2008 NETL Accomplishments

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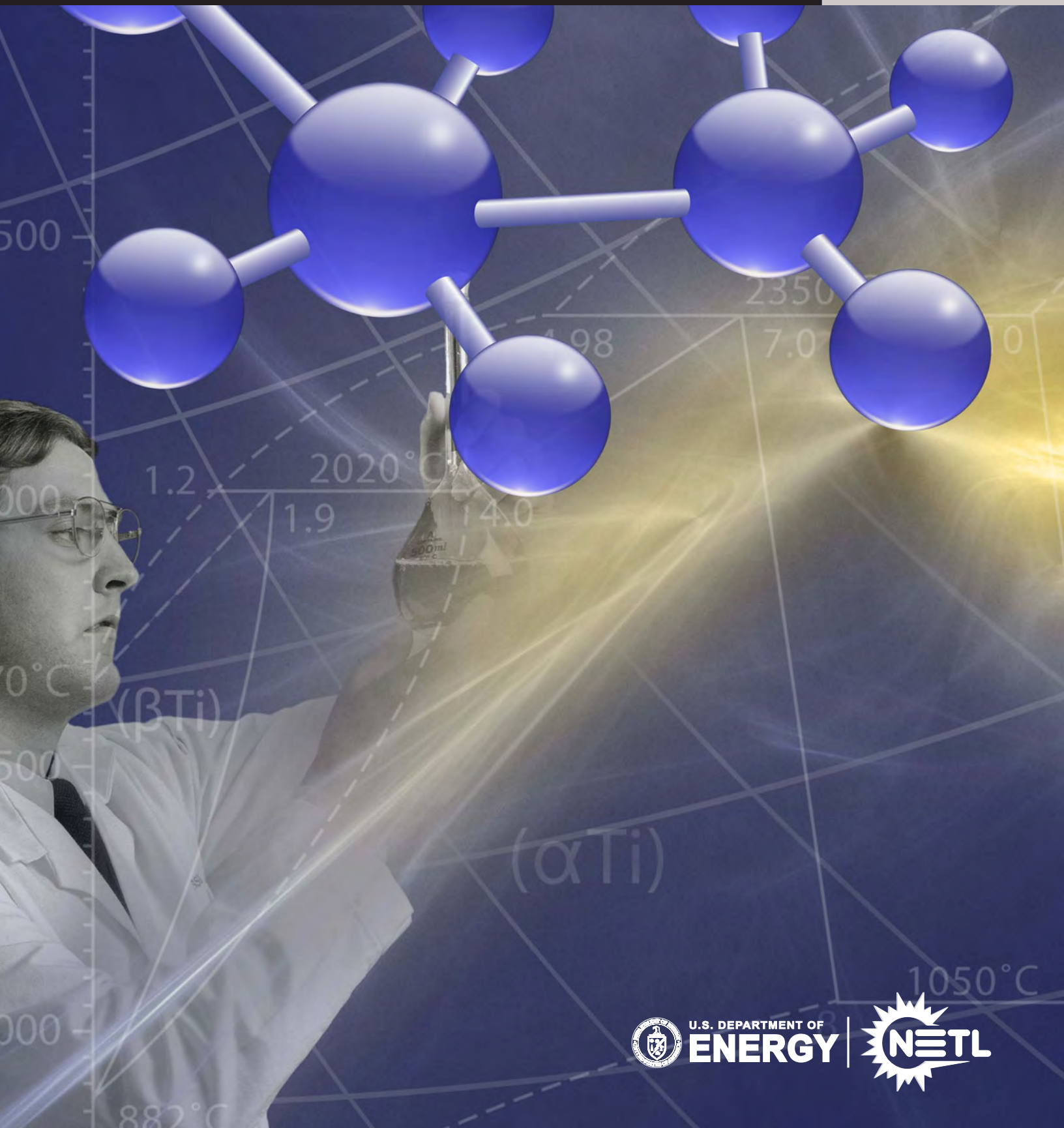
NATIONAL ENERGY TECHNOLOGY LABORATORY — the ENERGY lab



U.S. DEPARTMENT OF ENERGY | NETL

Mission

Advancing energy options to fuel our economy, strengthen our security, and improve our environment.

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Facing page—*NETL's new Technology Support Facility meets the highest Federal guidelines for energy conservation and efficiency. See page 18 for the full story.*

Renewed Prosperity Through Technological Innovation

Early in 2008, discussions about America's energy economy revolved around the rise of oil prices to over $100 per barrel and the renewed search for alternative fuel supplies with improved environmental performance. Today, as oil prices have eased, the national and global economic recession presents a new challenge: our Nation's ability to adopt a broader portfolio of energy resources while moving aggressively toward large-scale environmental solutions.

The compound challenge of propelling economic recovery, reducing greenhouse gas emissions, and enhancing the use of domestic energy resources is formidable, but it is also surmountable. As they have in the past, American scientists and engineers will deliver breakthrough innovations that help to provide abundant, affordable, environmentally sustainable energy, the basis of our national prosperity.

The National Energy Technology Laboratory (NETL), under the direction of the U.S. Department of Energy (DOE), takes a holistic view of the three areas we must consider to find effective energy solutions: environment, economy, and supply. Throughout our 100-year history, NETL has sought to balance these areas through energy research and technological innovation. The Laboratory develops technologies and processes that answer each decade's pressing energy issues and provides our Nation's policymakers with the scientific information they need to set sound energy policy.

By connecting basic and applied research, NETL develops and demonstrates advanced technologies to help the United States realize near-zero emission power production; increase demand- and production-side efficiencies; enhance proven, unconventional, new, and renewable energy sources; and modernize our Nation's energy infrastructure.

We analyze the dynamics of complex energy systems and the risks and benefits of pursuing various technology pathways. And we integrate our research and analysis with the efforts of our fellow national laboratories, other government agencies, industry, academia, and international research organizations.

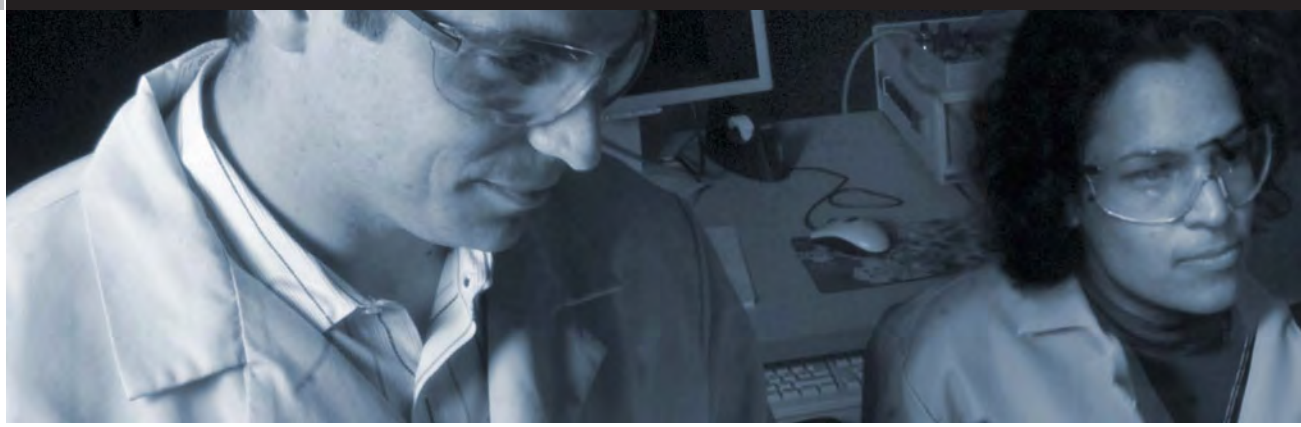
NETL's reputation as an innovator stretches back to the 1910 creation of the Pittsburgh Experiment Station. Our evolution has paralleled the transformation of the U.S. energy economy from a system almost entirely dependent on fossil fuels to the current mix of fossil energy, hydropower, nuclear energy, and renewable resources. Our work reflects this mix, as our scientists, engineers, and analysts advance not only coal- and natural gas-based power systems, but vehicle technologies, fuel cells, hydrogen turbines, water conservation technologies, and the potential of methane hydrates and fossil-biomass blends as new energy feedstocks .

Through these research activities, NETL is helping to assert America's leadership in solving the world's energy and environmental issues. Building on nearly a century of Federal energy research, we are developing and deploying modern technologies, creating jobs, and preparing our Nation's next generation of scientists and engineers—a resource as important as our energy supplies themselves.

I am pleased and proud to be part of such an important endeavor and to work with exceptional colleagues, who invest themselves wholeheartedly in addressing the energy needs of the Nation and the world.

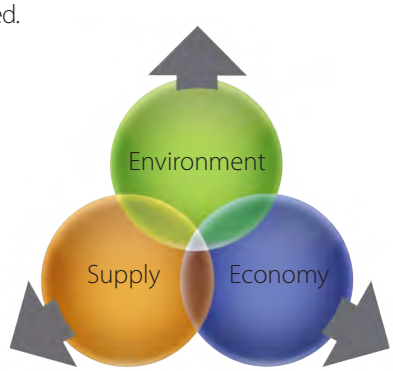
Carl O. Bauer, Director
National Energy Technology Laboratory

NETL: the ENERGY lab

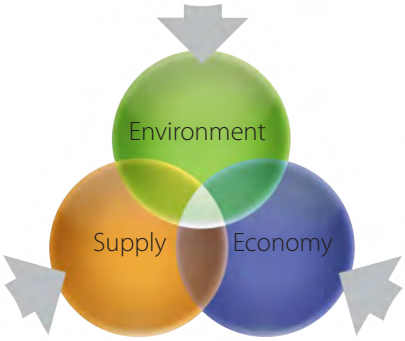


The energy economy is the complex system that allows us to extract, convert, deliver, and consume energy for electricity, transportation, industry, and home use. For 200 years, America's prosperity has been built on the bounty of its energy economy, and secure, reliable energy supplies remain essential to U.S. stability and growth.

To illustrate the dynamics of producing and using energy, NETL employs a Venn diagram showing three spheres labeled "environment," "supply," and "economy." When energy strategies consider these underlying spheres of influence separately, the importance of one may be viewed as greater than that of the other two. Such a one-dimensional approach, however, creates a competitive tension that pulls the spheres in opposite directions. Significant improvements may be realized in one sphere, but the others are left stagnant, or even damaged.



In a healthy energy economy, energy leaders consider the three interrelated spheres as a single issue that demands our careful attention. NETL develops and demonstrates technology solutions that push the spheres closer together, with the ultimate goal of finding tools and processes that drive toward the center mark, concurrently addressing multiple areas of concern.



One area of NETL research that hits that center mark is our Carbon Sequestration Program. NETL and its partners are developing technologies to capture, transport, and store the carbon dioxide (CO_2) produced by stationary sources without adversely affecting energy supplies or hindering economic growth. NETL envisions having a technology portfolio ready by 2020 that provides for the safe, cost-effective carbon management that will meet our Nation's goals for reducing greenhouse gas emissions.

A large part of this program is NETL's domestic and international transfer of technologies and processes. NETL sponsors the Regional Carbon Sequestration Partnerships, a government-industry effort to determine the technologies, regulations, and infrastructure changes needed to achieve carbon management in various regions of the United States and Canada. In addition, the majority of our collaboration with international research organizations, including the Carbon Sequestration Leadership Forum, focuses on technologies that can handle the scale of capture required by commercial power plants, by far the largest stationary producers of CO_2.

NETL is also hitting the target through our work with DOE's Office of Energy Efficiency and Renewable Energy. NETL researchers apply their technical and project management expertise to the development of demand-side technologies with high rates of efficiency. By using a smaller energy stream to achieve the same level of service, we can stretch domestic fuel supplies, shrink our environmental footprint, and save money.

Other research areas pursued by NETL drive toward the center. The Laboratory is studying the water-energy nexus, perhaps the most significant environmental issue after greenhouse gas reduction. We are investigating the potential of methane hydrate as a new energy resource that could dwarf known oil and natural gas reserves. And we are pursuing fuel cells, the smart grid, and other technologies to enhance domestic energy supplies and reduce the total environmental impact of energy production and use.

NETL believes in America's capacity to lead the development of advanced energy solutions. We believe the energy economy can be transformed through scientific discovery and technological innovation. We believe in our collective ability to find economic solutions to environmental challenges, expand our energy resources without undue cost, and use those resources in environmentally sustainable ways.

Throughout 100 years of scientific research, development, and demonstration, NETL has risen to the increasingly complex energy challenges faced by the United States and the world. Our research is wide-ranging. Our partnerships are far-reaching. By changing today's landscape of energy supply and demand, we are shaping the future of our Nation's energy economy. It is these endeavors, and the accomplishments to which they give rise, that make NETL the ENERGY lab.

Top image—*NETL researcher Chris Matranga and Dr. Neetha Khan begin an atomic-level materials analysis with a surface science and analysis instrument at the Laboratory's Office of Research and Development.*

Environment, Economy, & Supply

Hitting the Target

Image courtesy of Cree, Inc.

NETL combines advanced science and technology, complex systems analysis, and collaborative project management to help our Nation realize clean, affordable, abundant energy resources. All of these capabilities are essential to solving today's most pressing energy issue: the reduction of greenhouse gases to curb climate change. Through carbon capture and storage, we are tackling emissions from stationary sources, such as coal- and gas-fired power plants and industrial facilities. Through energy efficiency, we are helping reduce overall energy consumption to slash associated CO_2 production, extend domestic fuel supplies, and make energy more affordable for everyone.

Facing page—With stunning visual effect, NETL-supported XLamp® technology provides dramatic lighting to the exterior of China's Olympic National Stadium, also called "the Bird's Nest." See story on page 15.

