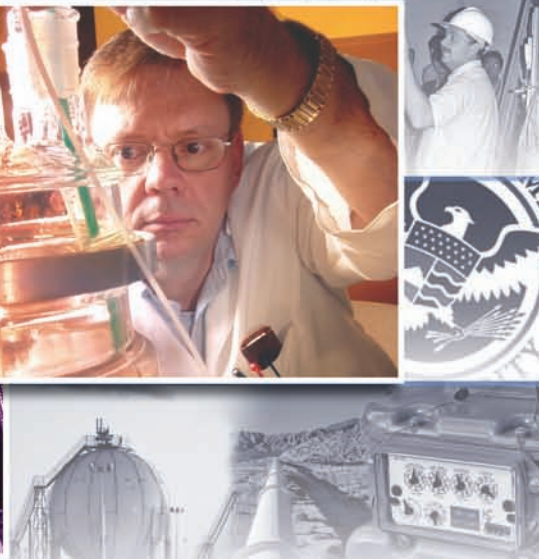
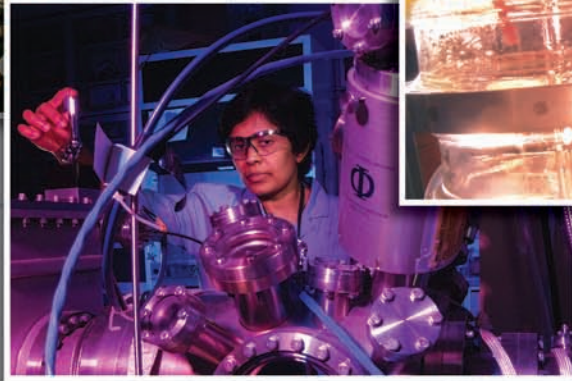


# 2005 ACCOMPLISHMENTS



Hydrogen  
Fuel Cell  
Strategic  
Power Initi  
Modeling Simulac  
PureGen  
Interna







## MESSAGE FROM THE DIRECTOR

It is my pleasure to present the National Energy Technology Laboratory's (NETL's) 2005 Accomplishments Report. This report describes the results of NETL's work over the previous fiscal year and demonstrates that our staff has upheld the trust of the American public by wisely investing taxpayer dollars to benefit the nation. The report also responds to the Government Performance and Results Act of 1993, which holds federal agencies accountable for achieving solid results.

NETL's mission is to conduct and implement wide-ranging research and technology development programs to ensure the fossil fuels industry can help meet America's increasing demand for affordable domestic energy. Funding is provided by the Department of Energy's Office of Fossil Energy, as well as other Department offices and federal agencies. NETL is committed to achieving science and technology advances and turning these advances into energy solutions that spur the growth of the nation's economy.

The successes NETL achieved in 2005 are the result of extensive onsite and contracted research, which focus on the production, transmission, and utilization of fossil fuels—coal, natural gas, and oil. Fossil resources provide 85 percent of our nation's energy supply today and will continue to satisfy the bulk of the nation's energy needs for decades to come. NETL's work provides new, affordable ways to leverage U.S. fossil resources consistent with national environmental and energy security objectives.

In late 2005, NETL proudly announced the merger of the Office of Fossil Energy's Albany Research Center with our family of research facilities. In 2006 and beyond, NETL's internal capabilities will be expanded by Albany's internationally recognized expertise in advanced materials sciences for next-generation fossil energy systems, enhancing the speed, scope, and impact of our results.

NETL delivers cutting-edge research and development, contributing to the clean production and use of our nation's domestic fossil energy resources. Please take the time to look through the following pages. We believe these accomplishments illustrate our commitment to America's energy future.

A handwritten signature in black ink that reads "Carl O. Bauer". The signature is fluid and cursive.

**Carl O. Bauer**

Director  
National Energy Technology Laboratory

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*The National Energy Technology Laboratory, owned and operated by the U.S. Department of Energy, implements research, development, and demonstration programs to resolve the environmental, supply, and reliability constraints of producing and using fossil resources.*

## **C**ONTRIBUTING TO AMERICA'S ENERGY FUTURE

### **Who We Are, What We Do**

The National Energy Technology Laboratory (NETL) is owned and operated by the U.S. Department of Energy (DOE). As part of DOE's national laboratory system, NETL supports the Department's mission to advance the national, economic, and energy security of the United States.

NETL is unique in both its mission and its approach. The only DOE national laboratory dedicated specifically to fossil energy research, NETL is focused on resolving the environmental, supply, and reliability constraints of producing and using America's most abundant energy resource—fossil fuels. To achieve this mission, NETL draws on over 1,200 federal and support-contractor employees to implement and manage its broad spectrum of energy and environmental research programs.

Across 47 states and more than 40 foreign countries, NETL implements over 1,400 contracted and onsite research and development activities. A large portion of NETL's funding is devoted to partnerships with industry, university, and government entities focused on improving fossil-energy production and use. This approach brings together a wealth

of scientific and engineering talent and creates commercially viable solutions to national energy and environmental problems.

NETL is a single organization comprising five facilities in Albany, OR; Fairbanks, AK; Morgantown, WV; Pittsburgh, PA; and Tulsa, OK. The laboratory's activities are primarily funded through DOE's Office of Fossil Energy, but NETL also conducts work for other DOE offices and federal agencies.

Devoted to developing technologies that use our nation's abundant fossil resources more cleanly and efficiently, NETL's efforts enable domestic coal, natural gas, and oil supplies to economically power America's homes, industries, businesses, and transportation while protecting our environment and enhancing our energy independence.

## Our Research Focus

In choosing our portfolio of projects, NETL works closely with the Office of Fossil Energy and other research partners to establish and meet national goals in three key areas:

- **Clear Skies**—America has made dramatic progress reducing air emissions since the first Clean Air Act was passed in 1970. In 2005, the Environmental Protection Agency (EPA) passed the Clean Air Interstate Rule and the Clean Air Mercury Rule. These regulations will further reduce power plant emissions of nitrogen oxides (NO<sub>x</sub>), sulfur dioxide (SO<sub>2</sub>), and mercury. Developing technologies to control these emissions while enabling the continued use of our nation's abundant fossil resources will protect human health and help ensure an adequate supply of affordable energy to power our economy. NETL's research includes projects that will control these pollutants at existing plants and in the power plants of tomorrow.
- **Climate Change**—President Bush has committed America to reducing greenhouse gas intensity—the ratio of greenhouse gas emissions to economic output—by 18 percent by 2012. This puts the nation on a path to slow the growth of greenhouse gas emissions and, as the science justifies, stop and then reverse that growth. Carbon sequestration—the long-term storage of carbon in vegetation or geologic formations—holds great promise for helping the nation meet this goal. NETL spearheads a number of projects to sequester carbon dioxide (CO<sub>2</sub>) and slow the growth of greenhouse gas emissions. In addition, NETL is conducting research focused on the prototype power generation system that will produce electricity and hydrogen with near-zero emissions.

- **Energy Security**—Energy security, a vital component of national security, is jeopardized by relying too much on any one energy resource or depending too heavily on energy supplies beyond our borders. It is also at risk when the nation's energy infrastructure is vulnerable. In response to these important issues, NETL is developing technologies to ensure that the nation has abundant and diverse supplies of clean energy from domestic resources. NETL is also supporting the DOE Office of Energy Assurance, the Department of Homeland Security, the Federal Emergency Management Agency, and local agencies to evaluate and protect America's energy infrastructure.

## Our Major Initiatives

To meet America's need for clean, affordable energy, some of the most important programs NETL implements are—

- **Clean Coal Power Initiative**—The Clean Coal Power Initiative is a cooperative, cost-shared program between government and industry. Its goal is to demonstrate and accelerate the commercialization of advanced, affordable, and environmentally sound technologies. Under this initiative, the nation's power generators, equipment manufacturers, and coal producers help identify the most critical barriers to coal's use in the private sector and select technologies that will economically meet environmental standards while increasing the efficiency and reliability of coal power plants.
- **FutureGen**—FutureGen is a \$1 billion industry-government partnership to design, build, and operate a coal gasification-based, near zero-emission electricity and hydrogen production plant. The 275-megawatt prototype plant will serve as a large-scale engineering laboratory for testing new clean power, carbon capture, and coal-to-hydrogen technologies. A direct response to the President's Climate Change and Hydrogen Fuels Initiatives, FutureGen will employ cutting-edge technology in nearly every aspect and will be the cleanest fossil fuel-fired power plant in the world.

# 2005

## NETL ACCOMPLISHMENTS

- **Methane Hydrate Research and Development**

**Program**—Enabled by the Methane Hydrate Research and Development Act of 2000, the program is designed to advance the energy community’s understanding of the nature and potential of naturally occurring methane hydrate. In a collaborative effort, researchers from industry, academia, DOE national laboratories, and federal agencies engage in a wide range of activities to better understand hydrate-related hazards to conventional deepwater oil and gas exploration, document the role hydrate plays in environmental processes, and realize the potential of methane hydrate as a source of domestic natural gas.

- **Solid State Lighting Initiative**—The Solid State Lighting Initiative, a component of our non-fossil energy work, focuses on research and development that will enable light emitting diodes and organic light emitting diodes to compete in the general illumination market. Solid state lighting—now used in traffic signals, flashlights, and automobile brake lights—uses 50 percent less electricity than incandescent and fluorescent lamps and is positioned to replace everyday lighting technology by 2025. A collaborative, cost-shared effort, the initiative will ultimately deliver substantial energy savings and position U.S. companies as technology leaders in the global lighting marketplace.

NETL’s fiscal year 2005 accomplishments are largely the result of partnerships created to foster the inventive genius of America’s citizens and industries. In combination, NETL’s successes represent progress—progress toward national energy security, an enhanced environment, and a robust American economy.

Because fossil fuels are the focus of NETL’s mission, this report groups the bulk of its accomplishment descriptions around these resources—coal, natural gas, and oil—that together provide 85 percent of America’s energy supply. The remainder of the laboratory’s achievements stem from the work it conducts with federal agencies outside the Office of Fossil Energy, its efforts to share knowledge with government and public organizations, and its awards, noteworthy publications, and patents.

The five major sections that follow are—

- Coal—Powering Our Nation Today and Tomorrow
- Gas and Oil—Tapping Domestic Resources with Innovative Technology
- Working Beyond the Office of Fossil Energy
- Sharing Our Energy Expertise
- Spotlighting Our Contributions

Each of these sections is introduced with an explanation of program objectives that put individual accomplishments in context. It is hoped the reader will see the interconnectedness of this work and how NETL’s accomplishments build on each other, moving America forward in the responsible use of its domestic fossil fuel resources.

# COAL

## POWERING OUR NATION TODAY AND TOMORROW

*Coal is a true measure of America's energy strength. One quarter of the world's coal reserves are found within the United States, and the energy content of the nation's coal resources exceeds that of all the world's known recoverable oil. Coal is also the workhorse of the nation's electric power industry, supplying more than half of the electricity consumed by Americans. To preserve this economically vital energy foundation and help the coal-power industry effectively steward our nation's fundamental energy resource, NETL is developing low-cost environmentally compliant technologies, efficiency-boosting innovations, and technologies for future energy plants with near-zero emissions.*







## MERCURY

NETL manages the nation's largest research program that investigates mercury emissions as they relate to coal-fired electric power generation. The program's goal is to develop control options that will help the coal-fired power industry meet regulations that place the first-ever caps on mercury emissions. NETL develops novel concepts at pilot scale, conducts large-scale field testing, researches technologies that co-control such pollutants as  $\text{NO}_x$  and  $\text{SO}_2$ , and seeks to expand our fundamental understanding of mercury emissions.

**Multipollutant Control Achieves 70–90 Percent Mercury Removal**—URS Group Inc., in cooperation with NETL, obtained 70–90 percent mercury removal at the City Public Service of San Antonio's Spruce Power Plant, which fires subbituminous Powder River Basin coal. Mercury was captured with existing flue gas treatment equipment designed to remove  $\text{SO}_2$  and particulate matter. Though these results are not conclusive for all coal types and plant configurations, the successful coremoval of mercury by conventional pollution-control equipment has important implications for controlling multiple emissions under the President's Clear Skies Initiative and for complying with mercury-control regulations.

**Novel Method Developed for Mercury Detection**—A team of NETL and West Virginia University scientists developed a prototype electrochemical analyzer for the rapid and inexpensive detection of mercury and other trace metals in various aqueous solutions at concentrations less than 1 part per billion. This new method can potentially be applied to monitoring drinking water, conducting environmental studies of water bodies, and analyzing power plant scrubbing liquors. An article, published in the *Journal of Electroanalytical Chemistry*, details the process.

## Technologies for Existing Coal-Fired Power Plants

Through the Office of Fossil Energy's Innovations for Existing Plants Program, NETL and its research partners provide solutions to air, solids, and water issues associated with the nation's existing fleet of coal-fired power plants. Key areas of research include controlling emissions of mercury,  $\text{NO}_x$ ,  $\text{SO}_2$ , and particulate matter, as well as innovations to minimize the impact of fossil-fuel use on the nation's water resources.

**NETL Licenses Mercury-Capture Process for Commercial Development**—NETL has licensed for commercial development its patented Thief Process to Mobotec, an international corporation focused on combustion improvement and multipollutant reduction for boilers. The process extracts partially combusted coal from the furnace of a pulverized-coal power plant and injects it into the downstream flue gas ductwork. The injected coal, now serving as a sorbent, demonstrated mercury-capture capacity comparable to that of commercially available activated carbons, but the Thief Process could prove to be more cost effective.

**Invention Disclosure Filed for Enhanced Mercury-Capture Sorbent**—Working in cooperation with NETL, researchers at the University of North Dakota Energy and Environmental Research Center developed a novel technology with greater potential for capturing mercury, especially in its difficult-to-remove elemental form. The technology features an activated carbon sorbent with a surface modification that allows the elemental mercury to be more readily oxidized, a key step for facilitating capture. Pilot-scale tests showed that the enhanced sorbent, in conjunction with an electrostatic precipitator, was highly successful in removing mercury from flue gas and could do the same in gasification streams—even at elevated temperatures (350–400 °C). A higher-efficiency sorbent suitable for use at elevated temperatures means lower overall costs of mercury-emission control during coal combustion and gasification.

**Sorbent Injection for Mercury Control Demonstrated at Three Sites**—ADA-ES Inc. of Littleton, CO, completed field testing of a sorbent injection process for mercury control at three coal-burning power plants. Researchers completed the long-term tests at AmerenUE’s Meramec Station Unit 2, where DARCO Hg-LH, a bromine-treated activated carbon, was injected over a 30-day period. An average vapor-phase mercury removal of 93 percent was achieved. Researchers also completed testing at Basin Electric’s Laramie River Station Unit 3 and removed mercury in excess of 90 percent during short-term parametric testing. Finally, researchers completed long-term testing at Detroit Edison’s Monroe Power Plant Unit 4, which fires a blend of Powder River Basin and bituminous coals. An average of 78 percent of the mercury was removed. These results show that sorbent injection can achieve high levels of mercury removal at costs significantly lower than the established baseline cost.

**New Mercury Removal Technology Demonstrates High Performance Levels**—In an NETL-managed project, ALSTOM Power demonstrated its MerCure™ sorbent injection technology at PacifiCorp’s Dave Johnston plant. The technology achieved 90 percent mercury removal on a unit equipped only with an electrostatic precipitator. The high level of performance was achieved with the lowest sorbent injection concentration of any project funded from the Office of Fossil Energy’s Innovations for Existing Plants program. Since the cost of activated carbon injection for mercury control is dominated by sorbent costs, a technology that can achieve high levels of mercury removal at extremely low injection rates is desirable.

