near major demand centers (Chicago, Indianapolis, Louisville, and St. Louis) creating a large potential energy market at a time when production of high-sulfur Illinois Basin coal has been declining.



The Illinois Basin Herrin coal structure, with wells drilled in the survey effort alongside current coalbed methane production areas (map courtesy of Illinois Geological Survey)

Nationwide, there are over 14,000 coalbed methane-producing wells, with a 2000 annual production of 1.35 trillion cubic feet (Tcf). New studies show the Illinois Basin to contain over 325 billion tons of remaining coal resources. The Illinois Basin is estimated to have a total 21 Tcf of in-place coalbed methane. The recoverable portion, according to the U.S. Geological Survey (USGS) 1995 National Assessment, is 2.77 Tcf. The 2002 assessment by the non-profit Potential Gas Committee puts the recoverable figure at 3.9 Tcf. As reported at the conference, the in-place Illinois coalbed methane resource is estimated at 15.8 Tcf; Indiana's resource is 3-5 Tcf, and Western Kentucky contains 2.9 Tcf.

Subsequent to release of the new survey data, industry has undertaken an aggressive development effort. Industry representatives gave details on their individual drilling projects, including new technologies for gas purification and compression. In particular, BPI, Inc. presented results of their Saline County, Illinois "Delta Project" involving a 50 well program, with 30 wells so far completed. In January 2005, there were 15 wells that produced the first sales of Illinois coal seam gas to the pipeline. BPI's other project, located in Sullivan County, Indiana, has nearly 30 wells delivering gas to market. Both projects will double or triple the number of wells in the next year. Other operators are evaluating multi-well projects in the eastern and southern sides of the Illinois Coal Field, where the coals are thick and vary from 300 to over 1,200 feet deep.

Industry drilling permits in the Illinois Basin have doubled in each of the past two years and look to double again as development of these initial fields takes place and newcomers join the effort.

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INTERNATIONAL INITIATIVES

FE PROVIDES TECHNICAL ASSISTANCE TOWARD "GREEN" CHINA OLYMPICS

As part of the U.S. China Beijing Energy Joint Working Group, the Office of Fossil Energy (FE) is providing technical assistance to China on fuel quality assurance with the view that U.S. operations practices applied to coal-fired heating plants can improve air quality in the Beijing region, which can assist in meeting the city's air quality goal prior to the 2008 Summer Olympics. These and other efforts — ranging from hydrogen and fuel cells, to combined heat and power, water quality and transportation — were discussed at the 3rd U.S.-China Joint Working Group Meeting under the framework of U.S.-China Green Olympic Cooperation. The Joint Working Group met at Argonne National Laboratory in Chicago, Illinois from November 30 through December 1, 2004.

FE co-funds the fuel quality assurance work through the U.S.-China Energy and Environmental Technology Center. Chinese participants include the China Coal Research Institute and the Beijing City Government. Beijing is modernizing its fuel use practices, which will include significant fuel switching and improvements in energy efficiency. Even with these measures, plans are to use over two million tons of coal per year in the Beijing heating sector. Overall, the Chinese heating sector will be using hundreds of millions of tons of coal per year. Some 80 percent of these heating systems are fired with stokers, a technology in which the United States has considerable experience. Over the past 80 years, in fact, the United States has refined operating parameters and come to understand the fuel quality needs of stoker plants. Through this project, FE is transferring these experiences to Chinese experts, for adaptation to China's situation.

After the Chicago meeting, delegates from the China Coal Research Institute met with Penn State Engineering Institute personnel to share insights on fuel quality management of stoker-fired heating plants and tour the Penn State Cogeneration plant, which operates four coal-fired vibrating grate stokers, fired with bituminous coal, in full compliance with applicable air quality standards. In the near future, FE will be working with Chinese participants in drafting a report on the U.S. stoker experience for the Beijing City Government.

FE-LED APEC GROUP HOLDS WORKSHOPS IN KOREA AND PHILIPPINES

In January 2005, the Energy Working Group of the Asia Pacific Economic Cooperation (APEC) sponsored two important workshops — a geologic sequestration training session in Seoul, Korea, and an Energy Technical and Policy Seminar in Cebu, the Philippines. The APEC Expert Group on Clean Fossil Energy, chaired by the National Energy Technology Laboratory's Scott Smouse, managed the two meetings for the Energy Working Group.