Carbon Capture and Storage

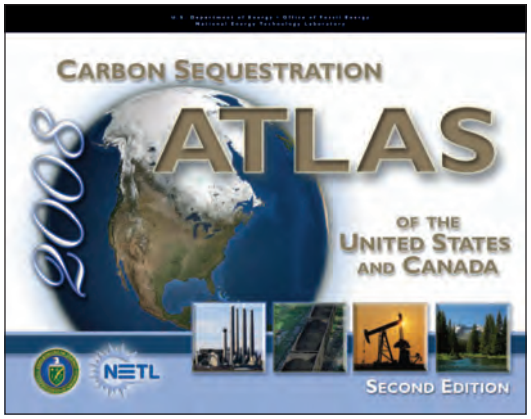
Since the 1990s, NETL has investigated technologies for capturing and storing CO_2 emissions from stationary sources. Carbon capture and storage is a primary means of reducing CO_2 emissions to curb climate change until other energy supplies—including solar, wind, nuclear, and hydrogen-based power—can be scaled to meet growing energy demand. NETL focuses on the fundamental mechanisms at work during CO_2 capture and storage, reducing costs, developing monitoring, verification, and accounting protocols, and developing methods for producing a sequestration-ready CO_2 stream and safely and effectively storing that stream. NETL's Regional Carbon Sequestration Partnerships initiative is demonstrating the permanent storage of CO_2 in terrestrial and geologic sinks.

NETL Sheds New Light on Unique Class of CO_2 Capture Materials—NETL researchers developed and applied a new optical technique to show for the first time that structural changes are responsible for the high CO_2 capture capacity of a new nickel-based metal-organic framework. Able to differentiate between captured CO_2 molecules and those still in the gas phase, the experimental technique uses infrared light to probe changes in the crystalline structure of the capture material that occur because of exposure to CO_2. The new approach, which relies on an optical phenomenon called "attenuated total reflectance," can provide molecular-level understanding of the CO_2 storage process that will enable computational chemists to model and design new capture materials.

NETL Computer Code Increases Accuracy of Reservoir Production Estimations—NETL researchers have established how to accurately model the flow of liquids and gases in underground reservoirs containing porous and/or fractured rock. NETL has incorporated this information into its NetfLow™ modeling software program, which it recently modified to run on parallel computers, increasing computational speeds by up to three times those attained by the nonparallel version. Using NetfLow, NETL is developing physically sound equations for the displacement of brine water and oil by CO_2 during carbon sequestration, among other applications.

NETL Study Describes Affordable Low-Carbon Diesel Fuel from Coal and Biomass—The NETL study, "Affordable, Low-Carbon Diesel Fuel from Coal and Biomass," has found that commercially demonstrated technologies can be used to produce affordable diesel fuel from coal and from a coal-biomass feedstock. The study focuses on integrating gasification, Fischer-Tropsch synthesis, and carbon sequestration to address the environmental, economic, and supply challenges of the U.S. transportation sector. Coal-based diesel fuel contains less carbon than conventional diesel fuels, and by adding up to 30 percent of a non-food biomass such as switchgrass to the coal feed, the carbon content is reduced even further. Producing fuel from coal could result in a profitable industry with associated domestic job creation, and the fuels produced by this pathway will become progressively more affordable if a carbon tax or trading scheme is put into place. The report can be accessed through the NETL website at www.netl.doe.gov/energy-analyses/ref-shelf.html.

NETL Method Estimates CO_2 Storage Capacity—NETL scientists have devised a way to estimate the CO_2 storage capacity of the Oriskany brine formation of central NY and northern PA. Employing geographic information system data, they have created two sets of mathematical equations: one to define the capacity of the formation's deep brine reservoirs to contain dissolved CO_2 and the other to calculate its capacity for holding pure, compressed CO_2. The first set of calculations—experimentally validated—show that the brine can store approximately 360 million metric tons of dissolved CO_2. When the CO_2 is in a supercritical form, the second set of calculations theorize that as much as 8.8 billion metric tons of pure CO_2 may be sequestered. A paper describing the study appears in the American Chemical Society publication, *Environmental Science and Technology*, February 9, 2008, issue.



Updated *Carbon Sequestration Atlas of the United States and Canada* Now Available

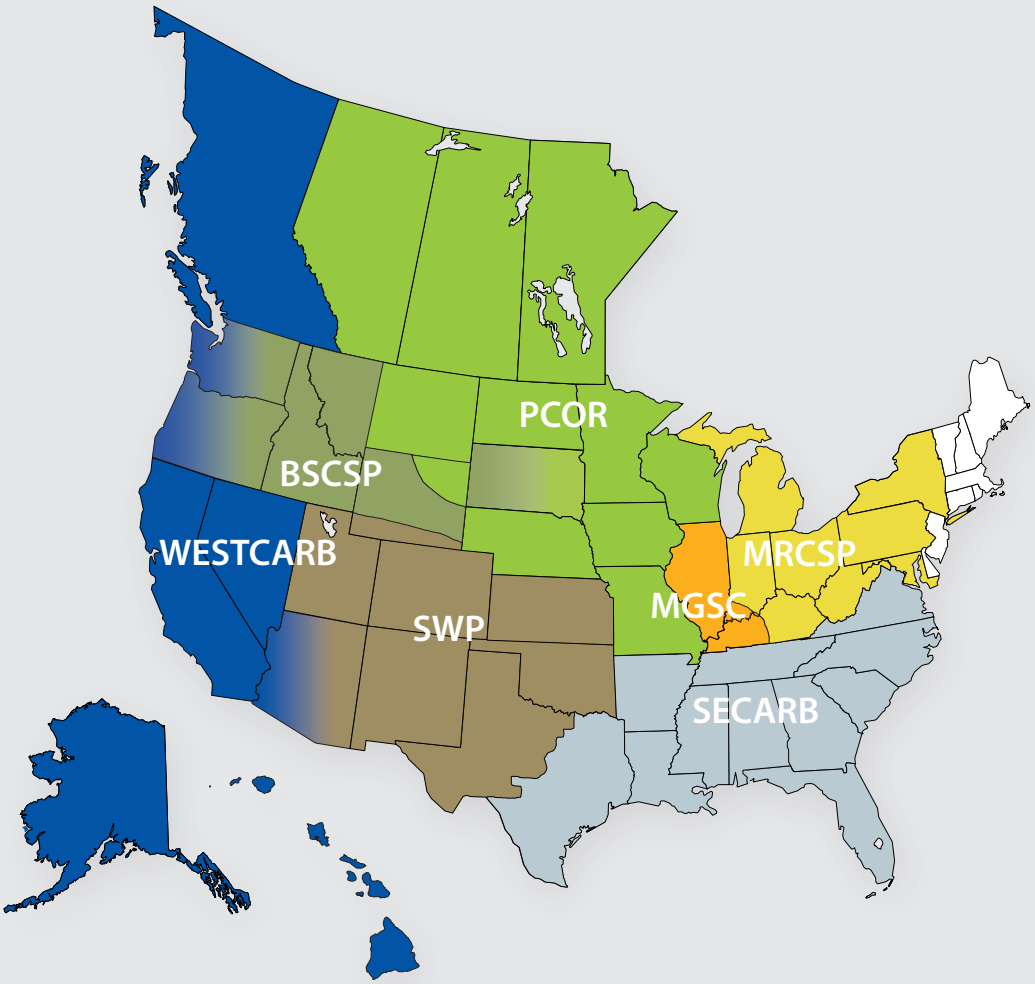
NETL has published a new edition of its award-winning *Carbon Sequestration Atlas of the United States and Canada*, which contains extensive information assembled by the seven NETL-managed Regional Carbon Sequestration Partnerships. The *Atlas* features updated maps illustrating the number, location, and magnitude of CO_2 sources in the United States and portions of Canada. Preliminary estimates suggest that the various geologic formations in North America could store more than 1,100 years of annual CO_2 emissions from the identified sources.

Also found in the new *Atlas* are information on NETL's revised Carbon Sequestration Program, results of Federal lands and CO_2 pipeline studies from NETL, estimates of CO_2 storage by State, and information about commercialization opportunities for carbon capture and storage technologies in each area of the country. The *Atlas* can be downloaded at www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasII/.

An interactive online version of the *Atlas* is available through the National Carbon Sequestration Database and Geographic Information System (NATCARB) at www.natcarb.org. NATCARB is a geographic information system that integrates carbon sequestration data from the Partnerships and various other sources to provide a view of carbon capture and storage potential in the United States and Canada.

NETL Research Improves Estimates of CO_2 Storage Capacity in Deep Coal Seams—Coal powder samples can be useful in estimating the CO_2-sorption capacity of shallow coal seams under low-pressure conditions. However, at the supercritical pressures found in deep coal seams, estimates vary widely among measurement techniques. NETL researchers have found that if the texture of coal after grinding is not exactly the same as before grinding, the high-pressure sorption capacity estimates based on the powder tests are likely to be misleading. NETL has also established a method for making more accurate predictions by keeping samples in equilibrium for longer periods. Results of a 9 month-long sorption-desorption study comparing the CO_2 storage capacity of dry Upper Freeport coal samples in powder and lump forms are reported in the American Chemical Society journal, *Energy & Fuels*, in the February 13, 2008, issue.

NETL Wellbore Integrity Research Informs Federal Policy on CO_2 Injection—In formulating a proposed rule on subterranean CO_2 injection, the U.S. Environmental Protection Agency relied on results of a study conducted by NETL and Carnegie Mellon University on the degradation of wellbore cement in the presence of CO_2. The research increased scientific understanding of the chemical reactions that occur among CO_2, brine water, and cement under carbon sequestration conditions, and indicated that corrosion of cement is not likely to cause failure in a properly completed well. Results of a year-long test that were extrapolated to predict longer-term behavior show excellent agreement with both the nature and extent of chemical reactions evident in field samples taken from an enhanced oil recovery site exposed to CO_2 for 30 years. The work is described in the July 2008 edition of the American Chemical Society publication, *Environmental Science & Technology*.



The seven NETL-managed Regional Carbon Sequestration Partnerships are Big Sky Regional Carbon Sequestration Partnership (BSCSP), Plains CO_2 Reduction Partnership (PCOR), Midwest Geological Sequestration Consortium (MGSC), Midwest Regional Carbon Sequestration Partnership (MRCSP), Southeast Regional Carbon Sequestration Partnership (SECARB), Southwest Regional Partnership on Carbon Sequestration (SWP), and West Coast Regional Carbon Sequestration Partnership (WESTCARB).

Partnerships Work to Reduce Atmospheric CO_2

The rise of average global temperatures is the most pressing environmental issue facing the world today. The power production required for modern living is a significant source of man-made CO_2 emissions, considered a major contributor to global warming. NETL is developing ways to sharply curtail these emissions through innovative research and strategies to put new technologies into practice.

In 2003, under DOE's Office of Fossil Energy, NETL launched the Regional Carbon Sequestration Partnerships, a strategy to involve multiple regions of the United States and Canada in CO_2-mitigation efforts. NETL leads the Partnerships through management, funding, organizing working groups, providing technical oversight, and organizing conferences where technologies and lessons learned can be shared.

The 7 Partnerships represent over 350 State agencies, universities, and private companies in 43 States and 4 Canadian Provinces. They are developing the best methods in their regions for storing CO_2, as well as creating public outreach documents, websites, and digital data information systems to further the understanding of CO_2 capture and storage. From the Partnerships' input, NETL has produced a valuable resource document, *The Carbon Sequestration Atlas of the United States and Canada*, and has prepared a best-practice manual for monitoring, verification, and accounting.

Phase I of the Partnership effort, completed in 2005, focused on characterizing each region and developing a framework for validating and potentially deploying CO_2 capture and sequestration technologies. The Partnerships established a national network of companies, professionals, and government officials interested in sequestration, created the National Carbon Sequestration Database and Geographic Information System (NATCARB), and raised awareness of CO_2 capture and storage as an option for mitigating greenhouse gases. Phase II is implementing small-volume field tests of geologic and terrestrial sequestration in areas found favorable for carbon storage during Phase I. Tests are expected to be completed by 2010.

Phase III began in 2008 and will run through 2017. Large-volume sequestration efforts will answer questions about such practical issues as sustainability, design of wells (for both integrity and capacity), and reservoir behavior with prolonged injections. Key operational issues will vary, because each region has distinct geologic formations, overlying seals, and structural concerns that can affect the safe and permanent storage of CO_2. Results from the Partnerships' Phase III efforts will provide the foundation for commercialization of carbon capture and storage technology, opening the door for new and existing power plants and fuel processing facilities to be fitted with CO_2 capture technologies. The goal of this effort is to have the commercial deployment of carbon capture and storage ready and cost effective by 2020.

Several of the partnerships initiated field tests in 2008:

- SECARB initiated innovative real-time monitoring of CO_2 injection for enhanced oil recovery. They are using scientific instrumentation installed nearly two miles beneath the surface of the earth to track the movement of the CO_2. The injection, performed by Texas-based Denbury Resources, Inc., will continue over the next several years at the rate of 250,000–500,000 metric tons per year at the Cranfield oil field, near Natchez, MS. The oil field is representative of the high-quality storage options that exist throughout the Gulf Coast region in the lower Tuscaloosa Formation.

- SWP began CO_2 injection into a 3,000 foot-deep unmineable coal seam in the San Juan Basin near Navajo City, NM. Injection of up to 35,000 tons of CO_2 is planned over the next 12 months. The pilot project includes a comprehensive monitoring plan that is designed to determine the fate of the injected CO_2 within the coal seam.

- MRCSP injected approximately 10,250 metric tons of CO_2 from a nearby gas processing plant into a saline formation 3,200–3,500 feet underground near Gaylord, MI. The injection was the first into a domestic saline formation undertaken by the Partnerships. Saline formations have a greater estimated capacity for storing CO_2 than depleted oil fields, gas fields, and unmineable coal seams combined.