**Slipstream Tests Demonstrate High Mercury Removal at Extremely Low Cost**—CONSOL Energy completed an NETL-managed project using its Low-Temperature Mercury Control process. The process was conducted at Allegheny Energy’s Mitchell Station using a 1.7-megawatt electric equivalent pilot plant. The technology works by cooling the exhaust gases with the air heater or water spray and permitting the mercury to absorb on the fly ash. The fly ash and mercury are then captured in the power plant’s existing particulate collection device. An alkaline material (magnesium hydroxide slurry) is injected to remove sulfur trioxide (SO<sub>3</sub>) and prevent corrosion and fouling of the power plant air heater and ductwork. Researchers achieved a maximum mercury removal of 96 percent during the long-term testing. The technology is cost effective when compared to activated carbon injection because it takes advantage of the in-situ fly ash as the mercury sorbent, does not require retrofitting of sorbent injection lances, and does not negatively impact the byproduct material.



## WATER

Water and energy are inextricably linked. Because thermoelectric generation and fossil-fuel extraction can impact water resources, it is critically important to protect U.S. water supplies while providing the energy needed to power the nation. Through integrated water- and energy-related activities, NETL is responding to this challenge by developing and applying advanced technologies and supporting science.

**High-Thermal-Conductivity Carbon Foam Prepared for Test**—In a project sponsored by NETL through the Small Business Innovation Research program, Ceramic Composites Inc. has produced carbon foam for testing in an air-cooled condenser. Ceramic Composites demonstrated the ability to increase the compressive strength and reduce the friability of high-thermal-conductivity carbon foam by 2½ times by treating the carbon filaments with a uniform silicon carbide coating. The company partnered with SPX Corporation, formerly Marley Cooling, to test the material's thermal properties. Ceramic Composites produced enough of the material and bonded it to metal tubing so the heat transfer properties can be tested. The ultimate goal is to use the material in an air-cooled condenser. The carbon foam has the potential to improve the efficiency of dry cooling systems and significantly lower the usage of water in power generation.

**Passive Wastewater Treatment System Completed at a Coal-Fired Power Plant**—The Tennessee Valley Authority held a site tour at the Paradise Fossil Plant in Kentucky to celebrate the completed construction of an integrated passive wastewater treatment system (constructed wetland) at a coal-fired power plant to minimize the release of arsenic, selenium, mercury, ammonia, and other trace elements to the environment. An extraction trench component was constructed for the removal of three of the elements as part of the Innovations for Existing Plants program managed by NETL. The component is a reaction cell containing a mixture of zero valent iron (cast iron shavings) and limestone. It brings wastewater into contact with iron surfaces where adsorption reactions take place. Monitoring of the system will continue for 2 years.

**Patented Process Yields Clean Water from Boiler Flue Gas**—Following irrigation, coal-fired power plants are the second largest users of water in the country. These plants present challenges to conserving and reusing the nation's water supplies. Siemens Westinghouse, in a cost-shared project with NETL, plans to commercialize its patented WETEX process, which uses a liquid desiccant (calcium chloride) to absorb water from flue gas. The absorbed water is then flashed off under a vacuum and condensed to yield clean water. Work continues toward the development of accurate cost estimates and performance curves for the process under varying conditions.

## CRITERIA POLLUTANTS

NETL's research efforts are aimed at near-zero emissions of criteria pollutants and CO<sub>2</sub> in the nation's coal-fired power industry. Emissions of these pollutants continue to decrease despite a steady increase in coal utilization. To continue that trend, NETL and its research partners are developing advanced, low-cost technologies to address current and future limits on NO<sub>x</sub>, SO<sub>2</sub>, and particulates, including difficult-to-control fine particulates.

**NO<sub>x</sub>-Control Technology Selected for Industrial Facility**—P.H. Glatfelter Company has licensed Praxair Technology Inc.'s patent-pending oxygen-enhanced combustion system, which can reduce NO<sub>x</sub> emissions below targets contained in the President's Clear Skies Initiative and EPA's Clean Air Interstate Rule. The technology was installed in two pulverized coal-fired boilers at the Glatfelter pulp and paper manufacturing facility in Spring Grove, PA. Operations began with the 2005 ozone season. Oxygen-enhanced combustion was developed in cooperation with NETL to help utilities meet near-term NO<sub>x</sub> limits while advancing combustion technologies (e.g., 100 percent oxygen-fired boiler) that produce low pollutant emissions and facilitate CO<sub>2</sub> sequestration. The technology is particularly suited for retrofitting older, space-constrained units with capacities of 300 megawatts or less, which represent 66 percent of U.S. boilers.

## **Novel Oxy-Fuel Burner Produces Less NO<sub>x</sub>**—

Commercial-scale tests, conducted at the CANMET Energy Technology Centre in Ottawa, Ontario, showed that a new burner, designed for combustion with oxygen instead of air, reduced NO<sub>x</sub> emissions from bituminous and lignite coals by as much as 80 percent. Cosponsored by NETL through the International Energy Agency Greenhouse Gas Research and Development Programme, the tests also indicated that the flue gas produced has a higher concentration of CO<sub>2</sub> than the flue gas found in conventional power plants. This facilitates CO<sub>2</sub> capture at lower cost and with less parasitic power consumption.

## **Low-Cost Approach for NO<sub>x</sub> Control Exceeds Targets**—

Pilot-scale tests conducted at The Babcock & Wilcox Company's Alliance, OH, facility used a cost-effective, retrofit technology to reduce coal-boiler NO<sub>x</sub> emissions to below targets contained in the Clean Air Interstate Rule and the President's Clear Skies Initiative. A wall-fired boiler burning subbituminous Powder River Basin coal with low-NO<sub>x</sub> burners and overfire air achieved emissions as low as 0.094 pounds per million Btu. The tests also revealed greater emission reduction—0.071 pounds per million Btu—with the addition of selective non-catalytic reduction technology. The potential for achieving such low levels in commercial boilers, even without the more expensive selective non-catalytic reduction technology, has important implications for multipollutant control. The project is funded by the Innovations for Existing Plants program managed by NETL.

## **Novel Technique Improves Particulate Capture**

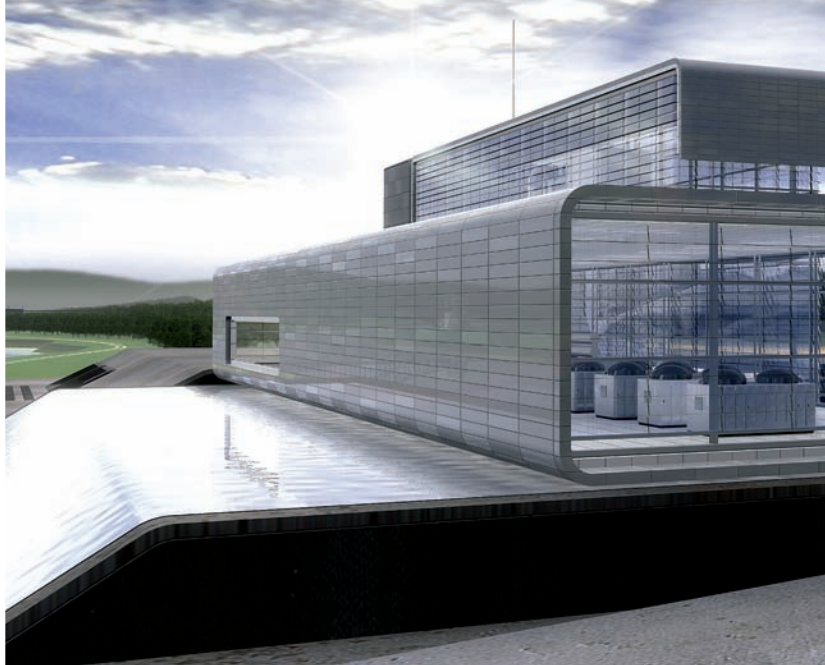
**Process**—An invention disclosure has been filed by researchers at the University of North Dakota Energy and Environmental Research Center for a novel fabric-coating technique that reduces blinding (closing of pores) in baghouse filter bags. Developed in cooperation with NETL, the proprietary process contributes to overall power plant efficiency by decreasing baghouse pressure drop and facilitating air-pulse filter bag cleaning. In addition, decreased filter blinding increases bag life and reduces replacement costs. By allowing such higher-efficiency baghouse designs, the innovation could lower overall costs for particulate-emission control at coal-fired power plants and in other particulate-intensive industries, such as cement making, metalworking, grain storage, flour processing, and petroleum refining.

## **Semicontinuous Emissions Monitor for SO<sub>3</sub> Successfully Tested**—

A prototype SO<sub>3</sub> monitor, developed in cooperation with NETL, was successfully tested in a pilot-scale facility at Southern Research Institute in Birmingham, AL. The test is a major milestone toward the development and validation of a rugged, low-maintenance SO<sub>3</sub> Continuous Emissions Monitor (CEM) suitable for unattended plant use. Output from the device was in good agreement with the manually controlled condensation method generally recognized as the most reliable approach to measuring SO<sub>3</sub> and H<sub>2</sub>SO<sub>4</sub> at concentrations relevant to power plants. The monitor is expected to perform well for SO<sub>3</sub> concentrations as low as 2.5 parts per million at a measurement frequency of two samples per hour, greatly facilitating studies leading to the control of sulfuric acid emissions. In addition to negatively affecting particulate collection, ash disposal, air preheater performance, and general maintenance, SO<sub>3</sub> formation can produce particulate emissions in the form of sulfuric acid aerosols that persist over long distances. Physiological responses, such as eye irritation and breathing difficulty, have been associated with episodes of highly visible ground-level plumes containing sulfuric acid aerosols.

## **Infrared Technique Could Improve Power Plant**

**Efficiency**—Chemical processing and fossil-fuel combustion often involve high-temperature operations during which equipment malfunction can lead to expensive and dangerous equipment failure. In cooperation with NETL, researchers at the University of North Dakota Energy and Environmental Research Center have developed real-time infrared thermography as an alternative to using hard-wired thermocouples for monitoring process temperatures. In the new approach, thermographic images of heated surfaces can be analyzed to predict or diagnose conditions, such as insulation degradation, alloy failure, and flow blockage or maldistribution. Process control based on real-time thermal imaging could improve the output and operating efficiency of power plants, as well as other industrial heat-transfer processes.



## ZERO-EMISSION TECHNOLOGIES

In NETL's vision of the future, coal-fired power plants will have a benign effect on air quality, emitting virtually no emissions while continuing to supply more than 50 percent of the nation's energy. FutureGen will be the first embodiment of that vision, and NETL and its research partners are developing a technology base for it and the other highly efficient, near zero-emission power plants of tomorrow.

## **T**echnologies for Future Energy Plants

Along each step of the research path, NETL has sought to improve the economic and environmental performance of coal-based power systems. The centerpiece of these efforts is FutureGen, an initiative to build the world's first integrated hydrogen production and carbon sequestration research power plant. To support coal and power systems development, NETL's research focuses on pollutant formation and removal, combustion technologies, distributed generation and fuel cells, and advanced materials.

**Novel Generator Produces Grid Power**—A unique 10-megawatt gas generator, developed in cooperation with NETL by engineers from Clean Energy Systems Inc., was utilized to provide grid power from the Kimberlina power plant near Bakersfield, CA, reaching a milestone vital for commercial deployment. Based on rocket engine technology, the device uses ultraclean combustion to produce a high-temperature, high-pressure working fluid consisting of steam and CO<sub>2</sub>. Following expansion through a turbine, the steam can be condensed and recycled, leaving behind the CO<sub>2</sub> for commercial use or sequestration. The net water produced during combustion is also available for additional applications. The technology has been developed and tested with natural gas and is applicable to coal-based gasification power systems. The demonstration effort was funded by the California Energy Commission, American Air Liquide, and power-producing corporations Mirant and AES. The Office of Fossil Energy sponsored engineering studies for reconfiguring the 5-megawatt Kimberlina power plant to accept the gas generator and for deploying the concept at larger scale.

**Oxygen-Fired Circulating Fluidized-Bed Technology Progresses Toward Commercialization**—A 9-day test campaign completed at ALSTOM Power's multiuse test facility in Windsor, CT, evaluated the environmental performance of oxygen-fired circulating fluidized-bed technology with a medium-volatile bituminous coal and petroleum coke. Results have been used to complete a techno-economic analysis of a demonstration retrofit circulating fluidized-bed plant design. The technology, still being developed in cooperation with NETL, will help reach goals of the Clear Skies and Climate Change Initiatives by reducing emissions of NO<sub>x</sub>, SO<sub>2</sub>, and other pollutants while providing a highly concentrated, sequestration-ready stream of CO<sub>2</sub> without costly separation.

## **Simulator Ready for Evaluation of Oxygen Transport Membrane**

—As part of a cooperative agreement with NETL, preliminary testing on a multitube boiler simulator was completed at the Praxair Technology Inc. research facility in Tonawanda, NY. The simulator, designed to further develop the application of Oxygen Transport Membrane (OTM) technology, has indicated that the system is capable of fully evaluating OTM performance. In further tests, the simulator will help to determine the best OTM tube configuration for a novel boiler concept that could reduce the cost of carbon capture to less than \$10 per ton of CO<sub>2</sub>, increase thermal efficiency, and lower pollution emissions. OTM tubes feature a ceramic membrane that has been shown to separate oxygen from air less expensively than conventional cryogenics. By using oxygen instead of air, boiler-produced CO<sub>2</sub> is more concentrated and easily captured with lower parasitic power consumption and at lower cost.

## **All-Ceramic Oxygen Production Submodules**

**Successfully Designed and Fabricated**—With NETL support, a team led by Air Products and Chemicals Inc. operated a subscale, all-ceramic oxygen separation module at commercially relevant conditions (200 psig and 850–900 °C) and produced more than 99 percent pure oxygen, proving the efficacy of all-ceramic construction and seal technologies. The team is developing the Ion Transport Membrane Oxygen technology for producing oxygen for integration in advanced power generation systems, such as integrated gasification combined cycle (IGCC) systems, at one-third lower capital cost and energy requirement compared to cryogenic processes. A critical milestone of the technology is the production of modules with all-ceramic parts and seals. Such modules are expected to possess better mechanical properties and longer life than those consisting of both ceramics and metals, as ceramic-metal interfaces are prone to degradation. The team has made significant advances in this area, and 12-wafer oxygen production submodules are now being made using all-ceramic technology.

## **HEAT ENGINES**

**Building on past successes in advanced turbine technology development, NETL researchers continue to develop advanced power generation technologies. During 2005, research focused on turbine monitoring instruments, efficient air compressors, combustion sensors, advanced turbine blades, and the use of hydrogen fuels.**

### **Turbine Monitoring Technology Ready for Commercialization**

—An online turbine monitoring instrument, installed by Siemens Westinghouse Power Corporation (Gas Turbine Division) as part of a project with NETL, surpassed 5,000 hours of operation, confirming that the technology is ready for commercialization. Functioning in a Westinghouse 501FD gas turbine at Empire Stateline Electrical Company in Joplin, MO, the monitor provides real-time infrared imaging of rotating turbine blades to detect the integrity of thermal barrier coatings. This type of monitoring could be applied to all gas turbines that use thermal barrier coatings for protecting critical turbine parts, eliminating frequent turbine inspections and associated downtime and reducing the risk of catastrophic turbine failure.

### **Fabrication Design Completed for Novel Air Compressor**

—In cooperation with NETL, Ramgen Power Systems Inc. of Bellevue, WA, completed fabrication design for the rotor of a second-generation Rampressor—a simpler, more efficient air compressor based on supersonic flight inlet technology. Using ramjet shockwave compression, the novel device develops higher pressure ratios per stage, therefore requiring fewer stages, decreasing aerodynamic loss, and reducing cost.

### **Second Test of NETL Sensor Technology Successful**

—Woodward Industrial Controls successfully tested for the second time the patented Combustion Control and Diagnostics Sensor (CCADS) technology. Incorporated into the fuel nozzles of a turbine combustor, the sensor can monitor several key combustion parameters, potentially improving NO<sub>x</sub> emissions control, increasing reliability, and lowering electricity costs. CCADS technology development began with an NETL patent on flashback detection and continues toward commercialization through cooperative research and development and licensing agreements with Woodward.