The two-day training workshop on geologic carbon sequestration was held in Seoul, January 20–21, 2005. The workshop followed the 1st International Symposium on CO_2 Reduction & Sequestration, which drew over 200 participants from around the region. The APEC training materials were developed and delivered by a team led by three Canadian participants — the Delhi Group with support from the Alberta Research Council, the GLOBE Foundation of Canada — and the Australian Cooperative Research Centre on CO_2 (CO2CRC). Over 100 Koreans from industry, government, academia, and non-governmental organizations attended the training. The training is part of an ongoing three-phase APEC project entitled "Carbon Dioxide Capture and Geological Sequestration Potential of the APEC Region." Phase I of the project, which is being conducted by the CO2CRC and is nearly complete, is developing a high-level inventory of sedimentary basins in the region that are located near large point sources of CO_2 emissions, and which have a large capacity to store CO_2. The Phase II training program was developed for use throughout the region to educate interested individuals and organizations on the potential to capture and store CO_2 from large fossil fuel-based energy facilities. A third phase of the project has recently been approved that will refine the Phase II materials, based on feedback from the Seoul workshop, and deliver the training materials in at least two additional APEC economies. Those interested in participating in or possibly hosting the future training workshops should contact Scott Smouse at scott.smouse@netl.doe.gov.

A second workshop, also in January, was held in the Philippines. As is the case with most of Asia, the Philippines plans to expand its use of fossil fuels, primarily coal, to generate affordable electricity. The country is interested in enhancing its energy security by continued development of its domestic coal and natural gas resources. This year's technical and policy gathering — "Meeting Today's Challenges to Supply Tomorrow's Energy" – enjoyed widespread sponsorship outside of DOE. Sponsors included: Japan's New Energy and Industrial Technology Development Organization (NEDO), the Japanese Committee for Pacific Coal Flow (JAPAC), the Philippines Department of Energy, the Philippine National Oil Company, Mirant Philippines, Toledo Power Company, Semirara Mining Corporation, and KEPCO Philippines Corporation. Philippines Undersecretary of Energy Cyril Del Callar gave the opening address, with Energy Secretary Vincent Perez making closing remarks. Over 200 attended the seminar, which featured two days of presentations on coal technology and policy, and one day on natural gas issues. Participants from around the region shared with the local audience their experience and knowledge of the latest technology developments and policy issues. Following the meetings, attendees visited the Toledo Power Plant, a small atmospheric fluidized-bed combustion plant that has been successfully operating since the 1980s. Seminar proceedings will be posted on the Expert Group's website at www.apec-egcfe.org. The next seminar will take place in Lampang, Thailand in December 2005, and will be sponsored by the Electricity Generating Authority of Thailand.

ACTIVE CCT DEMONSTRATION, PPII, AND CCPI PROJECT STATUS

CCT DEMONSTRATION STATUS

JEA – *ACFB Demonstration Project*. The four planned demonstration phase test burns, which began January 13, 2004, were completed on August 12, 2004. Fuels and fuel blends tested during the period included 100% Pittsburgh #8, a 50/50 blend of Pittsburgh #8 and petcoke, 100% Illinois #6, and a 80/20 blend of petcoke and Pittsburgh #8. The tests were conducted at 100, 80, 60, and 40 percent of full load. The three test report emissions were monitored at each load level and were well below permitted values. (Jacksonville, FL)

Kentucky Pioneer Energy (KPE), L.L.C. – *Kentucky Pioneer Energy Project*. The no-cost-to-DOE time extension for KPE and FuelCell Energy is scheduled to expire on March 31, 2005. (Trapp, KY and West Terre Haute, IN)

TIAX (formerly Arthur D. Little, Inc.) – *Clean Coal Diesel Project.* In July 2004, University of Alaska Fairbanks (UAF) decided to schedule the installation of a new transformer that would provide more flexibility for running the diesel engine generator at desired load points. Based on the schedule for these electrical interconnect upgrades, TIAX will conduct hard parts and selective catalytic reduction tests in mid 2005. TIAX is reviewing cost estimates for the design modifications to the baghouse at the Fairbanks Morse facility in Beloit, Wisconsin and will evaluate the options based on installation time and procedure. (Fairbanks, AK and Beloit, WI)

Western SynCoal LLC (formerly Rosebud SynCoal® Partnership) – *Advanced Coal Conversion Process (ACCP) Demonstration Project*. In January 2003, Westmoreland Power, Inc. transferred ownership of Western SynCoal LLC to ENPRO, of Butte, Montana. The Final Technical Report has been issued. (Butte, MT)

PPII STATUS

Otter Tail Power Company – *Demonstration of a Full-Scale Retrofit of the Advanced Hybrid Particulate Collector (AHPC) Technology*. The AHPC has been cleaning the full flow of gases from the power plant since October 2002. Otter Tail Power Company continues to operate the particulate control device and obtain superior particulate removal. However, superior particulate removal has been accompanied by greater operating costs due to increasing overall pressure drop or premature bag failure. Partial bag replacements have been occurring at 6-month intervals while bag life in the range of 5–7 years was expected. Compressed air used for filter bag pulsing has fluctuated considerably during the on and off peak operating hours. As power plant load through the unit has swung from an air-to-cloth ratio of about 11 during the day to about 9 at night, the compressed air usage rises to 2,000 acfm (A/C of 11) from nearly 0 (A/C of 9) or no pulsing. This seems to indicate that a sharp drop-off exists with respect to amount of filtration surface available for cleaning the flue gas verses pressure drop and need for filter bag pulsing. Current efforts to reduce the overall A/C ratio at full load from 11 to 8–9 by expanding the size of the AHPC should greatly improve the performance of the system. (Big Stone City, SD)