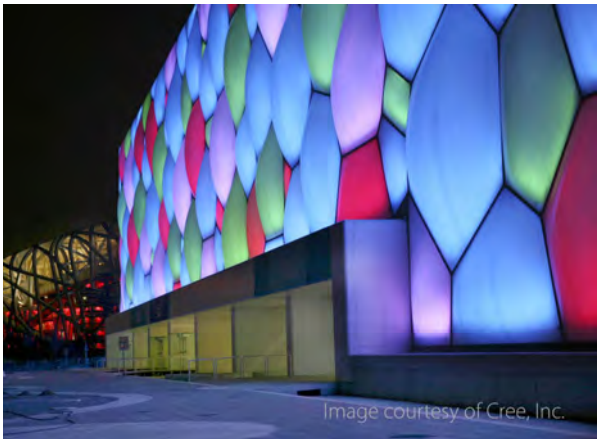
NETL Studies the Retrofit and Repowering of Conventional Pulverized Coal Power Plants for CO_2 Capture—To conform to anticipated efforts to curb carbon emissions from stationary sources, existing coal-fired power plants will need to make significant adaptations or face closure. NETL undertook an integrated analysis that models retrofit costs as a function of basic plant characteristics, such as heat rate, in the National Energy Modeling System (NEMS). The analysis included tradeoffs among retrofit, retirement, and the purchase of emission allowances, as well as the addition of repowering by means of integrated gasification combined cycle (IGCC) technology configured for capture and sequestration in a brownfield setting. NETL's series of three reports on this topic can be accessed at www.netl.doe.gov/energy-analyses/benefit.html.

Innovative Compressor Design Concept Could Cut Cost of Carbon Sequestration—As part of a cooperative agreement between NETL and Southwest Research Institute, the second phase of a conceptual design effort was initiated on July 1, 2008. The project aims to reduce the power required to compress CO_2 produced from an IGCC power plant. The project team at Southwest will test a liquid CO_2 pumping loop and a closed-loop CO_2 compressor with internal cooling to validate the thermodynamic predictions generated in Phase I of the effort. Phase II also seeks to quantify actual power savings. Modeling results show that combined power savings of 25 percent for CO_2 compression and 30 percent for pumping CO_2 are possible. These savings would reduce the associated power penalty at a 700-megawatt power plant by over 12 megawatts. More efficient and less costly carbon capture technologies will benefit the Office of Fossil Energy's Innovations for Existing Plants and Advanced Turbines programs being implemented by NETL.

Demand-Side Efficiencies

NETL maintains a strong commitment to energy efficiency as the most effective route to maximizing U.S. energy supplies and reducing the cost and environmental impacts of energy production and use. NETL and its partners investigate technical improvements for the U.S. transportation fleet, including hybrid technologies, fuel economy, and idle reduction. We pursue light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDS), which hold the promise of reducing our Nation's energy demands. We also implement efficiency programs that help low-income families reduce their energy use and manage energy programs delivered by State energy offices.

NETL Supports 2008 Challenge X Advanced Vehicle Competition—The Challenge X advanced vehicle competition held May 13–21, 2008, gave 17 universities from across the United States and Canada the task of re-engineering General Motors Chevrolet Equinox sport utility vehicles (SUVs) with advanced vehicle powertrains to improve fuel efficiency and reduce emissions—all while meeting the base performance standards of the unmodified Equinox and satisfying various consumer-acceptability tests. The modified vehicles completed track events in Englishtown, NJ, and road rallies to New York, NY; Baltimore, MD; and Washington, DC. NETL staff provided logistical support for the competition and helped ensure the vehicles performed as expected before official inspections and testing. The two main sponsors of the contest were DOE and General Motors Corporation.



The Olympic National Aquatics Center brightens Beijing with LED technology developed with NETL support.

NETL-Supported Technology Lights the 2008 Olympics

The XLamp®, based on a technology developed by Cree, Inc., in cooperation with NETL, was chosen to light two prominent buildings at the 2008 Olympics in Beijing, China.

The National Aquatic Center, nicknamed the Water Cube, was illuminated by approximately 496,000 XLamp LEDs in red, green, and blue. A computer controlled the lighting and coloring so that the lighted "bubbles" on the building dramatically changed in an infinite variety of shades and patterns every evening. The bubbles even formed words and created moving images.

In addition, the exterior of the Bird's Nest, China's National Stadium (pictured on page 8), was lit by approximately 258,000 Cree LEDs in white, amber, and red. XLamps also illuminated the video screen behind the main stage and were incorporated into the huge scroll that formed one of the largest LED screens in the world.

The Cree research team continues to work with NETL to achieve the DOE goal of producing LED devices that achieve a power efficiency of 160 lumens per watt for cost-effective, market-ready systems by 2015.

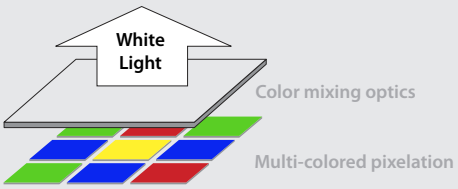
How it Works

Solid-State Lighting

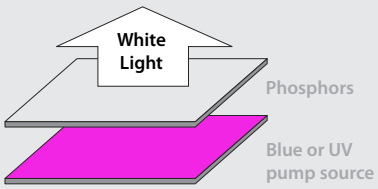
Lighting uses 22 percent of all electricity produced in the United States, with 12 percent of all residential energy dedicated to lighting. Most standard lighting is inefficient: only 10 percent of the energy in incandescent bulbs produces light while fluorescents use just 25 percent of their energy.

NETL's Solid State Lighting program develops more efficient light sources by using semi-conducting materials to convert electricity into light. Research focuses on LEDs, which are small-point light sources, and OLEDS, which are made in sheets and diffuse light over a larger area. Because LEDs last approximately 50 times longer than incandescent bulbs and 5 times longer than fluorescent bulbs, they help us decrease our power demand and the associated environmental impacts of energy production.

Color Mixing



Phospor-Down Conversion



Two primary strategies for obtaining white light are color mixing and phosphor-down conversion.

L•PRIZE™

The Bright Tomorrow Lighting Prize (L Prize™) competition seeks bold solutions for replacing two of today's most popular light bulbs: the 60-watt incandescent lamp and the PAR 38 halogen lamp. This challenge encourages industry to develop high-quality, high-efficiency solid-state lighting products with the potential to cut energy use by half. The L Prize also calls for development of a "21st Century Lamp" with a lifetime greater than 25,000 hours. NETL has released the competition under direction of the Energy Independence and Security Act of 2007. For more information, visit www.lightingprize.org.

NETL Teams with MotorWeek to Conduct Clean Power Drive—Producers of the PBS television show, *MotorWeek*, partnered with NETL coordinators of the Clean Cities program to measure and report on the fuel economy and emission levels of three popular vehicles. The Clean Cities program, sponsored by DOE's Office of Energy Efficiency and Renewable Energy, collects and publishes technical data and information on fuels, vehicles, fueling-station and truck-stop electrification locations, infrastructure development, industry resources, and State and Federal incentives and laws relating to the use of alternative fuels and vehicles. As part of the April 2008 *MotorWeek Clean Power Drive,* three sets of vehicles completed a 157-mile test loop from Frederick, MD, to Morgantown, WV, featuring both city and highway driving along U.S. Interstate 70, U.S. Interstate 68, and U.S. Route 40. The vehicles included gasoline and hybrid versions of the four-cylinder compact Honda Civic; gasoline and BlueTec Diesel versions of the V6 mid-size Mercedes-Benz E-Class luxury sedan; and a hybrid and a flex-fuel version of the V8 Chevrolet Tahoe 4X4 SUV. The two Honda Civics were tops in terms of economy, averaging 8.7 and 12.6 cents per mile for the hybrid and gasoline versions, respectively. While both Hondas did very well environmentally, the hybrid version was clearly the more environmentally friendly choice, especially in city traffic where the electric motors offset the emissions generated by the gasoline engine.

First Biofuels Corridor Completed—A 3-day Fall Corridor Drive the length of U.S. Interstate 65 marked the completion of America's first biofuels corridor. The Corridor designation means that a driver is never farther than 100 miles from a participating retailer of E85—an alternative fuel of 85 percent ethanol and 15 percent gasoline. Facilitated through a Clean Cities project coordinated by NETL and sponsored by DOE's Office of Energy Efficiency and Renewable Energy, the Corridor now makes E85 ethanol and B20 biodiesel—a blend of 20 percent biodiesel with 80 percent petroleum diesel—available from Gary, IN, to Mobile, AL. Clean Cities projects coordinated through NETL are designed to reduce petroleum consumption in the transportation sector by advancing the use of alternative fuel vehicles, idle-reduction technologies, hybrid electric vehicles, fuel blends, and fuel economy.

Project Records Highest Efficacy Ever for Organic Light-Emitting Diode—In a project managed by NETL, Universal Display Corporation has successfully demonstrated a record-breaking white OLED with a power efficacy of 102 lumens per watt at lighting brightness. The proprietary high-efficiency phosphorescent OLED technology marks the highest efficacy of an OLED achieved to date and represents a significant milestone for this unique arena. The performance displays the potential for OLEDs to surpass the power efficacy of two current lighting technologies—incandescent bulbs at less than 15 lumens per watt and fluorescent lamps at 60–90 lumens per watt. These markedly efficient white OLEDs should be capable of reducing energy consumption dramatically and also decreasing the amount of by-product heat. Further development of these OLEDs shows promise of meeting DOE's goal of providing a cost-effective 150-lumens-per-watt commercial OLED light source by 2015.

Record Efficacy Is Achieved for Blue Organic Light-Emitting Diode—Researchers at the University of Florida, in cooperation with NETL, have successfully demonstrated a blue phosphorescent OLED with a peak efficacy of 50 lumens per watt and a peak external efficiency of 25 percent, using no external light extraction techniques. This accomplishment is believed to be the world record in blue OLED efficacy. Blue emission is important in creating white light OLEDs for solid-state general illumination applications, but developing stable and long-lasting high-efficiency blue OLEDs is difficult because most of them possess an inherent imbalance of electrons and electron holes that limits internal efficiency. The University of Florida team has developed very high-efficiency blue OLEDs using a unique material with special electrical properties to resolve this issue.

Milestone Reached in Hybrid Solid-State Lighting Device—Working in cooperation with NETL, a research team at Eastman Kodak Company has demonstrated a breakthrough efficacy of 56 lumens per watt with a hybrid OLED device. The new technology applies a unique Kodak structure to extract light in a tandem-hybrid architecture comprising two light-emitting units. One unit has a fluorescent blue emitter; the other has a phosphorescent emitter with a yellow emitting layer and a red emitting layer. The device also achieves color coordinates that are well within the ENERGY STAR® color requirements for LED products. The team is now working on lifetime improvements to achieve the project goal of 10,000 hours for the hybrid device.

State Energy Program Promotes Clean Energy, Creates Jobs—In fiscal year 2008, the State Energy Program—comanaged by NETL and the Office of Energy Efficiency and Renewable Energy's Golden Field Office—distributed $33 million across the United States, its territories, and the Commonwealth of Puerto Rico. Recipients supplied an additional $150 million in cost share and leveraged funds to develop and expand State energy performance programs. Objectives included increasing energy efficiency, reducing energy use and costs, pursuing alternative and renewable energy sources, promoting environmental quality, stimulating economic development, and reducing U.S. reliance on imported oil. In one illustration of the program's success, the State of Kansas Facility Conservation Improvement Program made more than $140 million in energy improvements to public buildings, lowering public utility costs by more than $10 million annually.

Weatherization Assistance Program Grants $227 Million in Federal Funds—Low-income families spend an average of 15 percent of their income on energy, as compared to a 3 percent average nationwide. Through DOE's Weatherization Assistance Program, NETL and the Office of Energy Efficiency and Renewable Energy's Golden Field Office collaborate with State and local agencies to help these families make their homes more energy efficient, reducing energy bills by an average of $413 per year. In the 2008 program year, $227 million in Federal funds were used to help weatherize approximately 95,000 homes. As a result participants' heating bills were reduced by an average of 32 percent, and each dollar invested returned $2.69 in energy- and nonenergy-related benefits. The Weatherization Assistance Program not only decreases overall U.S. energy use by the equivalent of 18 million barrels of oil annually, it also generates 8,000 direct jobs and thousands more through indirect employment.

FYi

Energy efficiency means using less energy to provide the same level of energy service. Not to be confused with energy conservation, which means decreasing usage to save energy, energy efficiency can be as simple as replacing an incandescent bulb with a compact fluorescent bulb. The compact fluorescent provides the same amount of light but uses two-thirds less energy and lasts 6–10 times longer. Energy efficiency can also be highly complex. For example, state-of-the-art power plants operate at higher temperatures, burn less fuel, and release fewer pollutants while providing the same amount of electricity. Increasing plant efficiency reduces environmental impacts and saves consumers and industry up to 30 percent in energy costs.

In October 2002, NETL was ahead of its time in conceiving its Technology Support Facility, which showcases energy-conscious and environmentally friendly technologies. Green design was incorporated into every aspect of the modern facility.

New NETL Facility Showcases Green Technologies

On February 5, 2009, in his first official visit to DOE, President Barack Obama urged a "revolution in energy efficiency" as he outlined the modernization of 75 percent of Federal buildings and the improved efficiency of more than 2 million American homes. NETL's foresight enabled the Laboratory to immediately answer this directive with the completion of its newest building, the Technology Support Facility (TSF) in Morgantown, WV. The TSF embodies the President's national vision by applying modern green practices that use one-third less energy than an average office building, with a predicted energy savings of $290,000 per year. Total cost savings are predicted to be $1.2 million per year, including the closing of dated facilities.