### **Steam Turbine Blades for Higher-Efficiency Electrical Generation Tested Successfully**

Designed and fabricated by GE, a full-scale prototype steel-hybrid blade with an advanced three-dimensional aerodynamic shape was successfully tested. Developed in cooperation with NETL, the 33.5-inch prototype represents an intermediate step in designing ultralong full-speed last-stage buckets that will improve overall Rankine cycle efficiency up to 0.5 percent, reduce fuel consumption by 1 percent, and avoid the generation of 2 million tons per year of CO<sub>2</sub> by next-generation steam turbines. Moreover, in an IGCC system, capital cost could be reduced \$10–\$15 million. The prototype design will be used to introduce the technology in next-generation low-pressure steam turbines while development continues on more advanced bucket designs.

### **Reciprocating Engine Operates on 100 Percent Hydrogen Fuel at NETL**

For the first time, NETL researchers operated a reciprocating engine on 100 percent hydrogen fuel. The test engine operated smoothly over a range of oxygen-to-hydrogen ratios. The use of hydrogen in reciprocating engines offers the potential for substantial reductions in NO<sub>x</sub> emissions and provides a platform for power generation from future coal-derived hydrogen fuels.

## **FUEL CELLS**

Fuel cells are expected to play a major role in the nation's energy future by providing efficient, environmentally friendly electrical energy while extending the capacity of the nation's fossil fuel supply. Fuel cells are extremely attractive as a power source because they are virtually emission free. NETL, which helped develop and introduce the first fuel cells into the market, supported a number of key advances in fuel cell development during the year, including the operation of fuel cell power units.

### **Solid State Energy Conversion Alliance Continues Toward Commercialization Goals**

The Solid State Energy Conversion Alliance (SECA), managed by NETL in coordination with the Pacific Northwest National Laboratory, is a unique alliance among government, industry, and the scientific community. Its goal is to accelerate the commercialization of low-cost solid oxide fuel cells in the 3–10 kilowatt range. SECA is organized into industrial teams, which are developing prototype solid

oxide fuel cell systems, and a core technology program, which provides focused research and development to overcome barriers identified by the teams. Breakthroughs from the core technology program are made available to all industrial teams. The SECA program and its participants noted the following advances this fiscal year:

- Working in cooperation with NETL, GE Hybrid Power Generation Systems of Torrance, CA, is the first of six teams to successfully complete qualification tests for a prototype solid oxide fuel cell system designed for stationary power applications. Fabricated by means of a scalable mass-production technique, the unit logged 1,700 hours of operation, reaching design power output (5 kilowatts) using methane fuel and exceeding Phase I targets for availability, efficiency, endurance, and estimated production cost.
- A team, led by FuelCell Energy Inc. in cooperation with NETL, successfully operated a prototype 3-kilowatt planar solid oxide fuel cell system for more than 1,000 hours. Fueled with city pipeline natural gas, the system operated unattended, supplying 120-volt AC electricity to a simulated grid.
- Delphi Automotive Systems LLC and Battelle Columbus Laboratories, working in cooperation with NETL, successfully completed the initial test sequence for their first stand-alone stationary power unit. Operating independently of the grid, the unit produced a record peak net power output of 1.5 kilowatts and surpassed previous milestones for system runtime and efficiency. The record performance represents a significant advance toward meeting SECA programmatic goals in support of the Office of Fossil Energy's FutureGen project and the President's Hydrogen Fuel Initiative. Delphi is developing a 3–5 kilowatt solid oxide fuel cell prototype for use with a range of fuels in such applications as heating and air conditioning for homes, offices, and vehicles.
- Multiple single-cell tests conducted by the Siemens Power Generation industrial team have repeatedly demonstrated substantially improved power generation and production consistency using the Delta 9 next-generation fuel cell. The corrugated design of the Delta 9 has a 40 percent greater specific surface area, which could ultimately increase cell power by one-third over Siemens' current design.
- Siemens Power Generation Inc. successfully placed in operation a 100-kilowatt solid oxide fuel cell combined heat and power system at the facilities of Gas Turbine

# COAL

Technologies in Turin, Italy, delivering power to a local grid. After operating in Europe for a world record-setting 20,000 hours, the system was refurbished at Siemens' Science and Technology Center near Pittsburgh, PA, where it was originally built based on technology developed under DOE's solid oxide fuel cell program. Continued performance of the original cells included in the refurbished unit is extending that endurance record. The system, delivering 101 kilowatts of electricity to the grid, has accrued more than 25,855 hours of operation, including more than 5,375 hours at its present location. The system is expected to have greater than 98 percent availability and a combined heat and power efficiency of 75–78 percent (46 percent electrical).


- At a July 2005 dedication ceremony, Forest Service officials of the U.S. Department of Agriculture placed a 10-kilowatt solid oxide fuel cell in operation to supply heat and power at the Big Goose Ranger Station in Bighorn National Forest near Sheridan, WY. Located at an elevation of nearly 7,700 feet and 7 miles from the nearest electrical grid line, the station is used by fire-fighting crews during the summer and could prove to be a model for similar applications at remote sites, especially in Alaska. The solid oxide fuel cell was supplied by Acumentrics Corporation. Other partners in the demonstration project include NETL, the Federal Energy Management Program, the Department of Defense, and the Propane Education and Research Council.
- Researchers at Virginia Tech developed an active cancellation technique to suppress unwanted oscillating current on the DC side, which tends to reduce solid oxide fuel cell efficiency and cause controller instability. By incorporating a fast current controller into the existing voltage controller, the technique ensures that the converter output current (and thus the fuel cell current) remains constant without bulky and costly converter circuits or passive components. Experimental results showed that the modified controller reduced fuel cell current ripple to 1 percent. The reduction of current ripple, combined with high-efficiency DC converter design, allows the fuel cell to produce 20 percent more power. As a result, the energy-efficient power electronics technology developed by Virginia Tech would effectively reduce fuel consumption, as well as the size of fuel cell systems, helping to meet the 60 percent efficiency target and \$400-per-kilowatt cost target of the SECA program by 2010. Virginia Tech has filed a patent application and is making this technology advancement available to all SECA industrial teams.

- Researchers at the Pacific Northwest National Laboratory finished testing a stainless steel interconnect coated with a chrome-free ceramic that improved surface stability, minimized contact resistance, and prevented chrome migration known to degrade fuel cell performance. The achievement will help meet SECA performance and cost targets.

**NETL Concludes Long-Standing Partnership**—NETL and FuelCell Energy Inc. of Danbury, CT, have successfully concluded a 10-year cooperative agreement aimed at developing molten carbonate fuel cell technologies. The fuel cell project resulted in the development of a commercial product, FuelCell Energy's Direct FuelCell®, to serve stationary power generation markets. Several significant accomplishments were realized as a result of the project:

- FuelCell Energy reduced manufacturing costs of the Direct FuelCell power plant by a factor of three. The technology behind these fuel cell power plants converts natural or waste gas to electrical power (up to 1 megawatt) with the greatest efficiency and lowest emissions of any fossil-based technology. The power plants can be sited at or near end users where the heat byproduct can be used for cogeneration applications (e.g., district heating, hot water, or air conditioning) to achieve an overall energy efficiency of 70–80 percent.
- By meeting the stringent 2007 California Air Resources Board standard for distributed generation emissions, Direct FuelCell products qualify as ultraclean technology and are exempt from air pollution control and the board's air quality district permitting requirements.
- FuelCell Energy has shipped more than three dozen units to customers worldwide for use in hotels, hospitals, universities, wastewater treatment plants, telecommunication and data centers, and commercial and industrial facilities.
- The company has forged strong global alliances with original equipment manufacturers in Europe, Japan, Korea, and the United States for further plant cost reduction and product marketing.
- FuelCell Energy has commissioned Direct FuelCell units in both the United States and Asia to further the widespread deployment of the technology. Installations include the Santa Rita Jail in Dublin, CA; the U.S. Marine Corps Air Ground Combat Center at Twentynine Palms, CA; the Sheraton San Diego Hotel & Marina; "Super Eco Town" in Tokyo, Japan; and the Pohang University of Science and Technology in South Korea.





**Technology Selected for Next-Generation Hydrogen Energy Station**—Air Products and Chemicals Inc. has subcontracted FuelCell Energy to demonstrate a next-generation hydrogen energy station. Combining Air Products' advanced gas separation technologies with a Direct FuelCell® power plant, the high-efficiency, low-emissions hydrogen energy station would use readily available fuels (e.g., natural gas, propane, anaerobic digester gas) to coproduce heat, electricity (250 kilowatts), and enough hydrogen to fuel 20 cars per day. The approach could facilitate hydrogen infrastructure development while enhancing the versatility and value of Direct FuelCell products.

**Solid Oxide Fuel Cell System Demonstrated for Rural Alaska**—NETL's Arctic Energy Office sponsored the University of Alaska Fairbanks' successful demonstration of a 5-kilowatt solid oxide fuel cell system at a Fairbanks Natural Gas facility. The system continuously produced heat and electricity from natural gas for 365 days, with the exception of one software-related shutdown. The long-term test was part of an evaluation of fuel cells for such small-scale power requirements as communication devices, isolated dwellings, and railroad crossings found in remote locations where highly reliable, fuel-efficient, cost-effective, and unattended operation is essential.

**Fuel Cell Operates During Russian Power Failure**—A 200-kilowatt phosphoric acid fuel cell manufactured by United Technologies Corporation of Windsor Locks, CT, maintained power at an industrial site near Moscow despite a citywide blackout in May 2005. Installed with technical and logistical support from NETL and a Department of Defense Climate Change Grant, the unit has developed significant market interest throughout Russian organizations, including Gazprom—the world's largest gas producer—for use with its natural gas pipelines. Demonstration of the technology has been a key factor in Russia's qualification for State Department funding for the continued development of fuel cell capabilities. The project supports the Initiatives for Proliferation Prevention program, the Nuclear Cities Initiative, the Russian-American Fuel Cell Initiative, and the National Nuclear Security Administration's plan for commercialization of fuel cells in Russia.

**Reversible Solid Oxide Fuel Cell Operation Surpasses 1,000-Hour Mark**—A milestone was achieved by Ion America of Moffett Field, CA, in the first phase of an Office of Fossil Energy Advanced Fuel Cell Research project managed by NETL. The operation of a single-cell reversible solid oxide fuel cell for more than 1,000 hours demonstrated greater than 80 percent round-trip efficiency and exhibited 0.5 percent degradation without using costly noble metals—moving the technology toward commercially viable performance levels. Reversible solid oxide fuel cells can produce electricity and water from hydrogen or, in reverse mode, hydrogen from electricity and water. This dual capability could allow the fuel cells to use excess electrical grid capacity during off-peak hours to produce hydrogen fuel or to convert an intermittent source of power, such as solar, into continuous power for remote applications. Research in the second phase of the project will be directed toward long-term durability and scale-up to viable cell and stack sizes.

**Improved Sulfur Sorbent Lowers Fuel Cell Costs**—Under a Small Business Innovation Research Grant administered by NETL, TDA Research Inc. of Wheat Ridge, CO, has developed an improved sulfur sorbent for use in fuel cell systems. The sorbent removes sulfur-based odorants that are added to natural gas for leak detection but can degrade the performance of fuel cell systems. Considering nearly 8,000 hours of testing with 5-kilowatt proof-of-concept solid oxide fuel cell systems, researchers at Siemens Power Generation Inc. estimate that the TDA sorbent has more than 1.5 times the adsorbent capacity of the leading competitive material supplied by Tokyo Gas. Analyses also show that the cost of TDA's material would be 10 percent less than that of the Tokyo Gas material, providing a competitive sorbent supply source within the United States.

**Coatings May Prolong Life of Fuel Cell Metallic Interconnects**—Investigators at Montana State University are developing coatings to improve the oxidation resistance of metallic components used for interconnects in solid oxide fuel cells. Using a patented plasma coating process, extremely thin (a few nanometers thick) alternating layers of oxidation-resistant, conductive coatings are deposited on stainless steel substrates. Test data suggest that some coatings may meet the 40,000-hour power degradation target for stationary applications. Montana State University is a satellite center under the High Temperature Electrochemistry Center managed by NETL and Pacific Northwest National Laboratory.

# COAL

## CARBON SEQUESTRATION

NETL manages a portfolio of carbon sequestration projects that explore repository options; the mitigation of other greenhouse gases; sequestration measurement, monitoring, and verification; and sequestration as part of enhanced oil recovery. NETL also manages DOE's Regional Carbon Sequestration Partnerships, which collaborate with state agencies, universities, and private companies to determine the best approaches for capturing and permanently storing greenhouse gases in each region of the country.


**Second Phase of the Weyburn CO<sub>2</sub> Monitoring and Storage Project Initiated**—NETL, Natural Resources Canada, EnCana Corporation, and the Petroleum Technology Research Centre kicked off Phase II of the world's largest full-scale multinational scientific field study of geological carbon sequestration. Building on the Phase I conclusion that geological conditions at the Weyburn oilfield in Saskatchewan are favorable for long-term storage of CO<sub>2</sub> and can be monitored with the tools and technologies developed and assessed during the project, an estimated net 14 million metric tons of CO<sub>2</sub> will be stored in the Weyburn field over the next 15 years. Use of CO<sub>2</sub> as a miscible flood agent in enhanced oil recovery operations will also improve overall oil recovery in the field by 46 percent. Phase II also expanded to the neighboring Midale field operated by Apache Corporation. CO<sub>2</sub> flooding operations began in September 2005, and an estimated 8.75 million metric tons of CO<sub>2</sub> will be stored over the life of the project. The Weyburn CO<sub>2</sub> Storage and Monitoring Project is endorsed by the International Energy Agency Greenhouse Gas Research and Development Programme and the Carbon Sequestration Leadership Forum, an international climate change initiative with 19 partners including the United States.

**Highlights of Texas Geological Sequestration Field Test Presented**—Results obtained from studies performed during and after the injection of 1,600 tons of CO<sub>2</sub> into the high-permeability brine-bearing sandstone of the Frio Formation 1,500 meters beneath the Gulf Coast of Texas were presented at the Fourth Annual Conference on Carbon Capture and Sequestration held in May 2005 in Alexandria, VA. The internationally recognized sequestration pilot study, endorsed by the Carbon Sequestration Leadership Forum, is evaluating techniques for modeling, monitoring, and verifying the injectivity and capacity of the subsurface to store CO<sub>2</sub> and to do so without adverse health, safety, or environmental effects. The Bureau of Economic Geology at the University of Texas at Austin is leading the effort in cooperation with NETL. Multiple industrial partners, the U.S. Geological Survey, and several national laboratories, including Lawrence Berkeley, Lawrence Livermore, and Oak Ridge, are also participating. The project's success has led to a second, 2006 experiment to inject additional CO<sub>2</sub> into the brine reservoir.

**NETL-Developed Technique Measures Low Leakage in Carbon Sequestration Test**—Tracer-based leak detection technology developed at NETL has been successfully applied at the West Pearl Queen Field in New Mexico where DOE is sponsoring a geological sequestration experiment. Results over several months of monitoring indicate that less than 0.1 percent of the total injected CO<sub>2</sub> is escaping annually, apparently from surface faults and areas of discontinuity in the carbonate deposit underlying the soil.

**NETL Research Indicates CO<sub>2</sub> Causes Structural Changes in Coal**—Research at NETL has demonstrated that exposure to CO<sub>2</sub> can, in some cases, beneficially affect the ability of coal seams to sequester the gas by increasing its diffusion rates and solubility. Injection into deep, unmineable coal seams is one of the most promising options for storing CO<sub>2</sub> to reduce greenhouse gas emissions. The discovery suggests the need to collect data on coals before, during, and after CO<sub>2</sub> exposure when conducting sequestration.

**NETL-Developed Sorbent Achieves 99 Percent CO<sub>2</sub> Removal**—Laboratory experiments by NETL researchers demonstrated that an NETL-developed regenerable sorbent can remove 99 percent of the CO<sub>2</sub> in simulated coal combustion flue gas, reducing CO<sub>2</sub> concentration



from 15 percent to less than 1 percent at flow velocities of commercial interest. Development of more efficient, cost-effective technologies to remove CO<sub>2</sub> from gas streams is critical to the Office of Fossil Energy's Carbon Sequestration Program. Additional research will be directed toward testing the sorbent in bench-scale reactors and evaluating the feasibility of preparing the sorbent in large-scale units.