Sunflower Electric Power Corp. – *Demonstration of a 360-MWe Integrated Combustion Optimization System.* The combustion optimization sensors package is operational. Data are being archived on the MKE computer and by EtaPRO, which also collects plant performance data. The low-NO_x burner modifications and coal-balancing dampers have been installed. The coal-balancing dampers on Mill C are operating in automatic mode. The automated coal flow balancing system on Mill C is operational following resolution of a cable problem. Sunflower continues to evaluate the impacts of overfire air on furnace exit gas temperature. Despite slagging, the boiler continues to operate satisfactorily. Bid specifications currently are being developed for new burners and overfire air system, which constitutes Phase III of the project. (Garden City, KS)

Tampa Electric Company, Big Bend Power Station Tampa – *Neural Network Sootblower Optimization Project.* During 2004, the NN-ISB was successfully operated in closed loop mode without operator intervention. The project is now in the benefits demonstration phase. Test data to date has shown reduction in NO_x levels in the range of 10–20 percent and boiler efficiency improvements in the range of 0.5–1 percent. Successful application of this sootblowing system has developed significant technical information advancing neural network technology's acceptance within the electrical generating industry. In addition, Pegasus has made an invention disclosure as a result of testing/demonstration. (Apollo Beach, FL)

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 their distributor on a limited basis. Modifications and improvements have extended the continuous run time and increased the plant availability rate. The facility is now staffed 24/7 as efforts are made to adjust material additives and equipment configurations to produce a consistent product from the spray dryer ash removed from the Birchwood Power Generation Facility. The project is scheduled to be completed in May 2005. (King George, VA)

CCPI STATUS

NeuCo, Inc. – *Integrated Optimization Software*. The technical progress made in the first year of the four-year project is significant. Initial results of the combustion optimization showed stabilization of cyclone-fired combustor and SCR operations leading to enhanced slag control, and reduced stack NO_x emissions and ammonia slip at the host site of Baldwin Energy Complex. The Complex has three 600-MW Powder River Basin coal-fired boilers. (Baldwin, IL)

University of Kentucky Research Foundation – *Advanced Multi-Product Coal Utilization By-Product Processing Plant*. The Cooperative Agreement was signed in November 2004. The project is in the first budget period, Project Definition, which runs through May 2006. An assessment of the ash pond at Kentucky Utilities' 2,000-MW Ghent Power Station has been completed, including a statistical core sampling, analysis and characterization, and iso-grade mapping of the pond. Unit processing of fly ash, bottom ash and ultra-fine fly ash are ongoing, including evaluations of hydraulic classification, batch flotation, and pozzolan filtration. Initial product testing has begun at CEMEX, the commercialization partner. All work to date indicates that the ash materials in the pond are of very good quality and verifies that this is an excellent site to host the project plant. (Ghent, KY)

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

Western Greenbrier Co-Generation, LLC – *Western Greenbrier Co-Production (WGC) Demonstration Project*. The conceptual design for a 90-MWe (net) power-generating plant based on circulating fluidized-bed combustion was reviewed at a meeting in Morgantown, West Virginia in February 2005. After approximately nine months of Phase 1 – Project Definition, the WGC project team has evaluated a variety of options leading to definition of a baseline design for the project. Major project subsystems design bases, excluding the fuel handling and ash cooling systems, have been set. Preliminary specifications for major sub-systems including the FBC boiler system, the steam turbine generator, the stack, cooling tower, steam condenser, boiler feed water pumps, and circulating water pumps, have been developed for vendor discussions. Western Greenbrier Co-Gen has selected a plant configuration that optimizes performance, cost, and commercial viability. Plant design, construction, and operation will be led by Western Greenbrier Co-Generation, LLC, a for-profit organization owned by the municipalities of Rainelle, Rupert, and Quinwood, West Virginia. (Rainelle, WV)

Great River Energy (GRE) – *Lignite Fuel Enhancement*. GRE has successfully completed the design of the prototype dryer and associated auxiliary systems. Utilizing the pilot-scale database developed for various coals, including North Dakota lignite, GRE guided the prototype dryer design for a capacity of 75 tons per hour lignite feed, which is about one-sixth of the capacity required for one 546-MW unit at the Coal Creek Station, Underwood, ND. The dryer, a two stage fluidized-bed design with heating coils submerged in the bed, is designed to reduce lignite coal moisture by ten percentage points. The required design drawings and prototype dryer specifications have been developed and the dryer fabrication has been initiated. (Underwood, ND)

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