Designed to meet the U.S. Green Building Council's requirements for Leadership in Energy and Environmental Design (LEED) certification, the building is registered with the LEED certification program under the "Green Building Green Rating System," endorsed by DOE. The program is the only nationally recognized certification process for green buildings, and the TSF is expected to obtain a platinum rating, the program's highest. The new facility is also expected to meet the criteria for the U.S. Environmental Protection Agency's Energy Star Certification, which recognizes top-performing buildings in energy conservation.

NETL's energy conservation effort was in effect from the very beginning of TSF construction. Site excavators balanced cut-and-fill in such a manner that no soil was removed from the site. In addition, 90 percent of construction waste was diverted from the landfill through recycling or reuse. Avoiding soil removal and waste disposal cut transportation costs and eliminated the greenhouse gases normally emitted from trucks used to haul away earth and debris.

TSF designers chose recycled and sustainable materials where possible. The foundation walls, floor slabs, and piles were built with cement consisting of 18 percent flyash, a by-product of coal combustion. All carpet tiles, ceiling tiles, and structural steel were made from recycled materials, as well. To ensure responsible management of forest resources, designers used Forest Stewardship Council-certified lumber.

The roof, comprising two sections and coated with a reflective roofing material for solar protection, is a star performer of the TSF. The first section is a plant-filled rooftop garden. It acts as a thermal mass, absorbing and holding energy from sunlight, then releasing it when the ambient air cools. By functioning as a heat storage battery, the "living" roof reduces the building's heating and cooling demands.

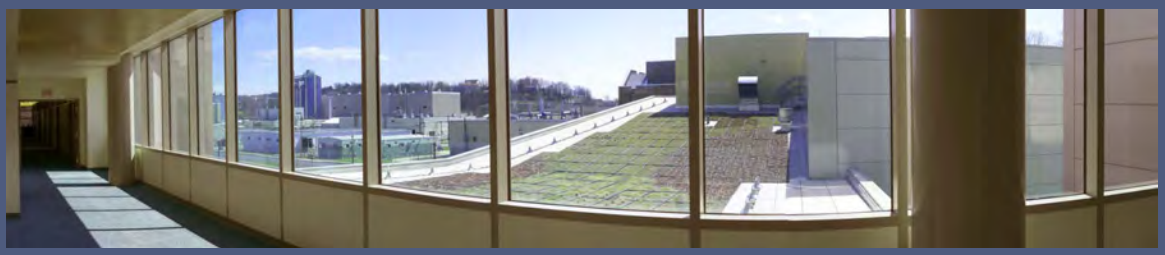
The second section of the roof holds large reservoirs to collect rainwater for use in septic and gardening systems. Further water preservation efforts can be seen both in the exterior landscape, where indigenous plants reduce irrigation requirements, and in the interior of the facility, which is equipped with the latest green plumbing technologies.

In today's generation of buildings, little air enters or escapes, so indoor air quality must be carefully managed. The TSF's tight shell was built with materials that contain low volatile organic compounds, such as light-colored paints and non-solvent-based adhesives. Heat recovery coils capture heat from general building exhaust air and precondition incoming fresh air according to the season. In addition, the main building uses a hybrid ventilation system consisting of a raised floor system that allows a constant underfloor fresh air supply and an overhead system that recirculates air.

NETL makes judicious use of natural light and lighting controls. Exterior and interior windows are designed to maximize natural daylight, and ambient-level light sensors and motion sensors ensure light usage only as needed. Energy-efficient T5 fluorescent and compact fluorescent lighting is used throughout the building. The Laboratory predicts a reduction of typical power usage from 2.5 watts per square foot to 1 watt per square foot, resulting in annual power savings of 50 kilowatts each for lighting and ventilation.

The TSF was dedicated on August 14, 2008. As NETL welcomed distinguished visitors and proud employees, the glass exterior mirrored the clear blue sky and white clouds overhead. Not only were attendees celebrating NETL's achievement of the innovative structure, they were celebrating the Laboratory's enduring commitment to our Nation's energy future.

The exterior and interior windows of NETL's TSF maximize natural daylight for energy efficiency.



The living roof, seen here from the top floor, reduces the building's heating and cooling demands.

Environment & Economy

Low-Impact, Cost–Effective Energy

Energy underpins our National and global economies by supplying electricity, transportation fuels, and industrial power. In today's economic downturn, it is essential that energy supplies remain affordable. At the same time, we cannot abandon the environmental strides we are making toward sustainable energy production and use. NETL brings a balanced approach to these challenges by performing complex systems analyses of emerging environmental issues, such as the water-energy nexus. NETL is also developing new technologies and processes that slash emissions, make beneficial use of waste products, improve materials and monitors for advanced combustion systems, and lead the commercialization and deployment of mercury-control technologies.

Materials

Emerging energy-production technologies—such as ultra-supercritical power systems, gasification, solid oxide fuel cells, and fluidized bed technologies—offer our Nation the opportunity to convert coal and other carbon-based fuels to energy with more efficiency and significantly lower environmental impacts than is possible with current power-industry processes. However, in many cases these advanced power systems produce harsh internal conditions that call for simultaneous advances in materials technology. NETL scientists and engineers identify the cost and performance gaps between currently available materials and those required by future energy systems and develop innovative new materials that can withstand the rigors of future energy production.

NETL Invents Novel Solid Oxide Fuel Cell Interconnect Materials—NETL has developed a simple, inexpensive treatment that reduces the oxidation rates of and scale growth on a ferritic stainless steel containing residual amounts of aluminum and silicon. Minimizing such impurities, which form nonconductive oxides that adversely affect solid oxide fuel cell (SOFC) performance, normally accounts for additional production costs. The cerium surface treatment, however, makes possible the use of lower-cost alloys with higher aluminum and silicon contents for interconnect applications. In a related project, NETL researchers developed a series of nickel-based alloy compositions less prone to heat damage than conventional nickel-based alloys. The new alloys are also more resistant to oxidation than iron-based alloys and could contribute to reducing system costs in SOFCs and other advanced power generation systems. NETL has submitted patent applications for both technologies. Detailed papers were published in the November 2007 issue of *International Journal of Hydrogen Energy.*

NETL Determines Evaporation Rates of Chromium from Protective Oxide Scales—NETL researchers have developed a method for calculating the chromium evaporation rate of chromia scaling in advanced steam boilers and turbines. In these power systems, chromia scaling acts as a protective layer for nickel-based alloys. When evaporation occurs, the protective layer thins and exposes the alloy to degradation. NETL has designed a series of laboratory experiments that reproduces chromium evaporation behavior under much lower steam velocities and pressure than those found in advanced steam turbines. The method can be used to develop technologies that sustain chromia scaling in advanced power systems. It can also be used in fuel cell research that seeks to eliminate chromia poisoning, which results from chromia evaporation. The NETL study is described in the April 2008 issue of *Oxidation of Metals*.

NETL Applies Low-Cost Casting Techniques to Titanium Alloy—Collaborators at NETL, Pacific Northwest National Laboratory, and CANMET Materials Technology Laboratory in Ottawa, Ontario, have developed techniques for casting a titanium alloy in a permanent mold. This approach could reduce the cost of titanium castings and expand their use in such applications as offshore oil drilling, where lightweight, corrosion-resistant materials are advantageous. NETL's work is described in the *International Journal of Metalcasting* in the Winter 2008 issue.

Metal Fabrication Processes Developed for Advanced Ultra-supercritical Boiler Construction—A consortium of major U.S. boilermakers has developed the necessary metal fabrication methods for forming, machining, welding, heat-treating, and otherwise processing six high-temperature, corrosion-resistant alloys to make components for advanced boilers operating at ultra-supercritical steam conditions (760 °C and 3500 psig). Information developed by the consortium is contained in a topical report issued by the Electric Power Research Institute, a consortium collaborator. The project was conducted under the Office of Fossil Energy's Materials program and managed by NETL.

Image courtesy of
Bruce Kang, West Virginia University

Innovative Device Performs Nondestructive Material Evaluations

Indentation testing, a mechanical testing process that measures a material's properties by indenting (marring) its surface, has long been an accepted method for determining such material characteristics as hardness. Today, indentation testing has extended into micro- and nano-capabilities and has become a test of choice for examining thin films, coatings, and surfaces that have been laser heat-treated or ion-implanted. Data on many mechanical properties are developed using indentation. Because of the equipment involved, however, most of these analyses can only be performed in a laboratory setting.

Researchers at West Virgina University, in collaboration with NETL, have developed a portable micro-indentation device that can analyze several properties of metals and coatings. Laboratory tests show that the device (pictured above) is capable of performing analyses on a variety of surfaces—flat, tubular, or curved—and performs well on metals, superalloys, single-crystal matrices, and coated material systems. Post-tests of indentation sites by optical microscope and scanning electron microscope identify no visible damage where indentations were performed. A table-top version capable of the same analyses was also developed.

Both devices have potential application for estimating the remaining service life of high-temperature thermal barriers, coatings, material degradation, and fracture toughness for advanced turbine components, and the hand-held version is currently being prepared for field service.

Q+A

Q What is "ultra-supercritical"?

A The earliest coal-fired power plants were characterized as "**subcritical**." They operated below the critical point of water—705 °F, 3,210 pounds per square inch (psi)—producing saturated steam no hotter than that from boiling water. Subcritical fossil fuel power plants can achieve energy efficiencies ranging 36–40 percent.

Today's plants operate at "**supercritical**" pressures above 3,210 psi. Water is no longer boiled. Instead, it gradually loses density by absorbing heat energy as the temperature increases. This process eliminates the need for drums and steam-separating devices, saving maintenance and operating costs. Supercritical power plant designs have efficiencies in the low- to mid-40 percent range.

Plants of the future will operate at "**ultra-supercritical**" steam conditions. These "once-through" steam generators will operate at supercritical pressure and elevated temperatures at or above 1,100 °F. Some ultra-supercritical designs can reach approximately 48 percent efficiency. Capital cost for an ultra-supercritical boiler is higher than that for a comparable supercritical boiler, but thermal efficiency improvements require less coal consumption and produce fewer greenhouse gases.

Prototype High-Temperature Ferritic Alloys Designed with Computational Tools—A University Coal Research grant administered by NETL has allowed the production of six new ferritic alloys with improved strength and ductility at room temperature based on computer-aided design efforts by collaborators at Northwestern University and Oak Ridge National Laboratory. With the new additions, a total of 12 prototype ferritic superalloys for fossil-energy applications up to 1,400 °F are now available. The use of relatively low-cost ferritic steel is currently limited in fossil energy applications because of its low creep resistance and poor corrosion resistance at temperatures above 1,100 °F. However, modern computational tools could hasten development of candidate ferritic steels strengthened mainly by nanoscale precipitates. The project is led by University of Tennessee researchers.

Successful Welds Made for Ferritic Steels Strengthened by Oxide Dispersion—The durability of steel strengthened by oxide dispersion, known as ODS steel, makes it a candidate for use in coal-fired power systems operating at supercritical and ultra-supercritical steam conditions. Conventional welding methods, however, undermine the strength of the material at the joint. Now, researchers at Materials and Electrochemical Research Corporation, Tucson, AZ, working under an NETL-managed Small Business Innovation Research (SBIR) grant, have found that plasma-assisted joining can successfully weld sections of Incoloy® alloy MA956, a chromium-rich ferritic ODS steel. Appropriate heat treatment restores as much as 98 percent of the metal's original tensile strength at the joint at temperatures up to 1,000 °C. Meanwhile, researchers at the Energy and Environmental Research Center at the University of North Dakota, also working in cooperation with NETL, have applied a transient liquid-phase bonding technique to join an ODS alloy to a nickel superalloy. The technique is similar to an older joining technique called brazing, except that the bonding material dissolves into the microstructure, avoiding the oxide redistribution that can undermine the strength of the joint.

Nano-technique Improves High-Temperature Alloys—Using a particle-mixing process developed for the pharmaceutical industry, researchers at West Virginia University successfully applied thin coatings of nano-sized metal oxide particles to the surface of a larger molybdenum particle without using binders. Participating in the Office of Fossil Energy's University Coal Research program managed by NETL, the researchers tested the technique as part of a project aimed at enhancing the malleability of molybdenum- and chromium-based alloys by the addition of metal oxides. Although brittle at ambient temperature, a number of these alloys exhibit an ultrahigh working temperature—more than 1,000 °C—and the excellent oxidation and corrosion resistance needed by structural materials for the next generation of coal-fired power plants.

New Coating Technology Demonstrated for Advanced Coal-Fired Boiler Materials—As part of an NETL-administered SBIR grant, product developers at Materials and Electrochemical Research Corporation successfully employed commercial-scale plasma transferred arc (PTA) technology to apply a chromium-iron-nitrogen composite to the surface of a steel substrate. The gradual transition between the corrosion-resistant outer layer and the tough base material results in an exceptionally strong bond between coating and steel. Compared to uncoated samples, a substantial reduction in weight loss was seen—which means much less corrosion—for PTA-coated samples placed in a coal ash-alkali sulfate environment at 700 °C at Argonne National Laboratory. The work demonstrates a less expensive approach to improving corrosion resistance in low-cost, mechanically sound materials for advanced coal-fired boilers.

Mercury

Under the Office of Fossil Energy's Innovations for Existing Plants program, NETL has managed nearly 50 full-scale field tests of mercury-control technologies since 2000. Many of the demonstrations, performed at U.S. coal-fired power generation facilities, exhibited a high level of reliability and performance, and now plant operators are deploying those technologies commercially. For example, orders have been placed to equip over 50 gigawatts of coal-based electric generating capacity with full-scale activated carbon injection systems. These systems achieve 50–70 percent mercury capture from all coal types and blends at the costs targeted by the program. The accomplishments realized in 2008 represent NETL's successful closure of its mercury-control portion of the Existing Plants program. Having achieved the mercury goals set by the Office of Fossil Energy, the program is now shifting its focus to CO_2 capture and water management for existing plants.