### **Climate Change Technology Projects Advance**

**Commercialization**—To help meet the Global Climate Change Initiative goal to reduce greenhouse gas intensity by 18 percent by 2012, DOE awarded \$100 million for seven projects to promote the commercialization of carbon sequestration. Results obtained during the testing of carbon sequestration technologies will be crucial to developing DOE's FutureGen power plant. The seven projects were proposed by DOE's Regional Carbon Sequestration Partnerships, whose cost-share took the total value to \$144 million. The partners will field-test and validate carbon sequestration technologies best suited to their respective regions.

- The Big Sky Regional Carbon Sequestration Partnership will demonstrate geological storage in mafic-basalt rock formations, which hold significant potential for long-term storage.
- The Midwest Geological Sequestration Consortium will determine the ability, safety, and capacity of geological reservoirs to store CO<sub>2</sub> in deep coal seams, mature oilfields, deep saline reservoir formations, and organic-rich shales of the Illinois Basin.
- The Midwest Regional Carbon Sequestration Partnership plans to conduct at least three small-scale CO<sub>2</sub> injection field tests in the region's deep geological reservoirs, which have more than 200 years of storage capacity.
- The Southeast Regional Carbon Sequestration Partnership will define the potential for storing CO<sub>2</sub> and conduct field sequestration validation tests in three target geological formations: enhanced oil recovery stacked reservoirs, coal seams, and saline reservoirs.
- The Southwest Regional Partnership for Carbon Sequestration will conduct five field tests to validate the most promising carbon sequestration technologies and infrastructure concepts.
- The Plains CO<sub>2</sub> Reduction Partnership will conduct four technology validation field trials and two investigations of carbon sequestration concepts.

- The West Coast Regional Carbon Sequestration Partnership will conduct two CO<sub>2</sub> storage tests in California and one in Arizona related to CO<sub>2</sub> storage in depleted gas reservoirs and saline formations.

## **HYDROGEN**

The nation is on a mission to transition to a hydrogen-based economy, in which hydrogen will ultimately power our vehicles, homes, businesses, and factories. To help achieve that mission, NETL manages a portfolio of research projects focusing on technologies that facilitate the production of hydrogen from coal fuels for use in fuel cells and other power generation systems.

### **Synthesis Gas Production Process Achieves Major Milestone**

—As part of a cooperative agreement with NETL, researchers at Air Products and Chemicals Inc. have achieved the target oxygen permeation rate critical to the economic feasibility of the Ion Transport Membrane Syngas process. In the process, oxygen is separated from air by selective ion transport through a ceramic membrane and is used to partially oxidize a natural gas-containing feed stream to produce a mixture of hydrogen and carbon monoxide known as synthesis gas. The project team achieved the target oxygen permeation rate at design temperature and pressure in a process development unit using pilot-scale membranes with the features essential for full-size membranes. The team is testing full-size membranes in 2006.

### **Novel Reforming Catalyst Proves Stable in 500-Hour Test**

—NETL researchers demonstrated exceptionally stable performance of a novel hydrocarbon reforming catalyst for production of hydrogen-rich synthesis gas from transportation fuels. The catalyst, synthesized at NETL, is expected to be more robust and tolerant of carbon and sulfur than traditional metal-supported catalysts.

# COAL

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## **Institution Achieves Milestone in Membrane**

**Technology**—Researchers at North Carolina Agricultural and Technical State University in Greensboro, NC, succeeded in fabricating and operating a membrane reactor made of a palladium thin film on porous substrates. Membrane reactors allow high-temperature reactions to proceed simultaneously with product separation in a single operation. Using the membrane reactor, the investigators converted cyclohexane to hydrogen and other constituents at nearly three times the conversion rate obtainable with conventional equipment at comparable conditions. In addition to investigating a way to provide hydrogen for FutureGen applications, the NETL-managed project provided students hands-on experience in conducting energy research.

## **Field Test Demonstrates Stability of Novel Hydrogen Separation Membrane**

—During a 100-hour field test, a novel carbon sieve-based membrane developed in cooperation with NETL at Media and Process Technology Inc., showed excellent hydrogen selectivity and permeance in the presence of hydrogen sulfide, ammonia, and hydrocarbons. The test was conducted using a hydrocracker purge stream at an operating refinery, affirming its commercial relevance. Teaming with Pall Corporation engineers, the researchers have incorporated the material into Pall's proprietary membrane reactor design. Combined with a unique approach to heat transfer developed by Media and Process Technology Inc., the system could allow the hydrogen-producing water-gas shift reaction, hydrogen separation, CO<sub>2</sub> capture, and contaminant removal to be conducted in a single operation. Collaborators at the University of Southern California developed a mathematical model that can quantify the improved efficiency of producing hydrogen from coal using a membrane reactor operating at commercially relevant conditions. Experimental data obtained with a commercial-scale membrane module have been consistent with the model's prediction that 98 percent carbon monoxide conversion and less than 2,000 parts per million carbon monoxide contamination of the hydrogen product are possible using typical coal-derived synthesis gas as feedstock.

**Novel Process Yields Ultraclean Synthesis Gas**—A new approach for reducing contaminant concentrations in synthesis gas to well below those achievable using any current commercial technology was demonstrated in a 10-ton-per-day pilot plant at the Gas Technology

Institute in Des Plaines, IL. The Ultra-Clean Process—a new precombustion gas-cleaning concept for controlling sulfur, chlorine, mercury, and ammonia—proved successful in a series of coal gasification tests. The process injects fine sorbent particles into the gas stream to collect contaminants for removal in a series of downstream filter-reactors. Contaminant levels in the range of 10–50 parts per billion by volume—well below the limits of detection by conventional means—were measured in the product synthesis gas, corresponding to removal efficiencies exceeding 99.99 percent. The process is being developed by Siemens Power Corporation of Pittsburgh, PA, in cooperation with NETL, to satisfy the demands of future environmental regulations and contaminant limits for gas turbines, fuel cells, synthesis chemical products, and transportation fuels.

## **MATERIALS**

Future power plants and energy systems will require new or improved high-performance materials able to withstand increasingly hostile fossil-fuel environments. NETL is working to ensure the success of these plants and systems by providing the needed materials technology base. Research is focused on developing high-temperature corrosion-resistant structural ceramic composites and alloys, as well as materials that perform specific functions in advanced fossil energy systems.

## **Materials Program Seeks to Extend Boiler Component**

**Life**—Under NETL management, a consortium of four prominent boiler makers—ALSTOM Power, The Babcock & Wilcox Company, Foster Wheeler, and Riley Power Inc.—is evaluating and developing advanced materials that will permit coal-fired power plants to operate at ultra-supercritical steam conditions for higher power plant efficiency (47 percent) compared to that of the current domestic fleet average (35 percent). Because more severe operating conditions that accelerate metal wastage from waterside and fireside corrosion result in aggressive mechanical and thermal loads, the evaluation includes long-term post-fabrication wear tests of candidate materials and component assemblies. The project is also supported by Energy Industries of Ohio, the Electric Power Research Institute, and Oak Ridge National Laboratory. Significant accomplishments for 2005 follow:

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- Oak Ridge National Laboratory scientists completed long-term tests (up to 17,000 hours at 1,300 °F) with several alloys being considered for service at ultra-supercritical steam conditions (4,400 pounds per square inch, 1,400 °F) and created a web-based data repository to allow free flow of information among consortium participants.
  - Foster Wheeler Development Corporation compiled corrosion-resistance data for a number of advanced alloys tested in the temperature range of 1,200–1,600 °F with simulated flue gas and ash depositions representing high-sulfur and mid-sulfur bituminous and low-sulfur subbituminous coal types. The database will be used to match candidate materials with coal type and temperature of exposure based on corrosion rate predictions.
  - Halfway into a 30-month test program involving exposure at temperatures exceeding 1,400 °F, two experimental superheater steam loops fabricated from seven different advanced alloys remained in excellent condition with no apparent degradation or wastage. The testing is being conducted at the Reliant Energy power plant in Niles, OH, using high-sulfur coal.
  - The Babcock & Wilcox Company's researchers identified ferritic steels that resist steam oxidation at high temperatures as well as—or better than—more expensive austenitic steels.
  - Researchers at ALSTOM Power have shown that applying advanced coatings to less expensive alloy compositions provides an alternative to using costly, highly alloyed materials for next-generation boiler designs. For example, a coated stainless steel suitable for service in 1,250 °F steam could replace a comparable length of a nickel-based alloy for only 63 percent of the cost.
  - Researchers at the University of Cincinnati found that ceramics based on mixed metal niobates and tantalates are particularly promising as protective coatings against aggressive environments associated with the high temperatures needed to produce greater boiler efficiencies. Unlike other ceramics, these materials possess the required phase stability at high temperatures in the presence of acid gases and slag deposition from coal combustion.
  - Investigators at Riley Power Inc. developed and met American Society of Mechanical Engineers standards for a welding procedure for an advanced steel known as SAVE 12. The high-chrome alloy is a candidate material for construction of advanced coal-fired boilers.
  - Using the latest pulsed gas metal arc welding technology from Lincoln Electric, welds were successfully made in 2-inch thick plates of a superalloy known as Haynes 230. Such high-nickel alloys can effectively function at operating conditions that would produce higher boiler efficiencies.
  - Investigators at ALSTOM Power successfully fabricated 15 U-bend specimens from nickel-based and high-chrome alloys that are candidate materials for the construction of advanced, high-efficiency coal-fired boilers. Follow-up mechanical testing and microstructural examination will determine if the process of bending to 3-, 5-, and 7-inch radii adversely affected the strength of the materials at high temperatures.
  - Researchers at the University of Cincinnati developed a precise method for specifying the heat-treatment formula needed to strengthen nickel-based alloys for service in ultra-supercritical steam conditions.
  - Researchers at Oak Ridge National Laboratory developed a neural net program to guide heat-treatment procedures for advanced alloys. Such improved methods for estimating heat-treating temperatures can increase the energy efficiency of the process and minimize waste.
  - The American Society of Mechanical Engineers approved new equations developed by ALSTOM Power for designing cylindrical components (e.g., tubes, pipes, headers, shells, and drums) based on an improved method for calculating stress. The new design approach permits the use of thinner wall components than allowed under Society and European rules without compromising reliability and safety and could reduce the cost of pressure parts for the higher-efficiency boilers by an estimated 12 percent. Since thinner wall components are less susceptible to thermal fatigue, the new standards also permit a wider selection of materials for use at high temperatures.

# COAL

**Materials Considerations Identified for Advanced Steam Turbines**—In an effort managed by NETL, researchers at North Carolina State University working with Siemens Westinghouse Power Corporation found that resistance to creep rupture is among the most important considerations in selecting alloys for construction of turbines placed in service at ultra-supercritical steam conditions (4,400 pounds per square inch, 1,400 °F). Alloys amenable to precipitation and dispersion strengthening methods—as opposed to classic approaches, such as grain size strengthening, strain hardening, and solid solution strengthening—have the potential to yield the desired strength at these high temperatures. The more severe steam conditions will produce higher thermal efficiencies, enabling coal-fired power plants to generate electricity at competitive rates while reducing CO<sub>2</sub> and other fuel-related emissions by nearly 23 percent.

**Hot Gas Clean-Up Filters Commercialized**—Partnering with Oak Ridge National Laboratory, Pall Corporation delivered more than 1,500 iron aluminide filters for installation in a commercial coal gasification plant. Commercialization of hot gas clean-up filters is an important step in achieving near-zero emissions from FutureGen processes coproducing electricity and other products from coal. The filters were tested at NETL and the Power Systems Development Facility in Wilsonville, AL.

**Novel Material Developed for High-Temperature Seals**—In an NETL-managed project, investigators at Ceramtec Inc. in Salt Lake City, UT, developed a composite glass that can join a variety of ceramic and metal components without breakage during thermal cycling. By varying the ratio of its vitreous and crystalline phases, the sealing material's coefficient of thermal expansion can be changed to accommodate a wide variety of membrane materials and mating components. Maintaining integral joints despite thermal cycling is a major hurdle in the commercial implementation of high-temperature membrane-based technology, which employs materials with widely dissimilar physical and chemical properties. Membrane technology is being developed to perform several functions in advanced fossil energy systems.



## Clean Coal Demonstration Projects

Since establishing the Clean Coal Technology Program in 1986, DOE has demonstrated and commercialized technologies that sharply reduce air emissions and other pollutants compared to older coal-burning systems. NO<sub>x</sub> and SO<sub>2</sub>, primary contributors to acid rain, were the program's initial targets. Through the 2001 Power Plant Improvement Initiative and today's Clean Coal Power Initiative, the program's focus has expanded to emissions of mercury, fine particulates, and greenhouse gases.



### **Demonstration Project Exceeds Performance Expectation**

—JEA, formerly Jacksonville Energy Authority, completed construction and demonstration of a large-scale circulating fluidized-bed combustion project at Northside Station in Jacksonville, FL. Researchers repowered two 1970s vintage gas- and oil-fired power generation units with clean solid fuel combustion technology. JEA issued a successful fuel capability report for Illinois No. 6 coal based on full-load performance tests that resulted in stack emissions below design and permitted levels. DOE provided cost-sharing of approximately \$75 million toward the repowering of Unit 2, now the world's largest (300 megawatt electric) coal fluidized-bed combustor, for use with high-sulfur coal or petroleum coke. This Clean Coal Technology project was managed by NETL.

### **“Intelligent” Invention Improves Efficiency and Lowers Emissions**

—Tampa Electric Company and Pegasus Technologies Inc. filed an invention disclosure for a neural network software used to control the novel sootblowing system that keeps clean the heat transfer surfaces in a 445-megawatt coal-fired unit at Big Bend Power Station in Apollo Beach, FL. The software uses operating data to continuously “learn” and respond to relationships between changing operating conditions and operating objectives (e.g., reducing harmful environmental emissions while improving plant efficiency). Developed as part of an NETL-managed Power Plant Improvement Initiative demonstration project, the dynamic online system has allowed Tampa Electric Company to increase boiler efficiency by 0.5 percentage points while reducing NO<sub>x</sub> levels 10–20 percent despite fluctuations in fuel quality and equipment performance levels. The invention could eventually be sold to other power plant operators.

### **New Mercury Monitoring System Field-Tested**

—In preparation for EPA-sponsored testing, ADA-ES Inc. field-tested various components of Thermo Electron Corporation's Mercury Freedom System™, a new commercial product capable of measuring mercury emissions at coal-fired power plants. The Mercury Freedom System has met or exceeded all performance requirements reviewed to date under the EPA's Mercury Continuous Emission Monitoring System Field Evaluation program. It was tested as part of the NETL-managed Clean Coal Power Initiative project demonstrating TOXECON™ mercury-control technology at the We Energies Presque Isle Power Plant in Marquette, MI.