NETL-Patented Sorbents Remove Mercury from Synthesis Gas at Power Systems Development Facility—Preliminary results show that palladium sorbents formulated by NETL removed 100 percent of the mercury present in a slipstream of high-temperature synthesis gas at the Power Systems Development Facility operated by Southern Company Services in Wilsonville, AL. A 10-pound test bed of the R&D 100 Award-winning sorbents treated 7,500 pounds of the synthesis gas at 500 °F over a 3-week period. Mercury data were obtained from the spent sorbent, as well as by monitoring the synthesis gas across the sorbent reactor during the test. Compared to low-temperature capture by activated carbons, the high-temperature capture of trace elements—mercury, arsenic, and selenium—helps preserve the high thermal efficiency of integrated gasification combined cycle (IGCC) plants. The results also hold important implications for other uses, such as the high-temperature separation of hydrogen.

First Clean Coal Power Initiative Project Completed—In partnership with NETL, NeuCo, Inc., of Boston, MA—a leading provider of optimization software for electric power producers—has significantly reduced emissions, improved efficiency, and increased power availability at Dynergy Midwest Generation's Baldwin Energy Complex in Baldwin, IL. Five separate but integrated optimization products addressed combustion, sootblowing, selective catalytic reduction operations, overall unit thermal performance, and maintenance. This inaugural Clean Coal Power Initiative project represents the first time that multiple optimization software modules of this breadth and depth have been integrated into a digital process network in a coal-fired power plant.

Multi-pollutant Control Project Achieves All Goals—CONSOL Energy Inc., AES Greenidge, and other industrial partners working in cooperation with NETL have successfully demonstrated the commercial readiness of an emissions control system that—because of low capital and maintenance costs and small space demands—is particularly suited to existing small to medium-size power plants. Representing almost 60 gigawatts of installed generating capacity in the United States, this large group of power plants is increasingly vulnerable to retirement or fuel switching because of progressively more stringent State and Federal environmental regulations. Installed at the 104-megawatt electric coal-fired AES Greenidge Unit 4 near Dresden, NY, the multi-pollutant control system features a catalytic nitrogen oxide (NO_x)-reduction technology that works inside the plant's ductwork. A dry circulating fluidized bed scrubber was also installed that is simpler and nearly half the cost of conventional wet systems. By meeting project goals for the removal of NO_x, sulfur dioxide (SO_2), sulfur trioxide (SO_3), hydrochloric acid, hydrofluoric acid, and mercury, the novel approach demonstrated control of multiple pollutants collectively for less money than it would cost to control them separately. The project was conducted under the Power Plant Improvement Initiative managed by NETL.

FYi

A **slipstream** is a small stream of fluid diverted from the main process fluid. Though total mass is reduced, the fluid composition remains identical. For research purposes, slipstreams are used to test the effects of sorbents on particulates in flue streams.

High-carbon fly ash stabilizes reclaimed pavement materials used for roadbed preparation.

High-Carbon Fly Ash and Recycled Asphalt Make a Strong Team

Fly ash, a particulate matter emitted when coal is burned to create electrical power, has historically been found useful in the production of concrete, cement, and plastics. However, when emissions-reducing low-NO_x burners are added to a power station, too much carbon makes the fly ash unsuitable for these purposes.

In an NETL-administered Small Business Innovation Research (SBIR) grant, a team consisting of Washington State University, University of Wisconsin at Madison, and Milwaukee-based Bloom Companies, LLC, found that mixing the high-carbon ash with ground asphalt produces a reliable base for roads.

In fact, this base out-performed traditional road bases in a test-road in Minnesota. Torrential rains occurred after different test bases were laid and before the new road surface could be applied. The result? All bases gave way—except the one combining high-carbon fly ash with recycled asphalt. The ash, a cementlike substance, bound to the asphalt to form a firm under-bed that even supported the trucks cleaning out the failed sections of the roadbed.

Not only did the hybrid base prove to increase the long-term performance of the pavement, but environmental monitoring revealed that this application prevents mercury contained in the ash from releasing into the environment.

Advanced Mercury Sorbents Show Effectiveness Despite Sulfur Interference—A variety of advanced mercury sorbents that either scavenge SO_3 or preferentially adsorb vapor-phase mercury from coal-fired power plant flue gas achieved 20–90 percent mercury removal during slipstream tests with flue gas containing high concentrations of SO_2 and SO_3. The sorbents were developed by Apogee Scientific, Inc., with an NETL-managed Phase I SBIR grant. The best performing sorbent, an advanced activated carbon prepared from bituminous coal, outperformed the lignite coal-based conventional-carbon mercury sorbent and the halogenated activated-carbon mercury sorbent. The ability for power systems to achieve mercury control with smaller quantities of a more effective sorbent is expected to reduce the cost of mercury removal from high-sulfur flue gas and potentially avoid "New Source" power plant classification, which would be triggered by potential increases in particulate emissions and make the plant subject to more stringent emission standards.

Successful Testing Completes Initial Stage of High-Temperature Mercury Sorbent Development—An adsorption study conducted at Western Research Institute (WRI) in cooperation with NETL completed an important first step in developing a high-temperature mercury sorbent for use in a patented WRI mercury-removal system. Activated carbon, generally used for mercury removal, typically removes 300 micrograms of mercury per gram of sorbent at 150 °C, but this is roughly halved as power system temperatures

double. However, in the study, a proprietary non-carbon material prepared by sorbent developer GCEE exhibited mercury loadings of 300–500 micrograms of mercury per gram of sorbent, even at 300 °C. In the WRI process, a sweep gas recycles through a sorbent bed to remove mercury that has evaporated from raw, crushed coal heated to approximately 300 °C. Removing mercury with a high-temperature sorbent significantly reduces required energy and operating costs by eliminating the need to cool and reheat the recycling sweep gas. The novel sorbent could also be used for mercury removal in postcombustion and gasification environments.

Commercial Wallboard Analysis Indicates Low Mercury Emission from Coal Utilization By-product—A 3-year investigation, completed in cooperation with NETL, has led USG Corporation of Chicago, IL—a leading manufacturer of gypsum-based products—to estimate that the U.S. wallboard industry as a whole emits less than 1.5 tons of mercury per year to the atmosphere. Five U.S. power plants, firing a variety of coals, supplied synthetic gypsum samples captured from the flue gas desulfurization process. The samples were used to investigate whether or not mercury would be released from synthetic gypsum feedstock during the manufacturing process at USG wallboard plants. Maximum mercury content of finished wallboard product made with the synthetic gypsum was approximately one part per million, and subsequent laboratory test data show no significant leaching of mercury from synthetic gypsum wallboard under simulated landfill disposal conditions. USG completed the investigation with collaborators at URS Group of Austin, TX, and the Electric Power Research Institute.

Membranes

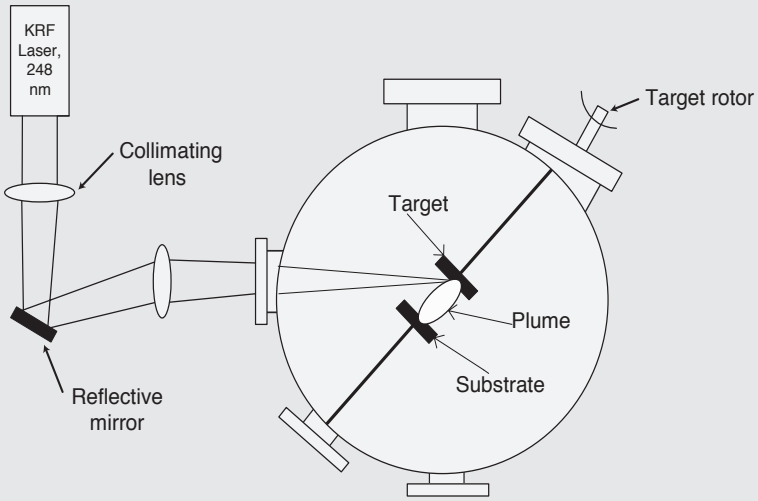
Starting modestly in the mid-1980s, NETL's membrane research has expanded to include a broad range of technologies that separate such gaseous compounds as CO_2, hydrogen, hydrogen sulfide, and ammonia. NETL's successes in the field have gained the Laboratory international recognition in professional forums dedicated to advancing membrane science. Membrane engineering at NETL is focused on improving the performance and cost-effectiveness of gas separation technologies for environmental gains, such as separating hydrogen from coal-derived synthesis gas to yield a capture-ready stream of CO_2.

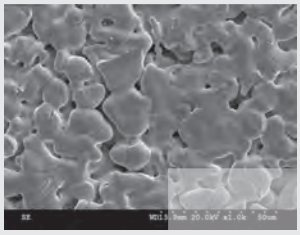
NETL Advances Membrane Technology for CO_2 Capture—NETL researchers have discovered a new class of membranes that are selective for CO_2 and require no aqueous transport phase. Developed under a Cooperative Research and Development Agreement with the University of Notre Dame, the NETL membrane consists of a high-temperature polymer support and an ionic liquid with the capability to form chemical complexes with CO_2. Because evaporation typically causes aqueous-phase membranes to fail at high temperatures, the design represents a major step forward in high-temperature CO_2-selective membrane development. A paper appearing in Elsevier's *Journal of Membrane Science*, September 1, 2008, details development of the membrane.

FYi

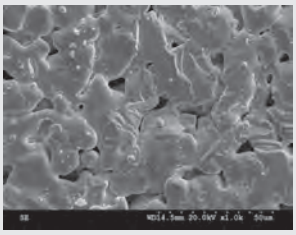
A **membrane** is a thin layer of solid or liquid material capable of separating liquid or gaseous materials when a driving force is applied. The driving force causes the separation to occur and can be as simple as a pressure drop. For example, high pressure on one side of a membrane disk can drive a selected gas through the membrane to the low-pressure side.

Graduate and undergraduate students at North Carolina A&T State University in Greensboro, NC, developed an innovative hydrogen membrane. In the background is the experimental setup for palladium-alloy membrane-reactor evaluation testing.





Bare substrate



Palladium-seeded substrate

Schematic of pulse laser process for depositing palladium, and examples of substrate before and after deposition.

NETL Education Program Produces Significant Achievement

Our Nation runs on energy, and our growing population needs affordable energy for home and business consumption. At the same time, responsibility dictates that the energy be produced in ways that do not harm the environment. These two goals—more energy with lower environmental impact—call for a substantial cadre of scientists and engineers to discover and develop innovative methods of energy production.

NETL has long been conscious of its social responsibility to engage bright young minds in solving the Nation's energy concerns. NETL sponsors and manages several education programs aimed at encouraging students in science and mathematics, especially as the subjects pertain to solving our Nation's energy challenges.

One such program, the Historically Black Colleges and Universities and Other Minority Institutions (HBCU/OMI) education training program, was initiated in 1984. The program expands students' learning opportunities through collaboration with NETL energy scientists, exposing them to career opportunities in the energy sector and encouraging a future generation of energy scientists and engineers.

HBCU/OMI gives students and faculty hands-on experience in developing technologies that will promote the efficient and environmentally safe use of coal, oil, and natural gas. The student-scientist collaboration thus serves a dual purpose: it offers our researchers the opportunity to mentor promising future scientists, and it seeks to solve energy challenges that will provide our Nation with a more secure energy future.

An example of HBCU/OMI's success comes from North Carolina Agriculture & Technical State University. Under a three-year grant that began in 2005, North Carolina A&T in 2008 completed development of a novel membrane to separate hydrogen from liquid or gaseous fuels at very high temperatures.

This is a significant development, because high-purity hydrogen is important for powering fuel cells, a technology attracting much interest today. Fuel cells offer high-quality power along with high efficiency and almost zero emissions. Because hydrogen is the cleanest fuel for this technology, researchers are seeking methods to produce it more economically. A promising possibility is to use a membrane to separate it from synthesis gas created during the coal gasification process.

North Carolina A&T advanced hydrogen separation technology with its new membrane—a thin, dense, uniform film on a porous stainless steel support. Made of a palladium-silver composite of extremely thin proportions—1.43–1.96 microns—the membrane demonstrates permeability and selectivity with respect to hydrogen. During the gasification reaction called "water-gas shift," this membrane shows promise of being part of an advanced reactor-separator that will operate at high temperatures to reform the coal-derived methane into hydrogen while also producing a capture-ready stream of CO_2.

The strides made at North Carolina A&T support both the economic and environmental issues associated with fossil fuel-based energy production. At the same time, the students' involvement supported DOE's efforts to strengthen America's role as a science and technology leader by engaging young scientists in energy research and development.

Hydrogen Separation Project Makes Significant Advance—A project team led by Eltron Research & Development, Inc., in partnership with NETL, has made the separation of hydrogen from a synthesis gas stream more effective and economical. Usually, "separation flux" varies inversely with membrane thickness—the thinner the membrane, the more hydrogen it can pull from a gas stream. However, costly techniques are required to deposit conventional membranes (5–10 microns thick) onto a suitable base. The Eltron team has developed a 500-micron-thick membrane that reaches DOE's 2010 separation performance targets in pilot-scale testing. Thicker membranes are not only more economical to produce, they are robust, easily shaped with conventional techniques, and resistant to failure. If proven effective in larger-scale testing, the Eltron membrane could be used to separate hydrogen from coal-derived synthesis gas to power turbines, fuel cells, and other advanced energy production systems.

Low-Cost Hydrogen Membrane Material Developed—As part of an NETL-administered SBIR grant, investigators at Eltron Research & Development, Inc., have developed a new hydrogen membrane material that demonstrates excellent permeability and good resistance to becoming brittle when exposed to hydrogen. Eltron developed the proprietary alloy using low-cost elements, and the membrane exhibited a standardized hydrogen flow rate that exceeded the programmatic target set for 2015. High flow rate, low cost, and resistance to embrittlement could make the novel alloy an excellent choice for producing hydrogen from coal.

Sulfur- and Moisture-Tolerant Hydrogen Transport Membranes Demonstrated—Using palladium-and-copper-coated tantalum membrane tubes, researchers at Aspen Products Group, Inc., maintained hydrogen permeabilty well above that of the pure palladium standard, even in the presence of significant quantities of hydrogen sulfide and water. This accomplishment represents a significant step toward fabricating an advanced water-gas-shift membrane reactor for the production of high-purity hydrogen from coal-derived synthesis gas. Combining hydrogen production and product separation in a single reactor would significantly increase hydrogen yield and potentially reduce capital and operating costs.

Novel Alloy Improves Flow Through Hydrogen Membrane—With an NETL-managed grant under the Office of Fossil Energy's University Coal Research program, researchers at Worcester Polytechnic Institute have produced novel membrane films by applying palladium and gold foils onto a porous stainless steel base. Tests show that a film made of a palladium-gold alloy allows hydrogen to permeate a membrane at rates 50–100 percent greater than similarly sized free-standing films of palladium only, the standard for hydrogen membrane permeability. The work is aimed at developing sulfur-tolerant hydrogen transport membranes that can separate hydrogen from synthesis gas at practical rates to produce high-purity hydrogen and sequestration-ready CO_2 streams.

New Model Predicts Hydrogen Membrane Permeability—Southwest Research Institute investigators have developed a computer model based on density functional theory that uses first-principle calculations to predict the hydrogen permeability of three-component alloys. Developed in a collaboration between NETL and a group of researchers at the Georgia Institute of Technology, the model will allow rapid and inexpensive screening of alloys that are candidates for fabricating membranes of optimum cost, durability, and flow rate needed to produce hydrogen efficiently from coal. Work to date has focused on membranes with palladium as the primary component, and the results have been verified for selected compositions by laboratory-scale testing.

Monitoring

NETL develops monitoring methods and equipment to plan the responsible future extraction of fossil fuel resources and to reduce the cost and difficulty of cleaning up existing mining, oil well, and natural gas well sites. NETL's portfolio of research in this area focuses on soil and water, especially produced water, a by-product of oil and natural gas extraction. Our monitoring efforts are also aimed at helping power plant operators track materials degradation and other trouble spots in advanced combustion systems to avoid unplanned shutdowns and their associated costs.

NETL Aerial Surveys of the Powder River Basin Help National Resources Conservation Service—The National Resources Conservation Service within the U.S. Department of Agriculture determined that high-resolution light detection and ranging (LiDAR) systems and hyperspectral imaging systems that span the visible and near-infrared regions of the electromagnetic spectrum are uniquely suited for developing new, improved methods of constructing soil maps in large, remote areas. Produced for NETL as part of complementary research authorized by the Energy PolicyAct of 2005 (EPACT), the datasets contain both topographic and reflectance information, enabling surveys to locate and identify the mineral composition of exposed soil or rock, as well as invasive and indigenous vegetation. The survey was unique in that the two systems were used simultaneously on the same airplane and the survey results were acquired during the same flight, enabling the datasets to be perfectly overlain and coregistered for comparative analysis. NETL conducted the surveys in Wyoming to determine the environmental impact of ongoing coalbed natural gas development within the designated flight area.

Chappel Fork, a stream in Allegheny National Forest damaged by vandalism.

NETL Study in Allegheny National Forest Assists in Oil Spill Recovery

One night in mid-August 2008, a vandal broke the valves on seven crude oil storage tanks in the Allegheny National Forest, McKean County, PA, resulting in a 36,000–45,000-gallon spill into the local watershed.

NETL supported cleanup efforts by the U. S. Environmental Protection Agency and the Pennsylvania Department of Environmental Protection by providing pre-spill stream condition data. The information became valuable in determining the impact of the spill on the stream ecology and the extent and type of cleanup effort needed.

NETL and graduate students from Clarion University had already been monitoring streams in that area for two months for a study initiated by the Laboratory under EPACT and with the cooperation of the U.S. Forest Service.

The research team was collecting baseline data on macro-invertebrate populations in the forest's watersheds to better understand how to control possible effects from planned roads and well-pads for oil and gas production. It was this information that became valuable to cleanup efforts.

Stream monitoring associated with the original project will continue through 2008.

Technique Nears Formal Approval as an American Standard Testing Method—The solid-phase micro-extraction (SPME) method, developed in cooperation with NETL by collaborators at RETEC and the Energy & Environmental Research Center at the University of North Dakota, has been provisionally accepted as a method standard by the American Society for Testing and Materials. Regulatory communities and coal tar product-related industries value the SPME method as an improved technique for predicting and measuring the effectiveness of extracting organic pollutants, such as polycyclic aromatic hydrocarbons, from contaminated sites. Preliminary reviews of sampling and analytical procedures have been completed, and multiple laboratories will soon begin conducting a commercially funded verification study. Formal approval is expected within four years. The method has also been evaluated and approved by the U.S. Environmental Protection Agency for use as a sampling and analysis technique related to Resource Conservation and Recovery Act compliance. Results of the investigation are presented in the September 2007 issue of the American Chemical Society publication, *Environmental Science and Technology*, and in the December 2007 issue of *Environmental Toxicology and Chemistry*.

Wireless Method Monitors Operating Turbine Temperatures—Working under a University Coal Research grant administered by NETL, researchers at the University of California at Santa Barbara have developed a unique method for monitoring the temperature of thermal barrier coatings used to protect turbine components at risk of failure at high temperature. The method relies on the luminescence emitted from rare-earth ions—such as Europium^{3+}—incorporated into the crystal structure of the coating as it is deposited. When the ions are excited by a laser probe focused on a designated turbine component, they emit a temperature-specific luminescence that can be detected using compact, fiber-optic-based instrumentation. Because rising temperatures increasingly impact the majority of mechanisms responsible for coating failure, the nonintrusive approach will allow operators to more easily estimate the remaining life of the barrier coating.

Water

Operation of the existing fleet of thermoelectric power plants and construction of new fossil- and nuclear-based power systems are being challenged by water-related issues at regional and national levels. Growing uneasiness over water availability, in combination with projected population growth rates, energy consumption patterns, and competition among water-use sectors, is poised to magnify the importance of water in the near future. The Office of Fossil Energy's Innovations for Existing Plants program is working through NETL's Water-Energy Interface to better understand the relationship between electricity production and water and develop and demonstrate technologies that will significantly curtail freshwater use in thermoelectric plants.

Interagency Collaborators Assess Potential Use for Produced Water in Wyoming—A team of NETL and U.S. Geological Survey scientists has collected water, soil, and electromagnetic data at a site near the junction of Powder River and Crazy Woman Creek in Wyoming. The data will be used to establish baseline conditions at the site and to evaluate a subsurface drip irrigation system. The team is assessing the potential of such a system as an environmentally beneficial means of irrigating agricultural lands with water produced during extraction of coalbed natural gas.

Water Supply Capacity Restored to North Dakota Municipality—Levels of contaminants in soils and groundwater menacing a municipal well in Carrington, ND, have been reduced to regulatory limits thanks to the joint efforts of NETL and the University of North Dakota Energy & Environmental Research Center (EERC). Through this collaboration, an equivalent of 2,022 gallons of gasoline was removed from within the capture zone of the municipal well by using high-vacuum multiphase extraction and soil vapor extraction techniques integrated with air injection into groundwater.

Zebra mussels clog the openings of pipes outside of power plants and other large water users.

Zebra Mussels Controlled, Environment Protected

Researchers at the New York State Museum Field Research Lab in Cambridge, NY, working in cooperation with NETL under the Office of Fossil Energy's Advanced Research program, have developed a bacterial control agent that targets zebra mussels—an invasive species responsible for over $1 billion in damage to electric utilities. The mussels are also responsible for causing significant ecological damage by eliminating native mussel species and disrupting the food chain.

The fingernail-sized mussel and its cousin, the quagga mussel, were introduced into this country from Europe in the 1980s and have become the most troublesome freshwater organisms in North America. They cause $3 billion in economic impact as they invade, foul, and block pipes that provide municipal drinking water and water to power plant cooling towers, factories, and fire-fighting water delivery systems.

Previous biocide treatments, such as continuous chlorination for periods of weeks to months, are unacceptable because they harm native species and form potentially carcinogenic substances. The new biocide is harmless to all native aquatic organisms while proving highly effective against zebra and quagga mussels. Methods for producing commercial quantities of the toxin are now being developed at a private laboratory in California.

U.S. Water Demand Study Completed—A study completed by Argonne National Laboratory in cooperation with NETL finds that U.S. water consumption in 2005 was approximately 114 billion gallons per day and is projected to reach 136 billion gallons per day by 2030—an increase of nearly 20 percent over the 25-year period examined. Topped only by irrigation for food crops, the energy-production sector is the second-highest—and fastest-growing—water consumer. Water consumption for energy production is projected to nearly triple from approximately 12 billion gallons per day in 2005 to about 31 billion gallons per day in 2030. The study, "Baseline and Projected Water Demand Data for Energy and Competing Water Use Sectors," complements the NETL report, "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements."

Flue Gas Dehumidification Supplements Power Plant Water Source—Working with NETL and industrial partners, investigators at EERC have demonstrated at pilot scale the recovery of water from flue gas using an aqueous solution of calcium chloride as the drying agent. This solution captures water from the flue gas and then is recycled. The captured water is used for plant operations. During a 20-day test, the system removed 30–60 percent of the water in the flue gas from EERC's coal-fired combustor. If that rate of water recovery were applied to a thermoelectric power plant, it would significantly reduce the amount of water the plant would otherwise withdraw from freshwater sources.

Economy & Supply

Powering Prosperity

America needs an ample, accessible, affordable supply of energy to maintain our standard of living and our standing as a global economic leader. Through a variety of programs, NETL is fostering technologies that will help maximize our domestic energy supplies, enhance national energy security, and keep energy costs in check. NETL's strategies, analyses, and technologies are modernizing U.S. energy transmission and distribution systems. We are developing advanced exploration and recovery techniques for America's conventional and unconventional resources. And, at the frontier of energy exploration, we are investigating the potential for tapping methane hydrates in marine and arctic environments.

Hurricanes can cause significant reductions in natural gas and oil production in the Gulf of Mexico for weeks at a time. NETL's prediction tool aids government and industry officials in preparing for, monitoring, and recovering from such disruptions.

NETL's Natural Gas Prediction Tool Aids Hurricane Recovery

When hurricane-force winds roar through the Gulf of Mexico, interruptions to natural gas and oil production can reach critical proportions. The Gulf region is our largest homeland resource for natural gas and oil, and disruptions affect us all by driving up the cost of gasoline and home heating.

When hurricanes Katrina and Rita hit the Gulf in 2005, they caused destruction and substantial damage to offshore production platforms and pipelines, onshore production wells and pipelines, processing plants, and other infrastructure supporting the Gulf's production and delivery system. Government officials and those in the industry found they had no way of predicting how long it would take to reestablish normal production. As it was, as late as June 2006, over 9 percent of the region's natural gas production was still "shut in," the industry term meaning closed down.

Katrina and Rita graphically demonstrated how vitally we needed a natural gas monitoring and prediction tool to provide the crucial information required to plan for and meet disruptions of this magnitude. The ideal tool would forecast natural gas production shut ins likely to occur during a hurricane or other event—and how long it would take for assets to recover. The tool would also monitor the disruption in near real-time to give a picture of the situation as it develops.

More accurate information would supply the basis for officials to take targeted action. For instance, should natural gas winter stores be released? Will temporary generators be needed to expedite the restarting of critical infrastructure? If cascading impacts are in danger of occurring, how should recovery priorities be set? And if the impending disruption looks to be extreme—where national security issues could arise—might it be necessary to provide monetary funds to aid recovery?

NETL's Natural Gas and Oil Project Management Division tackled the challenge of developing this natural gas prediction tool. The task included analyzing the complexities of the industry in the Gulf, which is made up of three mutually dependent parts: production, pipelines, and processing.

NETL completed the tool before the 2007 hurricane season, but no major activity occurred that year. So, for the 2008 season, NETL continued making updates and improvements. The design team added data between the various data sets and validated the mapping; made significant improvements to the tool's databases and graphic user interface; eliminated steps in calculating production values; created a response template; and added a model to estimate daily oil production, in addition to natural gas. When disruptions occur now, natural gas and oil models are immediately available to approximate how low production has fallen and to form a production recovery curve. This information is disseminated to government officials at DOE, the Department of the Interior, and the White House for analysis and planning.

The newly enhanced tool was first put to the test, not by a hurricane, but by the rupture of a faulty seal at the Independence Natural Gas Hub on April 9, 2008. The resulting curtailment caused the shut in of 850–900 million cubic feet of natural gas production. The prediction model tracked production of natural gas from the Gulf of Mexico and matched the model's predictions so well that the story was featured in *Energy Assurance Daily* produced by DOE's Office of Electricity Delivery and Energy Reliability.

Later in the year, the tool played a key role in predicting a slower-than-normal recovery from Hurricane Gustav because Hurricane Ike was looming in the Atlantic. This prediction was accurate. The only surprise was that recovery of production from Hurricanes Gustav and Ike paralleled that of the much stronger hurricanes Katrina and Rita. This finding is an important addition to the database and will help NETL further strengthen the prediction tool's capabilities.

Energy Infrastructure

To meet America's energy challenges, we must give our attention to every phase of the energy cycle—not only production and generation, but also transmission and distribution. We must ensure the reliability, integrity, and security of our Nation's power grid and oil and natural gas pipeline network, and we must respond to emergencies that can disrupt energy delivery at the regional and national levels. NETL lends its expertise to public and private efforts to build and protect the complex energy infrastructure on which our economy depends.