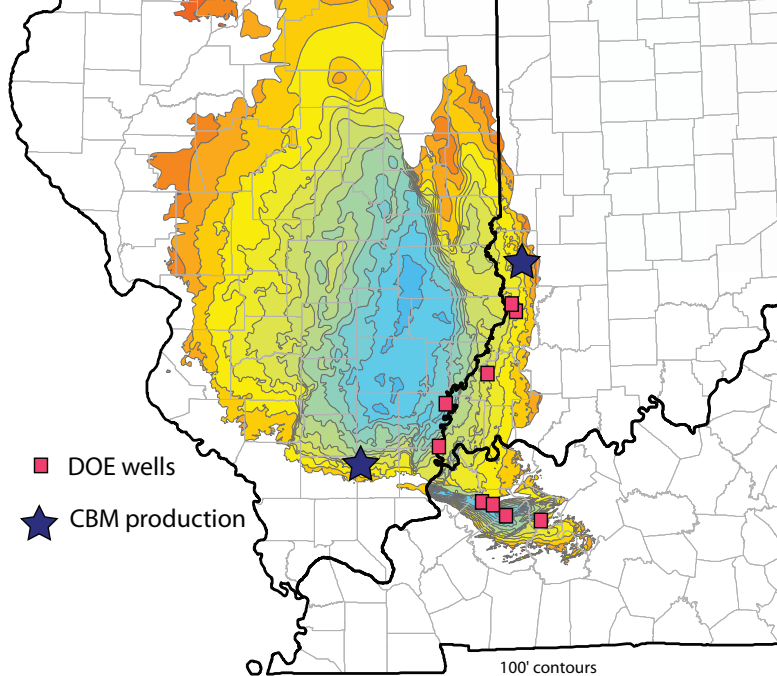
### **Ribbon-Cutting Marks Significant Milestone for Lignite Fuel Enhancement Project**

—Governor John Hoeven and U.S. Senator Kent Conrad were among honored guests at the Great River Energy Coal Creek Station in Underwood, ND, for an August 2005 ceremony marking completion of the design and construction of a prototype coal-drying module. The 75-ton-per-hour module uses waste heat to reduce the moisture in lignite, producing more power from a lower quantity of fuel. The technology is potentially applicable to the more than 100 gigawatts of installed capacity that represents units burning high-moisture coals, offering significant benefits to the U.S. power industry with regard to efficiency improvements and emissions reduction. The 45-month Clean Coal Power Initiative demonstration project, managed by NETL, builds on substantial Office of Fossil Energy-sponsored research on lignite drying.

### **Public Scoping Meeting for Project Well Attended**

—More than 100 participants, including officials in federal, state, and local government, attended a Public Scoping Meeting in August 2005 at Timber Creek High School in Orlando, FL, to comment on the proposed construction of an IGCC power plant in Orange County. A Letter of Intent, signed in August 2005 by Southern Company Services and the Orlando Utilities Commission, specifies terms and conditions for constructing and operating the plant, which features an air-blown coal-fed transport gasifier. The demonstration plant, planned for construction with the support of NETL through the Clean Coal Power Initiative, would gasify subbituminous coal to generate 285 megawatts of electricity at nearly 41 percent efficiency. Employing state-of-the-art emission controls, the plant would be the cleanest, most efficient coal-fired power generator in the world. The transport gasifier is based on Kellogg Brown & Root technology used successfully in petroleum refining for more than 50 years and is especially effective for low-rank coal.

# COAL



## NETL Tests Suggest Improved Control Strategy for Fuel Cell-Turbine Hybrid Systems

—A paper detailing the results of tests in the NETL Hybrid Performance (Hyper) test facility showed that thermal management during load transients in a hybrid system's fuel cell component was improved by diverting air around the fuel cell system. By integrating simulation models with actual system hardware, the Hyper facility is able to develop and test control strategies needed to maintain harmonious operation of fuel cells and turbomachinery under varying loads. Changes in hardware output were successfully entered into the model to study system response in real time without exposing fragile fuel cell components to possible damage. The facility was able to establish this successful strategy using a control platform developed by Woodward Governor Company, NETL's partner in a cooperative research and development agreement. The combination of fuel cells and turbines to create hybrid systems is being investigated as an approach to meeting DOE's high-efficiency power generation targets. The paper reporting NETL's results was presented at the American Society of Mechanical Engineers' Power Conference and was recognized with a Best Paper Award at the society's Turbo Expo 2005.


## Modeling, Simulation, and Assessment

NETL scientists integrate physical and chemical experiments with computational modeling and simulation to better understand and develop technologies, materials, and energy systems powered by coal. Scientific computing is particularly important in addressing problems that are insoluble by traditional approaches, hazardous to study in the laboratory, or expensive to solve by traditional means. Researchers also produce roadmaps for success through periodic forecasts, resource assessments, reviews, and investigations.

## First Solid Oxide Fuel Cell System Installed at NETL

—NETL employed a 5-kilowatt solid oxide fuel cell system supplied by Acumentrics Corporation to conduct preliminary tests of its newly constructed DOE Fuel Cell Test Facility, built to provide independent verification of the performance and efficiency of SECA-developed prototype fuel cells. The facility reliably recorded all process parameters required for the accurate determination of overall system and stack efficiency, and results confirmed that it is ready for deployment. The facility allows for the use of natural gas or methane fuel. It is configured with both AC and DC load banks that can accommodate fuel cells up to 10 kilowatts in size and can monitor failure events using both facility and vendor data acquisition systems.





**Live FutureGen Plant Simulation Highlights Supercomputing Conference**—NETL and the Pittsburgh Supercomputing Center (PSC) demonstrated a real-time FutureGen power plant simulation at the Supercomputing 2004 Conference, the world's leading conference on high-performance computing, held in November in Pittsburgh, PA. The FutureGen demonstration used NETL's R&D 100 Award-winning Advanced Process Engineering Co-Simulator technology to combine the computer-run simulation at the conference with high-fidelity equipment models operating in parallel on a supercomputer at the PSC. The powerful three-dimensional visualization capabilities of NETL's simulator technology illustrate how it can help engineers understand and optimize the coupled fluid mechanics, heat and mass transfer, and chemical reactions that drive overall plant performance and efficiency.

**Coal Technology Performance Parameters Developed for National Energy Modeling System-Based Benefit Analysis**—NETL technology managers and systems analysts teaming with Office of Fossil Energy program managers developed coal technology performance parameters for use in a National Energy Modeling System-based economic benefit analysis. System-generated scenarios with and without projections of the economic consequences of successful research and development can be compared to determine the impact and public benefit of such efforts. Year-by-year projections for cost and efficiency were derived from programmatic goals set for the Office of Fossil Energy's Gasification Technologies, Carbon Sequestration, Innovations for Existing Plants, and Fuel Cells programs.

**Research Results Encourage Industry Development of Midwest Coalbed Methane**—An investigation completed in cooperation with NETL by researchers from the State Geological Surveys of Kentucky, Illinois, and Indiana and multiple industrial partners helped determine that the gas content and permeability of coal deposits in the Illinois Basin are higher than previously thought. Prior to the research, the gas flow rates anticipated from the thin coal seams characteristic of the region were considered too low to be of commercial interest. Project results presented at a Midwest Petroleum Technology Transfer Council symposium are encouraging industry development of this unused natural gas resource close to Chicago, Indianapolis, Louisville, and St. Louis.

**New NETL Supercomputer Clusters Among World's Top 500**—NETL made significant advances in its scientific computing capability with the installation of two new computer clusters—a 256-processor cluster and a 232-processor cluster. These clusters position NETL's in-house research computing capability at the forefront of fossil energy research and development facilities. The 256-processor cluster is optimized for computational fluid dynamics calculations, and the 232-processor cluster for computational chemistry calculations. Preliminary performance benchmarks indicate that the larger cluster would rank at number 435 on the list of the world's top 500 supercomputer sites compiled at [www.top500.org](http://www.top500.org), with the smaller one ranking around 458.

# GAS & OIL

## TAPPING DOMESTIC RESOURCES WITH INNOVATIVE TECHNOLOGY

*Natural gas and oil account for more than 60 percent of the energy consumed in the United States. Though domestic resources remain plentiful, they are increasingly concentrated in geologically challenging and operationally complex settings. Deep formations, deepwater offshore reserves, and lower-permeability formations require innovative exploration and production technologies, along with sustained attention to environmental protection. NETL's research focuses on low-cost technologies to expand the life expectancy of individual wells, innovations to tap bypassed reservoirs, and critical emerging resources, such as tight gas, deep gas, heavy oil, and a promising new resource, methane hydrate.*



## **G**as Exploration and Production

NETL's natural gas exploration and production activities help expand domestic natural gas supplies to fuel the nation's economy while protecting the environment. To meet increasing demands for natural gas, new supplies must come from remote, complex sources. NETL's gas exploration and production program strives to produce a balanced portfolio of projects that address a wide range of near- and long-term gas-supply issues.

### **Successful Drilling Technology Ready for**

**Commercialization**—In the fifth of a series of test wells, IntelliPipe™ successfully drilled 13,000 feet in 1,100 hours while providing high-speed, real-time telemetry. BP America drilled more than 50,000 feet in five Oklahoma wells with the revolutionary pipe. IntelliPipe is a conventional drilling tubular with a high-speed communications cable running its length encased in a protective conduit. IntelliPipe transmits real-time data on local geology, temperature, pressure, and rate-of-penetration from downhole to the surface and returns drill bit control signals in the other direction just as fast (2 million bits per second). Used with conventional measurement-while-drilling tools and sensors, the pipe's communications can almost instantaneously direct a drill bit more precisely toward oil- and gas-bearing deposits and away from less productive areas, enhancing oil and gas exploration efficiency and reducing the number of wells needed to produce a reservoir. Developed in cooperation with NETL by Novatek Engineering Inc. of Provo, UT, and Grant Prideco Inc. of Houston, TX, IntelliPipe has logged more than 3,000 operating hours in harsh conditions, including high-shock air drilling, and has demonstrated the handling characteristics of standard drilling tubulars. It is expected to be commercially available in 2006.

### **Commercial Orders Placed for Flexible Drill Pipe—**

Oman-based Torch International LLC has placed two orders, each for 1,000 feet of a new type of flexible, lightweight drill pipe made from space-age carbon fiber composites. The composite drill pipe, developed in cooperation with NETL by Advanced Composite Products and Technology Inc. of Huntington Beach, CA, can remain bent for extended periods without suffering fatigue damage. This feature makes the pipe particularly amenable to short-radius horizontal drilling, which allows economic production from mature oil and gas formations using existing wells, thus avoiding the environmental impact of new drilling.

# GAS & OIL

**Key Components of Prototype Tool Improve Deep-Well Drilling**—Following the successful feasibility testing of a measurement-while-drilling tool for use in drilling deep gas wells in hostile environments, researchers at Schlumberger Technology Corporation of Sugar Land, TX, advanced the concept by developing and testing two critical subsystems:

- An experimental downhole data-acquisition system—one that can be replaced from the surface without retrieving the entire drill string—successfully acquired internal and annular pressure in a demonstration test.
- The mechanical assembly, sensor-mounting scheme, and data-acquisition circuitry of an experimental direction-and-inclination subsystem performed successfully in initial temperature cycling and shock tests.

The prototype tool is being developed in cooperation with NETL to improve the economics of deep-well drilling by increasing overall rate of penetration and the accuracy of well placement in deep hostile environments. By continuously monitoring tool vibrations, gamma radiation, annular pressure, and inclination, the tool would provide the earlier real-time data needed to detect high-pressure gas zones, achieve optimum rates of penetration, and reduce drilling costs.

**Improved Drill Bits Operate Under Record Pressures**—TerraTek Inc. of Salt Lake City, UT, obtained benchmark rate-of-penetration data with various drill bits and drilling fluids under a simulated well bore pressure of 10,000 pounds per square inch—a record-setting simulation pressure for the industry. The data were obtained as part of the Deep Trek project, managed by NETL, in pursuit of improved drill bit designs for increased rate of penetration in high-pressure environments, a potentially significant source of cost reduction in drilling deep wells.

**Major Milestone Reached in Deep-Well-Drilling Electronic Components**—Honeywell International Inc. produced 11,000 integrated circuits of a precision amplifier designed to operate under hostile downhole conditions. Samples will be tested by the members of the Joint Industry Partnership of petroleum service companies and operators organized by Honeywell under this NETL-managed Deep Trek project. The amplifier is one of several electronic components being developed for high-temperature (greater than 250 °C) instrumentation to reliably characterize and estimate recoverable gas reserves in the deep gas well domain and for other “smart well” applications that will unlock deep domestic natural gas resources estimated at tens of trillions of cubic feet.

**Microhole Technology Prototype Tools Set for Production**—The INTEQ division of Baker Hughes Inc. is manufacturing two prototype tools designed to provide accurate and precise real-time geosteering in a drilling operation. The first is an ultraslim sensor for providing real-time information about the rock being drilled. The second is a rib-steering device for 2-inch coiled tubing. Fully assembled tools will be field-tested in 2006. INTEQ is developing microhole technology in cooperation with NETL as a method for drilling oil and gas wells faster, cheaper, and more safely by using small, portable coiled-tubing drilling rigs that minimize environmental impacts.

**Laser-Cutting Test Results Signal Breakthrough in Gas and Oil Well Completions**—Laboratory tests show that a fiber-optic laser can cut a 12-inch long tunnel (1–2 inches in diameter) in both sandstone and limestone. Post-laser tests confirmed a 10–15 percent improvement in the permeability of the sandstone sample along the tunnel wall—a great improvement compared to the rock-damaging explosive perforations used in industry. Other tests conducted in simulated wellbore and downhole environments showed that the stress and pressure differentials of operating at underbalanced conditions could actually increase laser-cutting efficiency by causing cuttings to be more readily ejected. These high-power laser results obtained in cooperation with NETL by the Gas Technology Institute in Des Plaines, IL, represent a significant milestone toward reducing costs and improving the quality and accuracy of gas and oil well completions.

**Sonic Cleaning of Scale Improves Gas Deliverability**—In cooperation with NETL, the project team of Furness-Newburge Inc. and TechSavants Inc. increased the flow potential of a gas storage injection and withdrawal well approximately 30 percent by descaling the wellbore with high-frequency sound waves. Each year more than 17,000 gas storage wells average a 5 percent loss in their rate of natural gas transfer because of some type of damage. Previous studies have shown that scale, in the form of inorganic precipitates, is one of the leading causes of damage. The team’s sonic technology represents a low-cost alternative to drilling new wells or employing less effective remediation technologies—approaches that cost the industry more than \$100 million per year.



**Lightweight Drill Rig Demonstrates the Potential to Provide Gas to Remote Alaskan Areas**—A commercial lightweight drilling rig was successfully applied by researchers from the University of Alaska Fairbanks to drill and core through permafrost and gravel to evaluate coalbed methane potential from two coal seams at Fort Yukon. The operation was funded through an interagency agreement between NETL and the U.S. Geological Survey in Denver, CO. While coal seam gas yields were low at Fort Yukon, reducing drilling costs could make coalbed methane an economic replacement for expensive diesel fuel in other rural towns.



**Advanced Hydraulic Fracture Mapping Reaches Milestone**—Working in cooperation with NETL, Pinnacle Technologies Inc. of San Francisco, CA, successfully tested an advanced microseismic hydraulic fracture mapping system with improved instrumentation that incorporates geophones and tiltmeters into one tool. The laboratory bench test established that signals from the colocated sensor types could be received and transmitted without interference—a breakthrough for the industry where each sensor type is normally placed in separate observation wells. Using a single observation well simplifies field operations and can lower costs for this type of testing. Roughly 95 percent of all gas well completions include hydraulic fracturing, and the information on reservoir architecture provided by associated microseismic data is important for commercial production.

**Project Spawns New Process for Treating Coalbed Methane-Produced Water**—Researchers at Drake Engineering Inc. of Helena, MT, have commercialized a new water treatment system based on ion adsorption for treating water produced during coalbed methane recovery. The system was developed as part of an NETL-administered University Coal Research Grant to Montana State University for investigating the remediation of coalbed methane-produced water to mitigate the risk of groundwater contamination and explore its beneficial use. The process will help operators continue to develop coalbed methane supplies from the Powder River Basin of Wyoming and Montana in an environmentally responsible manner.

## **G**as Transmission, Distribution, and Refining

Delivering natural gas is an enormous enterprise. It demands efficient, reliable delivery to consumers through a complex network of pipes, compressors, pumps, metering stations, and refining systems—often from remote sites. Also critical is an improved domestic energy infrastructure in the face of aging systems. NETL's research investigates how America's energy transportation, storage, and refining networks can meet these challenges economically and with minimal environmental impact.

# GAS & OIL

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**Novel Liquefied Natural Gas Technology Ready for Commercialization**—Through successful field tests of three critical components—a high-pressure pump, the Bishop Process™ heat exchanger, and an offshore mooring and product transfer system—Conversion Gas Imports L.P. and its partners brought their novel liquefied natural gas process into commercialization in under 3 years. The process will bring the cost of offshore liquefied natural gas terminal construction in line with land-based terminals while offering greater capacity, security, and deliverability than onshore facilities. HNG Storage Company is planning to file a port application for the commercial development of an offshore terminal based on Conversion Gas Imports' process.

**Gas Delivery Infrastructure Improved**—As part of several cooperative agreements with NETL, Southwest Research Institute of San Antonio, TX, has made progress in enhancing the existing infrastructure associated with gas transmission pipeline compressors and developing next-generation compressor technologies that will increase the efficiency, reliability, and integrity of natural gas pipeline operations. Notable accomplishments for 2005 include:

- Full-scale tests demonstrated that the NO<sub>x</sub> margin of a natural gas-fueled pipeline compressor engine can be reduced from 30 to 10 percent by using a closed-loop NO<sub>x</sub>-control system. The system broadens the permissible engine operating range, which could save approximately \$1.8 million in annual fuel costs for every 100 6-cylinder engines (assuming 80 percent utilization with gas at \$7.32 per million cubic feet). The technique could also allow certain engine models to meet mandated NO<sub>x</sub> limits without expensive retrofits, such as turbocharging, saving significant capital cost. Cooper Energy Services of Houston, TX, is considering the methodology for compressors having trouble maintaining permitted NO<sub>x</sub> limits in California.

- A technique for detecting potentially damaging surge within natural gas pipeline compressors was developed. Surge is typically avoided by recirculating a portion of the compressor discharge at low demand to maintain flow through the compressor above a predetermined minimum—an approach that wastes energy by recompressing the same gas. Using Southwest Research Institute's technique, compressor recirculation can be actuated only when surge is impending, allowing the compressor to function safely over an expanded range of flow rates with reduced use of recirculation. The technique could save operators \$50–\$70 million per year in compression fuel costs while conserving the gas wasted in the recirculation process. The Gas Machinery Research Council, which cofunded the project, is currently in negotiations with two manufacturers who wish to commercialize the surge-control system as a new tool for the natural gas industry.

- Proof-of-concept testing was completed for a semiactive valve designed to last longer than ordinary valves, the most frequently replaced components of reciprocating compressors in natural gas pipeline service. The new valve would replace the typical spring-loaded design with an electromagnetic feature (with the standard spring as a backup) that acts to oppose the closing motion just as the valve nears its seat, reducing the impact and wearing effect of closure by as much as 30 percent. Because valves are replaced every 3 months at an average cost of \$40,000 per compressor, the change in valve life anticipated with the new design could offer significant maintenance cost savings for the industry.

**Miniaturized Laser Spark Plug System Could Replace Conventional Plugs**—A miniaturized laser system under development by NETL researchers employs solid-state technology to produce a compact device that may replace existing spark plugs on natural-gas-fired reciprocating engines. The system produced pulse energy levels that were able to generate laser sparks in air. Additional improvements are being made in the laser packaging to make the system more robust for testing and operation. If successful, the technology would improve engine performance and lower emissions.



### **Robot Successfully Inspects Operating Gas Pipelines—**

During a field demonstration, a self-powered robot developed by the Northeast Gas Association, Carnegie Mellon University, and NETL successfully inspected 1 mile of a live natural gas distribution main in Brockport, NY. Developed primarily at Carnegie Mellon University, the wireless robotic platform is designed for unrestricted movement in the 6–8-inch pipelines that represent many natural gas distribution mains. The device can maneuver freely through valves, tees, and bends while transmitting images of the pipeline interior over distances of several miles. The robot's roaming range is currently about 5 miles, but with in-line battery recharging it could be unbounded. This year, the robot also successfully inspected 87 feet of a 7-inch operating gas distribution main in Vestal, NY, providing data to help New York State Electric and Gas isolate and decommission the section. Performing the same tasks using today's inspection technology—a camera on a 100-foot tether—would have required several costly excavations.

### **New Technology Verifies Natural Gas Pipeline**

**Integrity**—In cooperation with NETL, researchers from West Virginia University successfully tested a new technology for minimizing natural gas loss and enhancing the integrity, operational reliability, safety, and security of pipeline systems. Through continuous monitoring of acoustic signals carried with the gas stream in a transmission pipeline, the Portable Acoustic Monitoring Package detected simulated leaks from and strikes to the line in real time at a distance of 0.6 miles. The technology is rugged, versatile, and costs less than \$1,000 per unit. Strategic placement of multiple units would allow the monitoring of an entire pipeline network. No comparable method is available for detecting and locating third-party infringement and leaks in natural gas pipelines.

**Novel Energy Meter Produced**—In cooperation with NETL and the Gas Technology Institute, Southwest Research Institute has developed and satisfactorily tested a prototype meter that can determine the energy value of natural gas delivered to the customer at a much lower cost than current technology. The device uses measured properties to determine heating value and other key gas properties as accurately as a gas chromatograph. Several developers have signed agreements to commercialize the algorithms and the prototype device. The energy meter will replace existing devices at lower capital and operating costs, allow accurate accounting for gas storage transactions, and make energy content measurement practical at smaller installations.

### **Novel Tools Offer Time and Cost Savings for Pipeline Maintenance—**

In cooperation with NETL, investigators at the Timberline Tool Company in Whitefish, MT, demonstrated the operation of two unique tools for repairing damaged or defective polyethylene natural gas distribution pipelines. Both tools employ keyhole excavation, in which repair crews access buried lines from above ground through a 12–18-inch core hole, reducing the time, cost, and public inconvenience of excavations.

- The first commercial orders were placed for an innovative tool that can squeeze off pressurized gas flow through 3–6-inch polyethylene distribution pipeline. The novel device was developed through a series of Small Business Innovation Research grants for the safe repair and maintenance of aging pipelines. The lightweight tool is operable by a single person and replaces typical truck-mounted systems, which require significant excavation and labor to operate.
- Teaming with researchers at Oregon State University, Timberline developed a unique chemical and mechanical process to repair severely damaged polyethylene lines. The system employs a unique mechanical application tool and either a solvent-based gel or a commercially available heat-activated film to permanently bond the repair patch to the damaged pipe. The technology is the first to demonstrate effective repair and the return to pressurized service. Demonstrations have shown the system can completely repair pipe sections with a single 1-inch diameter hole, as well as with two opposing 1-inch diameter holes in a 6-inch diameter line.

### **National Oil and Gas Inspector Certification Program Established—**

Through an NETL-managed project, the Interstate Oil and Gas Compact Commission has developed a state-tailored national certification program that will improve the competence of inspectors and provide the regulated community with a more consistent and streamlined regulatory approach. The commission assists states in developing uniform regulations, applying technology, and informing the public about emerging energy issues, such as liquefied natural gas and hydrogen delivery and storage.



## **M**ethane Hydrate

Methane hydrate—molecules of natural gas trapped in ice crystals—is a mixed blessing. Reserve estimates indicate a vast energy resource—up to 200,000 trillion cubic feet worldwide. But this “ice that burns” also poses a threat to deepwater drilling that passes through overlying marine hydrate deposits. NETL is developing the knowledge and technology base to enable commercial production of methane from domestic deposits and ensure the safety of deepwater drilling operations.

**Methane Hydrate Research Cruise Completed**—The semisubmersible drilling vessel Uncle John entered the Gulf of Mexico in April 2005 for a 35-day research voyage as part of the Gulf of Mexico Gas Hydrates Joint Industry Project led by ChevronTexaco in cooperation with NETL. During the expedition, researchers collected full-well log suites, borehole seismic data, and more than 200 meters of core samples from shallow sediments under more than 4,000 feet of water. The cruise marked the first use of newly developed tools for measuring the acoustic properties of sediments at subsea pressure and temperature conditions. While all study sites were dominated by fine-grained sediment, one location, known as Keathley Canyon, contained hydrate in saturations up to 30 percent within fractured shale formations. This confirmed the connection between hydrate saturation and reservoir quality. A comparison of cruise findings with estimates of hydrate saturation showed that, with advanced data-processing techniques, industry standard seismic data have the potential to enable direct hydrate detection. The 4-year effort is primarily focused on developing technologies for characterizing hydrate through remote sensing and enabling safe drilling through or near gas hydrate.

**Researchers Identify Recoverable Methane Hydrate**—A project team led by BP Exploration (Alaska) Inc. is characterizing and quantifying the commercial potential of gas-hydrate and associated free-gas resources that lie above the oil-containing strata in the Prudhoe Bay, Kuparuk River, and Milne Point fields. Conducted in cooperation with NETL, the project has yielded the first delineated methane hydrate prospects and the first estimates of the technical and economic feasibility of hydrate production. Statistical analysis based on these data shows that the prospects contain more than 600 billion cubic feet of gas in gas hydrate above the northern portion of the Milne Point field alone, and more than 33 trillion cubic feet across the broader Alaska North Slope. As much as 12 trillion cubic feet of these resources may be recoverable.





## **O**il Exploration and Production

DOE's role in oil exploration and production is to facilitate the development of critical technologies where a federal presence is needed to achieve national energy goals. Through such techniques as CO<sub>2</sub> flooding and seismic identification methods, NETL develops the emerging technologies that hold the most promise for increasing the nation's domestic oil production and coordinates the rapid transfer of innovations to commercial use.

### **CO<sub>2</sub> Flooding Resuscitates Abandoned Kansas Oilfield—**

The Hall-Gurney Oilfield near Russell, KS, was once considered 100 percent depleted. However, in December 2003, the Kansas Geological Survey, in cooperation with NETL, began continuous CO<sub>2</sub> injection into a 10-acre portion of the field, and data collected in 2005 showed that production had exceeded 1,500 barrels. While continuous CO<sub>2</sub> injection has been used to enhance production from oilfields in other states, the 8-year Hall-Gurney project is providing valuable data on the economic and technical feasibility of using CO<sub>2</sub> flooding to recover residual and bypassed oil, particularly from reservoirs that have been water-flooded either naturally or by planned development. An estimated 500 million barrels of incremental oil could be produced in Kansas using the method. Incremental oil production began in mid-2004.

### **Pilot Project Yields More Oil in Oklahoma—**

Oil produced from shallow, naturally fractured, low-permeability Bartlesville sandstone in Osage County, OK, can generate \$2.9 million over 6 years using horizontal injection wells for water flooding compared to \$1.4 million over 30 years using conventional water-flooding approaches. This finding is a result of a simulation and economic evaluation based on a successful field test completed by Grand Resources Inc. of Tulsa, OK, in cooperation with NETL under a Native American Initiative grant. The project team found that horizontal water-flooding and related techniques result in higher incremental oil production than pre-project production rates. A prolific oil producer for 100 years, the Bartlesville sandstone formation has yielded less than 20 percent of its original oil-in-place through traditional water-floods.

### **Geochemical Exploration Technique Finds More Oil—**

In an NETL-managed project, researchers at Michigan Technological University demonstrated how surface geochemistry can be combined with traditional exploration methods to reduce the risk of drilling dry holes. At Springdale, MI, four out of four horizontal wildcat wells drilled based on geochemistry profiles encountered hydrocarbons, and two were placed into production. An earlier demonstration in the Vernon Field verified the technique for mature fields in the Michigan Basin. Project results have convinced oil and gas industry companies operating in Michigan to include geochemical surveys in assessing exploration prospects.

### **University of Houston Develops Breakthrough**

**Technology for Finding Oil—**Working in cooperation with NETL, University of Houston researchers have developed an improved seismic method for identifying reservoir compartmentalization in mature fields. Application of the method will lead to additional production from

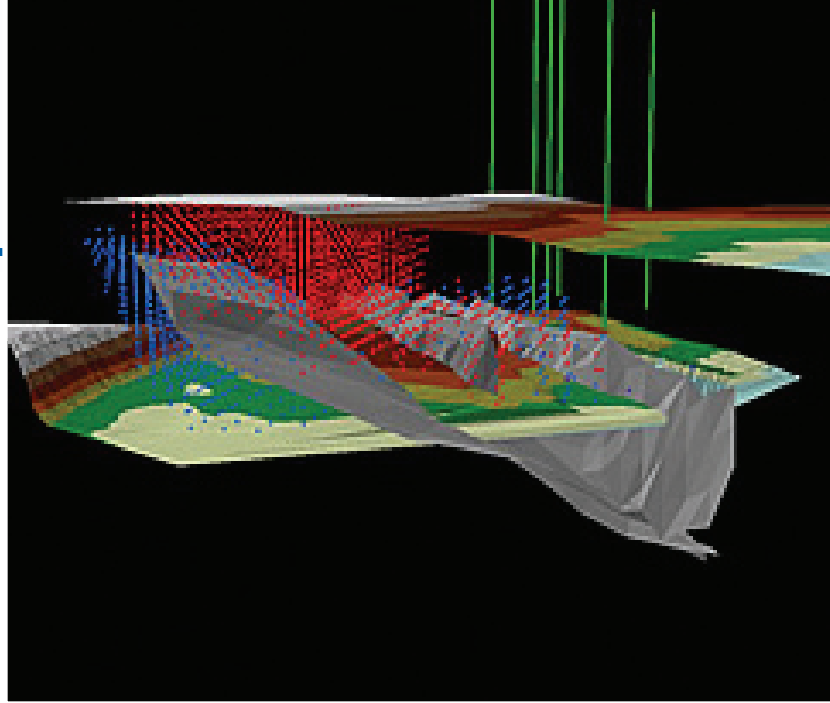
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mature and super-mature fields that in Texas alone have produced 5.3 billion barrels of oil to date. The method combines standard three-dimensional seismic and vertical seismic profile data to produce high-resolution images of reservoir compartmentalization and geometries of complex geological formations, such as salt domes and salt traps. The study produced six peer-reviewed articles for *Geophysics*, numerous presentations for industrial corporations and annual meetings of the Society of Exploration Geophysicists, and a Best Student Poster Award for images of the Vinton Salt Dome in Louisiana. It was also used to train a dozen doctoral- and masters-level geophysicists and was instrumental in naming the University of Houston as a Sun Microsystems Geoscience Center of Excellence, with receipt of \$5 million in modern computer hardware.

**New Method Improves Subsurface Imaging**—As oil and gas exploration moves into regions difficult and expensive to drill, more demands are placed on imaging for preliminary resource assessment. Now, researchers at Los Alamos National Laboratory, in cooperation with NETL and an industry consortium, have developed a suite of analysis tools that improves the reliability and efficiency of acquiring complex subsurface images of potential resources in increasingly problematic geological settings—notably highly prospective subsalt deepwater targets in the Gulf of Mexico.


**Wireless Surveillance Technology Optimizes Marginal Oil Well Production**—The Marginal Expense Oil Well Wireless Surveillance system, developed through a federal grant administered by NETL, is being patented by Vaquero Energy Inc. of Bakersfield, CA. The system monitors in real time the performance and production of rod-pumped wells. This affordable remote sensing and transmitting system will help optimize oil production based on the price of oil, which can mean the difference between profit and loss for marginal wells producing fewer than 10 barrels per day.

**Oilfield Problem-Solving Product Identified**—In an NETL-managed supercement project, researchers at Houston-based CSI Technologies were able to solve difficult downhole challenges and lower the overall maintenance cost of high-temperature, high-pressure well completions. After conventional cements failed, ULTRA SEAL®—a resin-based sealant produced by M&D Industries of Louisiana—sealed a persistent gas leak from the annular space of a well operated in the Gulf of Mexico. In another application, the resin sealed a leaking packer set in 7-inch casing at 10,559 feet with a bottomhole temperature of 205 °F.



## **M**odeling, Simulation, and Assessment

As they do with coal, NETL scientists integrate physical and chemical experiments with computational modeling and simulation to develop technologies associated with natural gas and oil. NETL and its partners also use a variety of assessment techniques that uncover new data, evaluate existing data, and complement the technological developments advanced through their energy research.



**Methane Hydrate Reservoir Simulator Released, Course Well Attended**—The first publicly available, fully dedicated methane hydrate reservoir simulator, TOUGH-Fx/HYDRATE v1.0, was officially released in March 2005 in conjunction with a week-long training course cosponsored by NETL and Lawrence Berkeley National Laboratory. The course drew an international audience representing private industry, research organizations, and academia. Led by the simulator's developer, the course introduced the capabilities and function of the model, which simulates the behavior of hydrate-bearing geological systems. The model will be used to evaluate hydrate production strategies for both permafrost and marine environments. Since its release, 20 no-cost licenses were issued to research organizations in eight countries. In addition, a commercial license was granted to a U.S. oil and gas company, and negotiations are in progress for licensing to two multinational oil and gas companies.