NETL Updates Projections of New Coal-Fired Capacity—The NETL report, "Tracking New Coal-Fired Power Plants," provides an overview of industry plans to construct new coal-fired power plants in the United States. The 2008 edition compares projected coal plant capacity—in terms of progress achieved since public announcement of development—to that of actual construction. This updated approach provides a more reliable indication of expected near-term growth in domestic coal-fired power generation. The report also reviews conventional and advanced technologies being considered for deployment. Timely development of new coal-fired generation is important for maintaining adequate available electricity to meet expected U.S. demand. The report is available at www.netl.doe.gov/coal/refshelf/ncp.pdf.

NETL Device Examines Integrity of Buried Natural Gas Pipeline—NETL scientists have developed an instrument that can determine without excavation the integrity of natural gas pipeline fabricated from polyethylene or other plastic. Deployed on a "pig"—a flexible tool for internal pipeline inspection—and introduced into an existing transmission or distribution network, the internally powered probe can detect tiny voids, revealing brittle cracks that develop over time. A proprietary electronic circuit allows data to be transmitted in real time or retained for later evaluation. Findings that detail the novel device appear in the peer-reviewed American Institute of Physics journal, *Review of Scientific Instruments,* December 18, 2007.

NETL Provides Analysis for Report to Congress Concerning Electricity Reliability—NETL analysts, in collaboration with DOE's Office of Electricity Delivery and Energy Reliability and the North American Electric Reliability Corporation, studied the possible impact on national electricity reliability under a scenario where mandatory wet cooling towers would be installed at all thermoelectric generating facilities that rely on once-through cooling. Analysis concluded that resulting power generation losses could cause a decline in the electricity generation reserve that now ensures reliable power delivery. Furthermore, the loss of native generation capacity due to reduced operational efficiency, in combination with early retirement of facilities that either cannot or will not retrofit, may jeopardize the ability of high electricity-demand regions—such as California and New York—to meet peak demand for electricity. Regulators and research managers can benefit from the study as they consider how best to balance energy security, economic sustainability, and environmental performance for power generation. The report, titled "Electricity Reliability Impacts of a Mandatory Cooling Tower Rule for Existing Steam Generation Units," can be accessed at www.netl.doe.gov/energy-analyses/technology.html.

NETL Publishes Greenhouse Gas Report on Petroleum-Based Fuels—An NETL study, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," assesses the greenhouse gases released during the life cycle of petroleum-based transportation fuels sold or distributed in the United States in 2005. Its results benchmark the performance of transportation fuels with respect to climate impacts, emphasizing opportunities to lower greenhouse gas emissions at each stage, and forms a basis of comparison for efforts to reduce carbon intensity in the transportation sector. The full report is located at http://www.netl.doe.gov/energy-analyses/trend.html.

Premium Carbon Product from Coal Successful in Commercial-Scale Test—Through a cooperative agreement with NETL, a team headed by West Virginia University developed and successfully demonstrated a synthetic binder pitch that could one day replace petroleum feedstocks. The synthetic binder pitch—

obtained from coal by an environmentally friendly solvent extraction process—was used to make full-scale graphite electrodes for testing in a commercial electric arc steelmaking furnace in Georgetown, SC. One of the main ingredients in standard electrodes is conventional binder pitch, a blend of coal-tar pitch and petroleum pitch; however, for the test, the petroleum pitch was replaced with synthetic pitch. Furnace data showed the electrodes made with the synthetic binder pitch performed as well as the standard electrodes, with no significant difference in electrode consumption. If applied nationally, the domestic product would replace approximately 19,000 tons of petroleum pitch annually, decreasing our reliance on foreign petroleum.

NETL Releases Final Report on Alaska Spur Pipeline Study—Results of a study comparing two potential routes for a buried spur pipeline from a proposed Alaska North Slope natural gas line to the existing ENSTAR natural gas transmission pipeline in Southcentral Alaska are available on the Oil & Natural Gas Technology page of the NETL website. Under NETL funding, ASRC Constructors, Inc., completed the report, which considers engineering, geologic, environmental, regulatory, socioeconomic, and other factors associated with candidate routes through Interior Alaska and terminating near either Wasilla or Palmer. More than 225 billion cubic feet of natural gas are consumed each year in Southcentral Alaska. Without additional natural gas supplies, curtailed operations for certain industries and higher natural gas prices for electricity and home heating could result. Potential spur pipeline sponsors used the report to generate their own estimates regarding costs and level of effort needed to complete a pipeline along one of the identified corridors. ENSTAR currently is investigating the feasibility of building the spur line from the North Slope to Wasilla, rather than from Fairbanks to Wasilla as formerly contemplated.

NETL's Fuel Interchangeability Findings Outline Potential Efficiency and Environmental Performance in California—NETL has released its key findings from a study requested by the Federal Energy Regulatory Commission to explore how the characteristics of liquid-natural-gas (LNG)-derived fuels—as opposed to domestic natural gas—may affect the efficiency and environmental performance of end-use equipment, such as appliances, turbines, and compressor engines. Stringent air quality standards and plans to introduce LNG-derived gas into southern California prompted initiation of the California Energy Commission (CEC) program that is studying fuel interchangeability for the State. The findings were presented in Sacramento to a stakeholder advisory committee and a technical project advisory committee for the CEC program.

Q+A

Q What are bench-, pilot-, and commercial-scale tests ?

A Bench-scale is a prototype or small-scale form of a technology meant to evaluate, under limited operating conditions, the potential of a concept or fledgling process. A bench-scale test is based on prior fundamental research and is usually performed in a laboratory setting.

Pilot-scale (aka engineering-scale) testing, the sequel to bench-scale, evaluates technologies and processes under continuous operating conditions at larger scale. Representing 5–10 percent capacity of planned industrial-scale power plants, pilot plants reduce technology development costs and the investment risks associated with unproven production methods. Technologies that succeed at pilot-scale are eligible for commercial-scale testing or implementation.

Commercial-scale (aka industrial-scale or full-scale) is the ultimate goal of technology deployment. Projects at this scale can meet consumer demand for a product or process, and they are economically and environmentally viable. Once a project has successfully achieved commercial-scale, project developers turn their attention to continuing improvements.

First Microturbine Approved for Use with Waste Fuels

Image courtesy of Capstone Turbine Corp.

This microturbine can provide power from waste gases.

In an NETL-managed project, Capstone Turbine Corporation has produced the first commercially available microturbine to pass the most stringent emissions limits in the country—California's—while running on waste gas.

The microturbine produces 65 kilowatts of electricity from waste gas while giving off only insignificant amounts of nitrous oxide (NO_x), CO_2, and volatile organic compounds, thus meeting standards set by the California Air Resources Board (CARB). "Waste gas" is so-called because it is made from digester gas from sewage decomposition, landfill gas from the decomposition and volatilization of landfill material, or oil-field waste gas.

Capstone's microturbine is certified for digester gas and landfill gas, combining ultralow emissions and lean premix combustion. An oxidizing catalyst allows the microturbine to run on natural gas as well.

The CARB certification of the new microturbine qualifies the technology for California state incentives. Capstone can now place the microturbine at landfills and farms where it will produce power from low-Btu-containing gases that otherwise would be wasted.

Innovative Ultralow-NO_x Technology Proves Successful in Turbine Engine Combustor Test—A full set of catalytic pilots, developed at Precision Combustion, Inc., North Haven, CT, produced low NO_x emissions at targeted base-load conditions during engine trials in Taurus 70 gas turbine fuel injectors. The catalytic pilots help ignite and sustain the flame in the turbine more efficiently and cleanly than previous approaches by incorporating Rich Catalytic/Lean-burn (RCL®) technology. This technology uses a greater air-to-fuel ratio, provides a leaner stable overall combustion, and produces very low NO_x emissions without postcombustion controls or efficiency penalty. NO_x emissions of 2.5 parts per million by volume at full-load conditions were achieved—well below the program target level of 5 parts per million. The RCL catalytic pilot supported the engine startup and shutdown process without any major modification to the existing engine control method. The successful engine test was performed and funded by Solar Turbines, Inc., at its engine test facility. NETL manages the project in cooperation with DOE's Office of Electricity Delivery and Energy Reliability.

Cyber Security Tool Addresses Vulnerabilities of Control and Data Systems—Working under an Office of Electricity Delivery and Energy Reliability contract managed at NETL, Digital Bond, Inc., released the first Bandolier© Audit Files. Designed to work with the Nessus® vulnerability scanner created by Tenable Network Security, these files will audit Supervisory Control and Data Acquisition (SCADA) systems at utility sites against an optimal security configuration. SCADA systems are a key vulnerability in the infrastructure cyber-security loop since they serve as the link between the Internet and critical infrastructure systems. Bandolier Audit Files will

flag vulnerable configurations in control system devices and applications, review security events to identify attack attempts on control systems, and integrate data historian security findings into enterprise security event manager products. The alpha version of the files is now available for electric-transmission and oil and natural gas pipeline-control systems. In upcoming months, additional support for other systems will be available to owners and operators through a Digital Bond subscription service.

Power Grid Modernization Moves One Step Closer to Realization—As part of an NETL-managed project to help accelerate the modernization of the Nation's electric delivery system, Zenergy Power, Inc., South San Francisco, CA, successfully tested a Fault Current Limiter (FCL) featuring superconducting wire, which has near-zero resistance capability and the potential to alleviate congestion on high-demand electricity grids. The FCL is designed to instantaneously and automatically respond to multiple surges in electric power while maintaining a stable, uninterrupted power flow to downstream devices at a voltage level consistent with utility power distribution. Conducted at Powertech Laboratories in British Columbia, the test exposed the device to realistic grid operating conditions, particularly the severe fault currents associated with national grid blackouts. The achievement, which was observed by representatives of the National Electric Energy Testing Research and Applications Center and a number of U.S. utility companies, is a significant step in developing a 138-kilovolt transmission-grade FCL suitable for the commercial market.

Milestones Reached for Second-Generation High-Temperature Superconductor—In an NETL-managed project, product developers at SuperPower, Inc., of Schenectady, NY, achieved a new world record with their second-generation (2G) wire, reaching a critical minimum current of 153 amps per centimeter of width (A/cm) for wire 1,311 meters long. Pilot technology for this wire—made from an yttrium barium copper oxide superconductor material—has been scaled up. Production rates of 90 meters per hour are now yielding wire 4 millimeters wide and 202 meters long, capable of carrying a minimum critical current of 314 A/cm. Meanwhile, product developers at American Superconductor Corporation (AMSC) are producing 4-centimeter 2G high-temperature superconductor tape at their facility in Devens, MA. By slitting the 4-centimeter tape into 10 strips, AMSC can now produce 8 strips of 2G wire in 4-millimeter widths and lengths of 500 meters. In addition, a rolling mill is now operating for 10-centimeter-wide tape, nearly tripling production. Qualification of the AMSC pilot production line will satisfy part of an interagency agreement between DOE and the Air Force Research Laboratory, Dayton, OH, under Title III of the Defense Production Act. The new high-temperature superconductor wire potentially will deliver three to five times more power to urban areas through existing cable ducts, reducing power-cable transmission losses from current estimates by DOE's Office of Electricity Delivery and Energy Reliability's Superconductivity program.

Methane Hydrates

Methane hydrates, found in ocean sediment at many locales where the water depth exceeds roughly 500 meters, are three-dimensional ice-lattice structures with natural gas locked inside. Through the Office of Fossil Energy's Methane Hydrates Program, NETL seeks safe, economical, and environmentally responsible ways to unlock the natural gas and produce this methane as an energy resource. NETL researchers are working with domestic and international industry and academic partners to assess this resource potential and understand the environmental role that methane hydrate deposits play in global climate change.

NETL researcher Kelly Rose with Dr. Tae Soo Chang, South Korean Gas Hydrate Expedition 2007.

NETL Participates in Voyages of Discovery

NETL participates in ocean expeditions to better understand the role of naturally occurring methane hydrates as a potential energy resource and its possible relationship to climate change and seafloor stability. Not only do these collaborative efforts help identify occurrences of methane hydrates in the subsurface, they also help determine its pathways from subsurface to seafloor, through the water column, and possibly into the atmosphere.

In late 2007, an NETL researcher was the sole U.S. scientist to join a 5-week-long methane hydrates expedition in the East Sea off the Korean Peninsula, serving as the lead shipboard sedimentologist. Organized by the government of South Korea, the expedition evaluated exploration techniques for determining the location and occurrence of gas hydrate accumulations.

In fall 2008, researchers aboard the Canadian Coast Guard ship *The Tully* spent 3 weeks collecting sediment cores and conducting geophysical surveys to characterize slumps and vent sites, the seafloor features likely associated with methane hydrate occurrences. The expedition focused on the Cascadia Margin region near Vancouver Island with participating researchers from DOE, the U.S. Geological Survey, the Canadian Geological Survey, and Canada's McGill University.

In 2009, NETL is contributing to the first expedition in the U.S. Beaufort Sea dedicated to characterizing the occurrence and fate of methane from sub-seafloor sediments and gas hydrate accumulations.

NETL Is New Curator of Hydrate-Bearing Core Samples—With the delivery of the first hydrate-bearing core samples under agreement with the U.S. Geological Survey, NETL became the leading federal curator of gas hydrates and associated sediment samples. Stored in liquid nitrogen since being recovered from drilling operations during a 2006 research expedition in the Indian Ocean, the samples represent a significant investment in research and funding. Retrieval of additional samples is anticipated from future expeditions in both oceanic and permafrost regions. NETL will coordinate the distribution and analysis of these samples based on protocols now in development.

NETL Scientists Propose a Model for Gas Hydrate Formation—NETL researchers have developed an empirically based thermodynamic model useful for predicting the formation of gas hydrates from a single-phase solution of gas dissolved in fresh water or seawater. The work is relevant to understanding the formation and dissociation of methane hydrates as

applied to possible methane production or release from hydrates as well as its role in climate change and seafloor stability. The model would also be applied in understanding CO_2-hydrate formation if geologically stored CO_2 were to come in contact with cold, subterranean or suboceanic water-containing systems. Details of the experiment and theory of phase equilibrium in two-phase, water-rich hydrate systems appear in the January 16, 2008, issue of the American Chemical Society journal, *Industrial & Engineering Chemistry Research*.