**Reservoir Simulation Software Ready for Use**—Researchers at the University of Texas at Austin developed a new-generation chemical-flooding simulator capable of efficiently and accurately simulating oil reservoirs in less than 24 hours. Using a cluster of personal computers working in parallel under a Linux operating system, the technology overcomes the limitations of the memory size and computational speed of traditional, high-end desktop computer workstations. The achievement, attained through a cooperative agreement with NETL, the state of Texas, and a joint industry partnership, will help minimize the risk involved in reservoir development decisions by allowing more detailed simulation with geological, physical, and chemical models.

**NETL Model Forecasts Increased Significance of Marginal Wells for Domestic Oil and Gas Production**—More than two-thirds of domestic wells are classified as marginally economic, each producing fewer than 10 barrels per day of oil or less than 60,000 cubic feet per day of natural gas. In 2003, however, the aggregate of these wells accounted for approximately 29 percent and 10 percent of onshore oil and gas production, respectively, from the contiguous United States. Based on recent production and well count trends, NETL forecasts that the total number of marginal natural gas wells will grow by over 60 percent to more than 400,000 by 2025. Modeling also shows that the volume of crude oil and natural gas from marginal wells will increase nearly 20 percent above 2003 volumes to approximately 4 trillion cubic feet equivalent.

Such forward-looking model output, including well counts, locations, economics, and other particulars, will be used to shape upcoming solicitations by the NETL-sponsored Stripper Well Consortium—an industry-driven consortium focused on the development, demonstration, and deployment of new technologies needed to improve production from natural gas and oil stripper wells.

**Unconventional Resources Abound in Appalachian and Illinois Basins**—A comprehensive resource assessment completed by the Regional Directors of the Interstate Oil and Gas Compact Commission in cooperation with NETL documented vast quantities of fossil resources yet to be produced in the already mature Appalachian and Illinois basins. Advanced technologies would be the key to unlocking more than 400 billion barrels of unconventional crude oil and as much as 90 trillion cubic feet of natural gas from an area covering 233,000 square miles in 10 states. Representing 37 gas- and oil-producing states, the commission assists in maximizing the production of domestic onshore oil and natural gas while maintaining high environmental protection standards and minimizing threats to security.

**Study Targets Vast Heavy Oil Resource on Alaska's North Slope**—As part of an NETL-managed project, University of Houston researchers identified an optimal recovery method for an untapped oil resource estimated at 36 billion barrels on Alaska's North Slope. The resource lies at shallow depths (3,000–3,500 feet), and its proximity to subsurface permafrost renders the already low-gravity crude extremely viscous and difficult to recover. The recommended procedure includes the tertiary recovery technique of combined water alternating with gas injection and electromagnetic heating. By identifying ways to fully commercialize the resource, the study will help stem declining North Slope production, which accounts for 20 percent (down from 25 percent) of domestic oil supplies.

# BEYOND

## WORKING BEYOND THE OFFICE OF FOSSIL ENERGY

*NETL is the lead research and development center for the Office of Fossil Energy, but it shares its wide-ranging expertise with other offices and departments within the federal government. Our nation's goals of energy security, reliability, conservation, and efficiency are best met through collaboration and coordination rather than isolated efforts. NETL supports DOE's Offices of Energy Efficiency and Renewable Energy (EERE), Electricity Delivery and Energy Reliability (OE), and Engineering and Construction Management (OECM) and the U.S. Department of Homeland Security.*





## Office of Energy Efficiency and Renewable Energy

**LED Project Achieves Technical Success**—In a project sponsored by NETL, Cree Inc., a leader in high-brightness LED solid state lighting component manufacturing, announced breakthrough performance results achieved in the continued development of its white XLamp™ 7090 power LED. Cree's advanced XLamp demonstrates maximum flux of 86 lumens, a 43 percent increase in brightness compared with the XLamp 7090 Cree currently has in production. The lamp has also reached an efficiency of 70 lumens per watt at 350 milliamperes, nearly matching the 80–90 lumen efficiency of fluorescent lightbulbs. These performance improvements demonstrate a major step toward meeting DOE's Solid State Lighting goal of developing a high-quality, low-cost, high-efficiency white LED by 2015.

**SAGE Electrochromics Changes the Light of Day**—SAGE Electrochromics Inc. made great strides in 2005 toward the widespread commercialization of SageGlass® electrochromic windows. Incorporating production systems and techniques developed as a result of projects sponsored by NETL, SAGE completed the construction and outfitting of a new, full-scale manufacturing plant that will increase its production capacity and range of window sizes available on the market. Electrochromic windows let in daylight and maintain a view, but they can be cleared or tinted electronically to control heat gain and glare for comfort and energy savings.

**BAIHP Demonstrates Homes That Are More Energy Efficient**—The Building America Industrialized Housing Partnership (BAIHP), managed by NETL and led by the University of Central Florida's Florida Solar Energy Center, helps factory and site home builders and developers produce, test, and showcase homes that are 30–50 percent more efficient but only marginally more expensive than conventional homes. For fiscal year 2005, the partnership reported the following accomplishments:

- Provided systems engineering technical assistance to over two dozen leading builders that led to the construction of highly marketable homes in Florida, North Dakota, Washington, Oregon, and Idaho and to awards for exemplary energy efficiency.
- Developed a patented high-efficiency condenser fan for air conditioning and heat pump systems and began the construction of test structures that deploy an innovative building-integrated night sky-based cooling system.

- In response to the Florida hurricanes of 2004, began researching retrofit approaches for hurricane-damaged residences to maximize energy efficiency and reduce future storm damage. In the wake of hurricane Katrina, the organization began working with Habitat for Humanity International to develop and disseminate design specification packages for replacement, retrofit, and Federal Emergency Management Agency housing that is durable, affordable, and energy efficient.
- Provided technical support to Congress Building America, wherein members of Congress partner with Habitat for Humanity to produce low-cost, energy-efficient housing.

**Capstone Completes Preproduction Testing of 200-Kilowatt Microturbine**—After 5,400 hours, Capstone Turbine Corporation completed preproduction testing of its 200-kilowatt microturbine, designated the C200 and called Beta 1. Beta 1 testing began in May 2004 at the National Fuel Cell Research Center and Combustion Lab at the University of California, Irvine. The microturbine demonstrated NO<sub>x</sub> emissions lower than 0.2 pounds per megawatt hour, a lower-heating-value efficiency of 34 percent, and 99 percent availability, with only two minor faults in the final 3,800 hours of testing. Beta 1 is being developed under EERE's Advanced Microturbine Project, managed by NETL.

**Precision Combustion Demonstrates Low Emissions in Gas Turbine Combustor**—Precision Combustion Inc. achieved promising results in high-pressure single-module testing of its piloted Rich Catalytic Lean-burn (RCL®) combustor. The RCL combustor demonstrated less than 3 parts per million NO<sub>x</sub> emissions and zero carbon monoxide emissions for a primary zone temperature range of 2,550–2,830 °F. As a result, NETL has extended its support of Precision's efforts. In 2006, the company will fabricate and test a set of 12 modules in a Solar Turbines Centaur gas turbine.

**High-Efficiency Low-NO<sub>x</sub> Reciprocating Engines Introduced by Caterpillar**—Caterpillar introduced its Advanced Reciprocating Engine System Phase I engine into the 2005 marketplace and is in the process of completing orders for over 100 engines in the megawatt size range, for a total of 1.3 gigawatts. These improved natural gas-fueled engines were developed under EERE's Distributed Energy Advanced Reciprocating Engine System program, managed by NETL. The engines have demonstrated a lower-heating-value efficiency of 44 percent and 1.0 gram per brake horsepower-hour of NO<sub>x</sub> emission.

# BEYOND

## Office of Electricity Delivery and Energy Reliability

**NETL Responds to National Disasters**—NETL's Energy Infrastructure and Security Research Group (EISRG) supports OE in emergency preparedness and response. In this role, EISRG leads and coordinates a national laboratory consortium known as the Visualization and Modeling Working Group (VMWG). Both independently and with VMWG, NETL conducts predictive and actual impact analyses during natural and manmade emergencies and exercises. Analyses include custom mapping, computer modeling, and written summaries of impacts and recovery efforts as they relate to the energy infrastructure. EISRG realized several significant accomplishments in 2005:

- During the 2005 hurricane season, EISRG led pre-, trans-, and post-event analyses for most named storms with full VMWG team activation for hurricanes Dennis, Katrina, Rita, and Wilma. Team analyses enabled decision makers to position staff and energy resources in advance to reduce emergency response times. EISRG and other NETL staff worked with OE, the Federal Emergency Management Agency, other emergency responders, state officials, and energy companies to resolve such issues as electrical outages and interruptions to transportation fuel supplies, oil and natural gas production, and refinery operations.
- EISRG analysts responded to the Powder River Basin coal transportation emergency of summer 2005. A 6-month service suspension for repairs to the South Powder River Basin Joint Line forced a major railway to reduce coal delivery to an estimated 80–85 percent of demand and resulted in a cascade of forces majeures through its customer coal and power companies. EISRG evaluated the situation on the ground, including the potential impact to the power grid, and helped federal agencies determine alternate fuel supplies in case of a severe shortage.

- In partnership with the Defense Department's Program Office for Mission Assurance, EISRG led VMWG through a high-level training exercise in which a major event widely disrupted natural gas and electrical infrastructures in the northwestern United States. NETL independently conducted smaller follow-up exercises that tested its response process. Using systems established over the previous two years, the exercises shortened EISRG's response time and trained headquarters personnel in EISRG procedures.

**NETL Develops Tools to Assist in Emergency Response**—NETL developed a web-based interface for the extranet site used by OE and Emergency Support Function-12 responders. This password-protected site provides information needed during an energy emergency, including energy, federal, state, and general information; response options and authorities; contacts; and maps. NETL also supported the design of OE's Emergency Operation Center logbook and its expansion of the incident response reporting and tracking procedures for duty officers.

**New Facility to Support Energy Infrastructure Decision Makers**—NETL worked with the West Virginia Army National Guard, the National Guard Bureau, and the United States Army Reserves to develop a conceptual design for the Joint Interagency Training Center East. NETL represented OE in the process, helping to establish design requirements and conceive a facility that would meet the needs of all agencies. Installation of the training center is planned for the West Virginia Army National Guard, Camp Dawson post, in Kingwood, WV. The facility—a joint effort between the Departments of Energy and Defense—is expected to support such enterprises as DOE's Emergency Operations Center simulator, which would train energy sector personnel in energy emergency response.



## **O**ffice of **E**ngineering and **C**onstruction Management

**NETL Manages Over 40 External Independent Reviews**—In support of OECM, NETL managed the completion of more than 40 external independent reviews on major DOE projects. Such reviews, required on all major capital acquisition projects, provide verification of the cost and schedule baseline before large projects are permitted to proceed by the responsible headquarters approving official. Since the review program began in 1999, more major projects are meeting their cost and schedule commitments. This success is attributed to the external independent reviews that have resulted in demonstrated improvements in the management of major projects within DOE.

**NETL Implements DOE’s Value Engineering Policy**—NETL directed the implementation of DOE’s value engineering policy (P 413.2) across the Department by establishing a joint effort between OECM and the Energy Facilities Contractors Group (EFCOG). Value engineering was formally chartered and incorporated into the EFCOG Engineering Practices Working Group, and formal value studies were conducted. One study resulted in a unified approach to the configuration management being adopted across DOE for facilities transitioning into closure. Five sites conservatively estimate that annual savings of \$16–20 million will be realized by adopting the study’s best practice recommendations. In addition, NETL led the development of a 3-day value engineering course, which is now included in Project Manager Career Development Program Level 2 certification training. Teaching federal project directors how to apply this valuable tool will increase its use in future DOE projects.

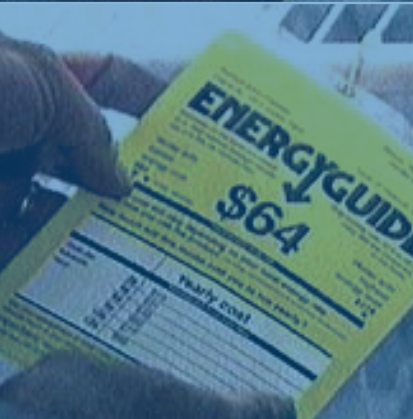
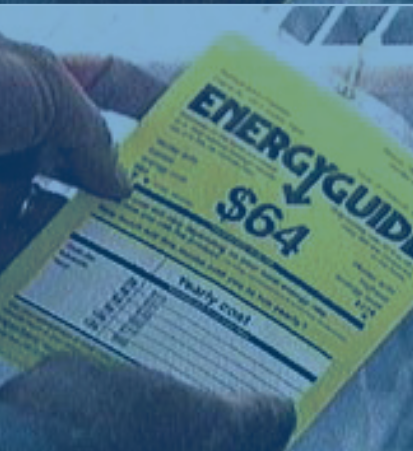
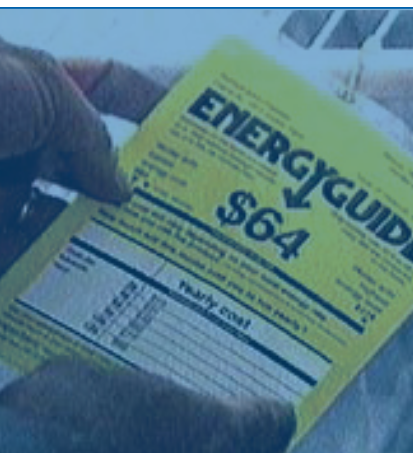
## **D**epartment of **H**omeland **S**ecurity

**NETL Provides Protective Equipment to Local Law Enforcement and Critical Chemical Sites**—NETL helped 54 local law enforcement agencies across the United States procure over \$1 million in monitoring and protective equipment. NETL also managed the pilot installation of Internet-enabled video surveillance systems that now monitor the buffer zones of critical U.S. assets in the chemical sector. The systems allow local law enforcement and the Department of Homeland Security to remotely monitor the selected sites.

# SHARING

## SHARING OUR ENERGY EXPERTISE

*NETL has long recognized that its vast knowledge of fossil fuels can benefit its research partners and the public at large. Through training courses, interagency cooperation, domestic and international workshops, and database exchanges, NETL plays a key role in supporting DOE's efforts to be the authoritative source of energy-related information in the nation.*







### **Technology Steers Drill Bit Through San Andreas**

**Fault**—In August, a deep observation well was drilled through the San Andreas Fault near Parkfield, CA, to study the mechanism of earthquake rupture in a seismically active portion of the fault. The 13,090-foot well trajectory was guided in part by a borehole seismic system developed by Paulsson Geophysical Services Inc. in cooperation with NETL. Paulsson's downhole seismic receiver array is the world's longest and consists of closely spaced, high-fidelity geophones that can withstand temperatures up to 400 °F and pressures up to 25,000 pounds per square inch. In addition to mapping the precise location of the San Andreas Fault, the borehole seismic tool recorded more than 1,000 earthquakes over a 2-week period, including many events too small to detect with conventional seismographs positioned on the ground. Developed under the Office of Fossil Energy's Oil and Gas Supply and Delivery research and development program with the intent of lowering exploration and production costs, this high-resolution seismic technology is demonstrating benefits beyond the energy sector.

**NETL Trains Foreign Service Officers**—For the sixth consecutive year, NETL organized and conducted a week-long course in coal and power technologies for Foreign Service Officers. Participants represented the U.S. Agency for International Development and the U.S. Departments of Commerce, Defense, Energy, and State, including Foreign Service Officers assigned to posts in Australia, Indonesia, Kazakhstan, and Kosovo. The mission of these officers is to identify export markets, negotiate international agreements, and interpret U.S. policies and interests for foreign governments, opinion leaders, and public citizens. Subject matter included:

- Electricity generation, transmission, and distribution
- The mining, preparation, combustion, gasification, and byproduct utilization of coal
- Natural gas-based power generation using turbines, microturbines, fuel cells, and other distributed energy technologies
- Hydrogen production
- Carbon sequestration and FutureGen

### **Three Projects Promote Clean Coal in Asia-Pacific Region**

**Region**—The Asia-Pacific Economic Cooperation (APEC) Expert Group on Clean Fossil Energy, chaired by NETL's International Coordination Team Leader, completed directing three projects aimed at promoting clean coal technologies in an Asia-Pacific region, which increasingly relies on coal for power generation.

- Powerhouse Engineering Ltd. assessed and ranked the costs and effectiveness of available approaches for improving the performance and reliability of older coal-fired power plants. The report covers overall pulverized-coal plant design and basic equipment operating concepts to help utility managers understand the costs and benefits of power plant upgrades and refurbishment.
- The Cooperative Research Centre for Greenhouse Gas Technologies, an Australian private-public partnership, completed a review of publicly available information on sedimentary basins to assess the geological storage potential for CO<sub>2</sub> in the APEC region. The location of large point sources of CO<sub>2</sub> emissions (e.g., power and fertilizer plants) were overlaid on digitized maps showing regional sedimentary basins so that promising sequestration sites could be identified.
- A team led by the Delhi Group of Ottawa, Ontario, provided training on CO<sub>2</sub> capture and geological sequestration during a 2-day workshop in relation to the First International Symposium on CO<sub>2</sub> Reduction and Sequestration held in January 2005, in Seoul, South Korea. More than 100 participants from Korean industry, government, academia, and nongovernmental organizations attended the course, developed to educate interested individuals and organizations throughout the region on the potential for capturing and storing CO<sub>2</sub> from large fossil fuel-based energy facilities. The training was supported by the Cooperative Research Centre for Greenhouse Gas Technologies, the Alberta Research Council of Edmonton, Alberta, and the GLOBE Foundation of Canada in Vancouver, British Columbia.



**American Firms Benefit from United States-China Pollution-Control Workshops**—For a second year, NETL collaborated with counterparts in China to organize a joint United States-China workshop on NO<sub>x</sub> and SO<sub>2</sub> control. More than 150 senior representatives of the ministry, other government agencies, major Chinese utilities, and related industries met with 47 representatives of 16 U.S. companies at the workshop held in Dalian, Liaoning Province, in August 2005. An adjunct workshop on the results of a joint study of postcombustion options to control NO<sub>x</sub> emissions from several Chinese coal-fired power plants was conducted the following day. Chinese utilities could spend an estimated \$6 billion in 2006 on equipment to control air pollution from new and existing coal-fired plants and \$22 billion over the next 15 years on flue gas desulfurization systems for coal-fired plants. The joint workshop series helped participating U.S. firms win a significant share of this market by facilitating a variety of business relationships with Chinese companies.

**Workshop Addresses Electricity Market in India**—A workshop in New Delhi in March 2005 attracted more than 250 participants and delegates from a broad spectrum of the Indian power sector to work on issues of regulation and financing facing the Indian power market. The workshop was organized through an interagency agreement between NETL and the U.S. Agency for International Development, with support from the U.S. National Association of Regulatory Utility Commissioners and India's National Thermal Power Corporation. The costs associated with India's plan to double its 109,000-megawatt generating capacity by 2012 are estimated at \$160 billion.

The expansion represents a great opportunity to export U.S. technologies for pollution control, power plant efficiency improvement, and advanced coal power developed through DOE-funded research, development, and demonstration programs. Significant opportunities also exist for U.S. firms to support and counsel Indian utilities on the changes required in the regulatory environment, such as balancing financial return against consumers' desire for affordable and reliable electricity.

**NETL Provides Clean Coal Chapter to High School Science Textbook**—At the invitation of the Museum of Science in Boston, MA, NETL staff contributed a chapter on clean coal technology for a new high school science textbook, *Engineering the Future: Designing the World of the 21st Century*. Written from a first-person perspective by practicing engineers, the textbook aims to foster students' creative talents and analytical skills by examining the engineer's central role in the interplay between societal advance and technological change. The Museum of Science plans to distribute the textbook nationally in 2006, initiating a process of improving public energy awareness that will lead to well-informed energy choices in the coming decades.

**NETL Discusses Approach for Interagency Collaboration**—NETL staff members were invited to EPA's Collaborative Problem-Solving Summit, held in Estes Park, CO, in September 2005, to discuss how the laboratory's successful approach to interagency collaboration leads to performance improvements and reduced operating costs. The summit, sponsored by EPA Region 8, brought together high-level field representatives from EPA, several bureaus within the Department of Interior, and several states in the Rocky Mountain region.

# SPOTLIGHT

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## SPOTLIGHTING OUR CONTRIBUTIONS

*External recognition affirms NETL's commitment to meeting America's energy and environmental challenges. Through awards, publications, and patents, NETL and its researchers received such recognition from a wide variety of stakeholders in 2005. NETL is pleased that its accomplishments have added value to our nation's efforts in advancing fossil energy technologies.*



# SPOTLIGHT

## Awards

**Four Products Earn 2005 R&D 100 Awards**—Four technologies developed with support from NETL were selected by an independent judging panel and the editors of R&D Magazine as among the 100 most technologically significant products introduced into the marketplace in 2004 and 2005. Recognized by industry, government, and academia as proof that a company has commercialized one of the most innovative ideas of the year, an R&D 100 Award provides an important boost to technologies just entering the marketplace. The four awardees are described below:

- Eltron Research Inc. of Boulder, CO, in partnership with NETL, has developed a novel high-flux hydrogen separation membrane material that shows stable performance under water-gas shift conditions. The membrane enables the efficient integration of hydrogen separation modules with water-gas shift reactors of certain coal gasification schemes. Successful scale-up of the Eltron membrane design will help increase thermal efficiencies and reduce the capital and operating costs of coal gasification-based FutureGen concepts.
- The Short-Radius Composite Drill Pipe, developed by Advanced Composite Products and Technology Inc. of Huntington Beach, CA, in cooperation with NETL, is a flexible, lightweight drill pipe made from space-age carbon fiber composites. The composite pipe is particularly amenable to horizontal drilling, allowing production from formations where much U.S. oil and gas remains. Able to remain bent for extended periods without suffering fatigue damage, the pipe allows access to these formations from old wells, thereby avoiding the environmental impact of drilling new ones.
- Ohio State University was recognized for its reference-free solid-state oxygen sensor used in high-temperature combustion applications. Developed in partnership with NETL, the ceramic device is inexpensive and small enough—1 centimeter in diameter and 0.3 centimeters thick—to permit multiple sensor placements for more precise control of the combustion process.
- Drill String Radar™, developed by Stolar Research Corporation of Raton, NM, in cooperation with NETL uses high-frequency radio waves to detect the planar boundaries of rock formations above drilled strata.

Designed for use with drilling systems, the highly specialized radar can estimate the orientation of fractures and bedding plans in layered materials, such as coal, sandstone, and limestone, helping to map, navigate, and detect hazards in unknown strata.

**NETL Technology Transfer Achievements Recognized**—The Federal Laboratory Consortium presented 2004 Technology Recognition and 2005 Excellence in Technology Transfer awards to NETL onsite researchers. Both awards recognize outstanding achievement in transferring a new technology from a federal laboratory to the commercial marketplace.

- The novel Combustion Control and Diagnostics Sensor (CCADS)—a patented gas turbine combustion control technology—received the 2005 Excellence in Technology Transfer Award. CCADS monitors several key combustion parameters and improves combustion control to reduce NO<sub>x</sub> emissions, increase reliability, and lower electricity costs. NETL has licensed CCADS to Woodward Industrial Controls for commercial development.
- A photochemical process for enhancing mercury removal from coal-produced flue gas received both awards. Developed by NETL researchers, the patented process will enable utilities to economically remove a large percentage of elemental mercury from flue gas with equipment similar to the ultraviolet lamp assemblies used for the purification of drinking water. Powerspan Corporation of New Durham, NH, has licensed the technology for application to coal-fired power plants.

**Innovator Wins Platts 2004 Global Energy Award**—Denver-based Vortex Flow Inc. won the Newcomer of the Year Award offered by *Platts POWER* magazine in New York City in December 2004. For the oil and gas industry, Vortex tools improve production and reduce operating costs by controlling single- or multiphase flow for more efficient oil and gas removal. Product testing of the Vortex VX was funded by the Stripper Well Consortium, which offers small, independent operators the opportunity to collaborate with technology developers and researchers across the country. The consortium is managed by Penn State University and receives funding from NETL and the New York State Energy Research and Development Authority. Now in their sixth year, the Platts Global Energy Awards have become the most prestigious in the industry.



**DOE Small Business Grantee Receives Low NO<sub>x</sub> Emissions Award**—The 2005 Gas Turbine Award was presented to Precision Combustion Inc. of North Haven, CT, by the American Society of Mechanical Engineers at its June 2005 Turbo Expo in Reno, NV. The award recognizes single- and combined-cycle combustion technologies designed to achieve very low NO<sub>x</sub> emissions without postcombustion controls or efficiency penalty. Under DOE's Small Business Innovation Research program, Precision Combustion developed its Rich Catalytic Lean-burn (RCL<sup>®</sup>) combustion technology in cooperation with NETL. Tests have confirmed single-digit parts-per-million levels of NO<sub>x</sub> and carbon monoxide emissions from natural and coal-derived gases using the advanced combustor.

**Praxair Researcher Receives American Society of Mechanical Engineers Award**—A Praxair Technology Inc. researcher received the 2004 Percy W. Nichols Award for notable achievement in the field of solid fuels for work sponsored by NETL. Named for a pioneer in the science and technology of fuels utilization, the award is presented annually to a member of the American Society of Mechanical Engineers or the American Institute of Mining, Metallurgical, and Petroleum Engineers. Praxair advanced the concept of oxygen-enhanced combustion, which it developed and commercialized in cooperation with NETL. During the 2003 ozone season, the system maintained generating capacity while reducing NO<sub>x</sub> emissions to below 0.15 pounds of NO<sub>x</sub> per million Btu at the Northeast Generation Services Mt. Tom Station in Holyoke, MA. The award presentation was made at the 30th International Technical Conference on Coal Utilization & Fuel Systems in Clearwater, FL, in April 2005.

**NETL Wins ESS&H Award**—The Office of Fossil Energy awarded NETL one of two 2005 Excellence in Environment, Security, Safety, and Health Awards for its implementation of a unique air sparge-bioremediation system near Gillette, WY. The system incorporates manifolds that direct contaminant-free air to selected monitor wells, volatilizing organic contaminants and increasing dissolved oxygen in the groundwater to enhance the biological population. As a result, contaminant reduction met state standards in less than 5 years. A conventional pump-and-treat system would have taken as many as 50 years to accomplish the same objective.

**Researcher Receives American Society of Materials Award**—A researcher for the Electric Power Research Institute was selected by the American Society of Materials International to receive the 2006 William Hunt Eisenman Award. The award recognizes unusual achievements in industry for the practical application of materials science and engineering. The researcher was recognized for his development of advanced boiler materials for next-generation ultra-supercritical coal-fired power plants. The work is funded by the Office of Fossil Energy's Materials Program managed by NETL.

**Multipollutant-Control Project Attracts Attention**—We Energies was recognized with an Award of Excellence for the environmental benefits offered by TOXECON<sup>™</sup> and the favorable economic impact of construction-related activities on Michigan's Upper Peninsula. In a cooperative agreement with NETL, We Energies conducted a full-scale test of the TOXECON technology at the Presque Isle Power Plant in Marquette, MI. The honor was bestowed at the annual meeting of Operation Action UP, an organization of private-sector leaders dedicated to the economic development of the once-depressed 15-county region. TOXECON is a patented sorbent-based technology developed by the Electric Power Research Institute as a low-cost retrofit option to achieve high levels (up to 90 percent) of mercury control at coal-fired power plants.

## **N**oteworthy Publications

**NETL Research Published in *Science***—Results obtained by NETL and Carnegie Mellon University were reported in the January 28, 2005, issue of the prestigious journal *Science*, published by the American Association for the Advancement of Science. Team members use advanced computational methods to predict hydrogen flux through engineered membranes. This approach offers time and cost savings in the development of advanced technologies by prescreening candidate membranes designed to separate hydrogen from other gases and impurities resulting from fossil-fuel utilization.



**Projects Produce Best Papers at 22nd Annual International Pittsburgh Coal Conference**—The paper selected “best” by the Pittsburgh Coal Conference advisory board was authored by researchers from Pratt & Whitney Rocketdyne, who, in cooperation with NETL, are developing a novel gasifier by applying rocket engine technology to gasifier design. The gasifier is expected to improve reliability and cost-efficiency in coal gasification power plants. NETL onsite researchers authored the first runner-up paper, which addresses NETL’s advancement of novel processes for capturing mercury in coal-fired power plant emissions.

**Methane Hydrate Project Report Judged Among 25 Best**—The March 2005 issue of *The LEADING EDGE* recognized an NETL-sponsored project report as one of the TOP 25 Papers presented at the Society of Exploration Geophysicists’ Annual Meeting held in Denver, CO, in October 2004. Chosen from more than 600 papers offered, the report describes a three-dimensional, vertical seismic profile at the site of the Hot Ice #1 well on Alaska’s North Slope. The report was presented by Anadarko Petroleum Corporation researchers, who completed the profile in an effort to map methane hydrate deposits in the vicinity of the well. *The LEADING EDGE* reaches roughly 20,000 subscribers worldwide, including a majority of U.S. geophysical professionals. In addition to recognition in the newsletter, the TOP 25 authors receive assistance for presenting their papers to other geophysical societies in the United States and overseas.

## Patents

**Project Produces Patent for Oil Shale Upgrading Process**—A U.S. patent was issued to James W. Bunger and Associates Inc. of Salt Lake City, UT, for a process that enhances the value of natural resources containing hydrocarbons. Developed as part of NETL-managed research on oil shale, the process employs a unique solvent system to separate the constituents of shale oil into two fractions. After solvent removal, the fractions are used directly or as feedstock for petroleum, chemical, and industrial products. The method allows separate processing of the fraction containing heteroatoms, such as nitrogen, which are undesirable in refining oil shale syncrude.

**Solid Sorbent for CO<sub>2</sub> Removal Receives Patent**—A new method for utilizing a low-cost CO<sub>2</sub> sorbent to capture CO<sub>2</sub> emitted from power plants received a U.S. patent. Developed by NETL as part of DOE’s research on carbon capture and sequestration, the method prepares the solid sorbent for CO<sub>2</sub> capture in gas streams at low temperatures (25–40 °C). NETL conducted bench-scale multicycle experiments with an industrial-scale unit sample to achieve 99 percent CO<sub>2</sub> removal from a simulated coal combustion gas stream at industry-accepted gas velocities. The capture capacity of the sorbent is twice that of the commercial amine technique, which is operated at similar capture temperatures. In addition, the solid sorbent can be regenerated at temperatures in excess of 35 °C.

**Patented Method Uses Bacteria to Produce Hydrogen**—An NETL researcher was issued a patent for a process that uses thermophilic bacteria to produce hydrogen gas from a variety of feedstocks. The bacteria maintain hydrogen production while tolerating relatively high concentrations of oxygen. Some of these organism types can tolerate oxygen levels close to that of ambient air for short periods of time at room temperature. Although most hydrogen gas today is produced by natural gas reformation or coal gasification, these processes are costly and environmentally unfriendly. Biological processes are attractive because they use renewable feedstocks, such as biomass and organic waste streams.

**Patented System Improves Monitoring Within Gas Turbines**—NETL patented a combustion monitoring sensor called Combustion Control and Diagnostics Sensor (CCADS) that detects and assesses conditions within gas turbine combustors. A number of available detection systems concurrently measure and control the behavior of flames and the overall combustion process in gas turbines. However, NETL researchers recognized the need for a system that is fast, durable, and requires minimal burner-assembly and operating-parameter modifications. The patented sensor has been successfully tested in industrial settings.





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