NETL Increases Insight on Hydrate Thermal Properties—Researchers at NETL in collaboration with the University of Pittsburgh have determined that the solid water structure, or lattice, in methane hydrates plays a more important role than expected in lowering the compound's thermal conductivity value as compared to normal ice. Thermal conductivity of methane hydrates has been the subject of experimental and theoretical investigations for more than two decades. Still, the mechanisms behind this phenomenon have not been clearly understood. Improved understanding of this parameter will lead to better predictive models for controlling the breakdown of methane hydrates in methane production and in understanding how methane hydrates may impact climate change. The study appears in *The Journal of Physical Chemistry B* in the August 21, 2008, issue.

Science Team Investigates New Hydrate Mapping Technique in the Gulf of Mexico—Working in cooperation with NETL, a science team from Scripps Institution of Oceanography embarked on a 3-week voyage on the research vessel *Roger Revelle* to determine if marine electromagnetic surveying could provide accurate images of hydrate amounts in shallow marine sediments. If successful, the new approach promises to improve the reliability and accuracy of mapping hydrates over large areas and of locating economically viable accumulations for production testing. In addition, more accurate mapping of subsurface hydrates should enhance computational models aimed at predicting the climatic impacts of methane release from hydrates.

Oil and Natural Gas Production

Oil and natural gas meet vital industry, business, and residential needs, supplying more than 60 percent of U.S. energy requirements. To meet projected future demand, competitively priced domestic oil and natural gas will continue to be an essential part of the U.S. energy portfolio. NETL integrates all elements of the Office of Fossil Energy's oil and natural gas research to discover ways of accessing and producing conventional and unconventional supplies more economically with attention to environmental issues. The majority of our technologies are developed in cooperation with small independent producers, who drill up to 90 percent of America's wells, provide 80 percent of domestic natural gas and nearly 70 percent of domestic oil, and employ an average of 12 people each.

New NETL Model Describes Highly Fractured Geologic Formations and Oil Reservoirs—NETL researchers have developed a "blocks-and-springs" model to study how second-generation fractures intersect first-generation fractures in underground oil reservoirs affected by two separate geologic events. Understanding these flow-enhancing interconnections is important for commercial energy production, especially in areas of limited permeability. The insights and equations obtained with the model will improve NETL codes for describing fracture networks from field data (FRACGEN™) and for engineering simulations of fractured reservoirs (NFFLOW™).

NETL Porous Flow Device Aids Studies in Oil and Natural Gas Production—Researchers at NETL in collaboration with Clarkson University in Potsdam, NY, have developed a new method for constructing a laboratory-scale porous medium with increased pore-level variability. The medium is useful for realistic two-phase flow studies in oil and natural gas production and carbon sequestration. The flow going through the produced medium is consistent with theoretical predictions of fractures. The method of constructing the medium and the resulting improvements are detailed in the April 11, 2008, issue of *Review of Scientific Instruments*, published by the American Institute of Physics.

Project Increases Natural Gas Production from Restricted Michigan Formation—Working in cooperation with NETL, investigators at Michigan Technological University and Jordan Development Company, LLC, of Traverse City, MI, have demonstrated a low-impact technology that has nearly doubled natural gas production in the shallow Antrim Formation in Michigan. To overcome an environmental restriction on drilling shallow wells, the project team drilled a directional hole to the required regulatory depth and then angled through the producing horizon using a long-reach, nearly horizontal well. The demonstration well was cased, as required by State regulations, to prevent groundwater contamination and leaks to the atmosphere. More efficient than conventionally drilled vertical wells for producing natural gas from shale, the new method requires far fewer wells and can avoid sensitive surface areas such as wetlands, golf courses, and residential developments.

Small Business Innovation Research Demonstrates Novel Heater for Oil Shale Recovery—Under a Phase II Small Business Innovation Research grant administered by NETL, product developers at Composite Technology Development, Inc., of Lafayette, CO, have successfully tested an innovative high-temperature downhole heater cable for 5,000 continuous hours at temperatures ranging from 760–850 °C—well within the range needed for bringing the underground shale to temperatures required for oil recovery. The team developed a process for fabricating the cable and filed two patents. The technology overcomes many of the limitations of commercial mineral-insulated heater cables, such as conductor instability, moisture-induced degradation, and limited operating temperatures. The heater cable has potential applications for enhanced oil recovery, geothermic fuel cells, and geothermal energy, as well as oil production from the vast oil shale deposits of Colorado, Wyoming, and Utah.

Electromagnetic Survey Data Offer Support for Increased Coalbed Natural Gas Production—Fugro Airborne Surveys, Inc., completed a helicopter electromagnetic survey of two sites in the Powder River Basin in Wyoming as part of NETL's plan to improve the management of water coproduced with coalbed natural gas (CBNG). Survey information for one of the sites will help in designing a subsurface drip irrigation system that avoids areas of low permeability, mineral salt accumulations, and groundwater with high levels of dissolved solids. Data from the second site will help determine the suitability of sub-irrigated land on the flood plain of Beaver Creek—a tributary of the Powder River—for CBNG discharges that will meet Wyoming's Agricultural Use Protection Policy. Both projects have the potential to increase CBNG production by providing beneficial and environmentally benign uses for produced water. The U.S. Geological Survey provided quality assurance oversight for the survey. Partnering with NETL on the projects are the Wyoming Department of Water Quality, the U.S. Bureau of Land Management, Anadarko Petroleum Corp., BeneTerra LLC, and West Virginia University's Natural Resource Analysis Center.

South Korean Group Joins NETL-Led International Collaboration in Oil and Gas Research—A research group from Hanyang University in Seoul, South Korea, has joined NETL scientists and engineers in the study of subterranean fracture networking that can enhance gas flow in petroleum reservoirs. The work builds on the pioneering development of NETL codes for describing fracture networks from field data (FRACGEN™) and for engineering simulations of fractured reservoirs (NFFLOW™). Now five institutions in four countries are collaborating in a unified program to conduct laboratory experiments, interpret field project results, and develop new theory, computations, and reservoir simulators. Important applications include the injection of water into oilfields to increase production and the injection of CO_2 into brine-saturated geologic strata to avoid releasing greenhouse gases into the atmosphere.

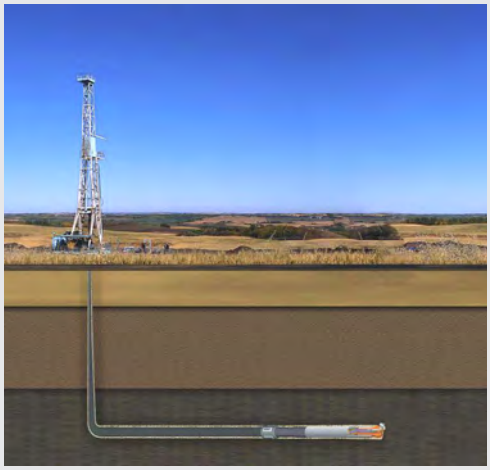
Microhole Tool Successfully Demonstrated—Working in cooperation with NETL, product developers at Western Well Tool have completed a field demonstration of the Microhole Drilling Tractor (MDT) with a major oil company working in Alaska. Operating inside 4½-inch tubing at depths of 800–950 feet, the MDT successfully demonstrated on-off capability, pulled with up to 1,465 pounds of force, and verified its capability to transmit torque. The MDT is designed to provide forward thrust for the drill bit at the end of a coiled-tubing drill string when it locks up or fails to deliver sufficient weight on the bit to drill ahead. The hydraulically powered device will allow producers to drill shallow holes with long, horizontal well sections up to 3,000 feet beyond the ability of existing technology. The MDT shows promise of accomplishing this drilling economically and effectively and will require fewer wells to be drilled, thereby minimizing surface environmental impacts.

Bottomhole Assembly Successful in Field Test—General Electric Company's product developers, in cooperation with NETL, have successfully developed and field-tested a prototype assembly that integrates existing, proven technologies for measurement-while-drilling and logging-while-drilling. The prototype provides a cost-effective downhole measurement system for drilling small, shallow—less than 5,000 feet in depth—boreholes using coiled tubing technology. The 3⅜-inch system embodies an important capability needed for rapid expansion of both coiled-tubing drilling and conventional small-diameter drilling for oil and gas exploration and production. Commercial orders have already been placed for a 3½-inch diameter version of the technology.

How it Works

Horizontal Drilling

During horizontal drilling, the lower part of the drill hole runs parallel beneath the oil zone instead of perpendicular to it, as in typical vertical drilling. The flexible drill pipe in a horizontal well can reach isolated pockets or follow an expansive reservoir, greatly reducing the "drilling footprint" above ground.



Supply & Environment

Advanced Power for Clean Energy

How will we supply our growing energy needs while protecting our environment? By finding new and better ways to utilize U.S. fossil fuel resources: oil, natural gas, and coal, our most abundant and inexpensive energy resource. Every study and forecast shows that meeting America's growing power demands will, in the foreseeable future, require reliance on fossil fuels. Around 80 percent of the world's energy is expected to come from fossil fuels until at least 2030. Securing environmentally sound energy for the 21st century means developing advanced fossil-fuel combustion systems that have greater efficiencies. It requires new means of converting coal into electric power and liquid fuels. Environmentally sound energy also includes the realization of dependable, affordable fuel cells powered by coal-derived hydrogen and synthesis gas.

Advanced Combustion

Environmental responsibility begins with responsible energy production. At NETL, scientists and engineers are working on varied solutions for producing power with negligible environmental impact. One solution is the development of advanced combustion technologies for fossil-fuel power plants. NETL research in advanced combustion focuses on such technologies as chemical looping and oxy-fuel combustion, in which the system fuel is combusted with oxygen instead of air. Because nitrogen-laden air is excluded from combustion, these processes reduce nitrogen oxide (NO_x) emissions and improve the efficiency of the combustion process while producing a sequestration-ready CO_2 stream.

NETL Researchers Make First Measurements in Unique Oxy-fuel Flame Test Facility—By making the first measurements of an oxy-hydrogen flame with high steam dilution, NETL researchers have taken an important step in obtaining data for flame speed and heat radiation. The information is needed for accurate simulation of oxy-fuel combustion systems that are compatible with carbon capture and storage. Power system designers are considering oxy-fuel combustion schemes as part of a strategy to achieve zero emissions with the use of fossil fuels. The accomplishment demonstrates the viability of flame-speed measurements in an environment with very high steam concentrations. Removing nitrogen from air and substituting a diluting agent—such as steam, CO_2, and/or recycled flue gas—to replace up to 70 percent of the flow to the burner prevents the hydrogen-oxygen flames from overheating.

NETL and Industry Join to Assess Benefits of Pulverized Coal Oxy-fuel Combustion—NETL analysts, working extensively with investigators at The Babcock & Wilcox Company and American Air Liquide, assessed the technical, environmental, and economic performance of pulverized coal oxy-fuel combustion as an option to reduce greenhouse gas emissions from pulverized coal power plants. The analysis showed that oxy-fuel combustion with pulverized coal has a small but definite economic and performance advantage over current amine scrubbing technology for the separation of CO_2 from flue gas. Several cost-saving strategies were identified as well as potential barriers that need to be overcome before commercial implementation. The study provides a baseline for evaluating future advances in oxy-fuel combustion based on technology that could be constructed between 2010 and 2015.

Oxy-fuel Combustion Offers Environmental Benefits for Coal-Fired Power Plants—Studies completed by American Air Liquide, in partnership with NETL, show that replacing combustion air in coal-fired power plants with pure oxygen diluted with recycled flue gas results in a viable emissions-control option. Compared to flue gas from air-blown combustion, the emissions from oxy-fuel combustion—using Powder River Basin coal in a 5 million Btu-per-hour pilot unit—contained about 65 percent less NO_x. Although oxy-fuel combustion yielded a higher amount of mercury, it was produced in a state more susceptible to capture than with traditional coal combustion. Moreover, the flue gas was reduced in volume by around 70 percent and was richer in CO_2 content (80 percent vs. 15 percent), making the CO_2 easier and more economical to capture and sequester. By adjusting burner parameters and oxygen-to-recycled-gas ratios, overall combustion characteristics can be achieved to make furnace temperatures compatible with conventional materials. An engineering feasibility study—supported by experimental observations—indicates that oxy-fuel combustion, with its efficient multi-pollutant emission-control attributes, can be applied to existing pulverized-coal-fired boilers with minimal modifications.

New Membrane Material Developed for Oxygen Production—In cooperation with NETL, Ceramatec, Inc., Salt Lake City, UT, a member of a team developing an ion transport membrane (ITM) for the production of oxygen, has cast more than one mile of thin, flexible, ceramic ITM material. This tape contains a precursor to the membrane and can be shaped and layered to make commercial-size membrane wafers for a 150-ton-per-day oxygen-production module.

Significant Milestone Reached Toward Commercialization of Oxygen Technology—Two commercial-scale ITM oxygen-production modules in a 5-ton-per-day subscale prototype facility have logged nearly 9,000 hours of cumulative operating time, producing oxygen with a purity greater than 99 percent during optimal production periods. An advanced process-control technique allows unit cycling from full operating conditions to ambient temperature and back again with minimal ITM material or performance degradation for either module. A key milestone for the program, the technique significantly improves ITM module reliability by cutting heating and cooling cycle times nearly in half and decreasing stress in vital ceramic parts. In cooperation with NETL, Air Products and Chemicals, Inc., of Allentown, PA, leads the team that is developing the ITM oxygen process toward the goal of producing oxygen at a cost and energy requirement one-third lower than current processes. Integrated gasification combined cycle (IGCC) and other advanced power-generation systems, as well as traditional plants, stand to profit from the technology.

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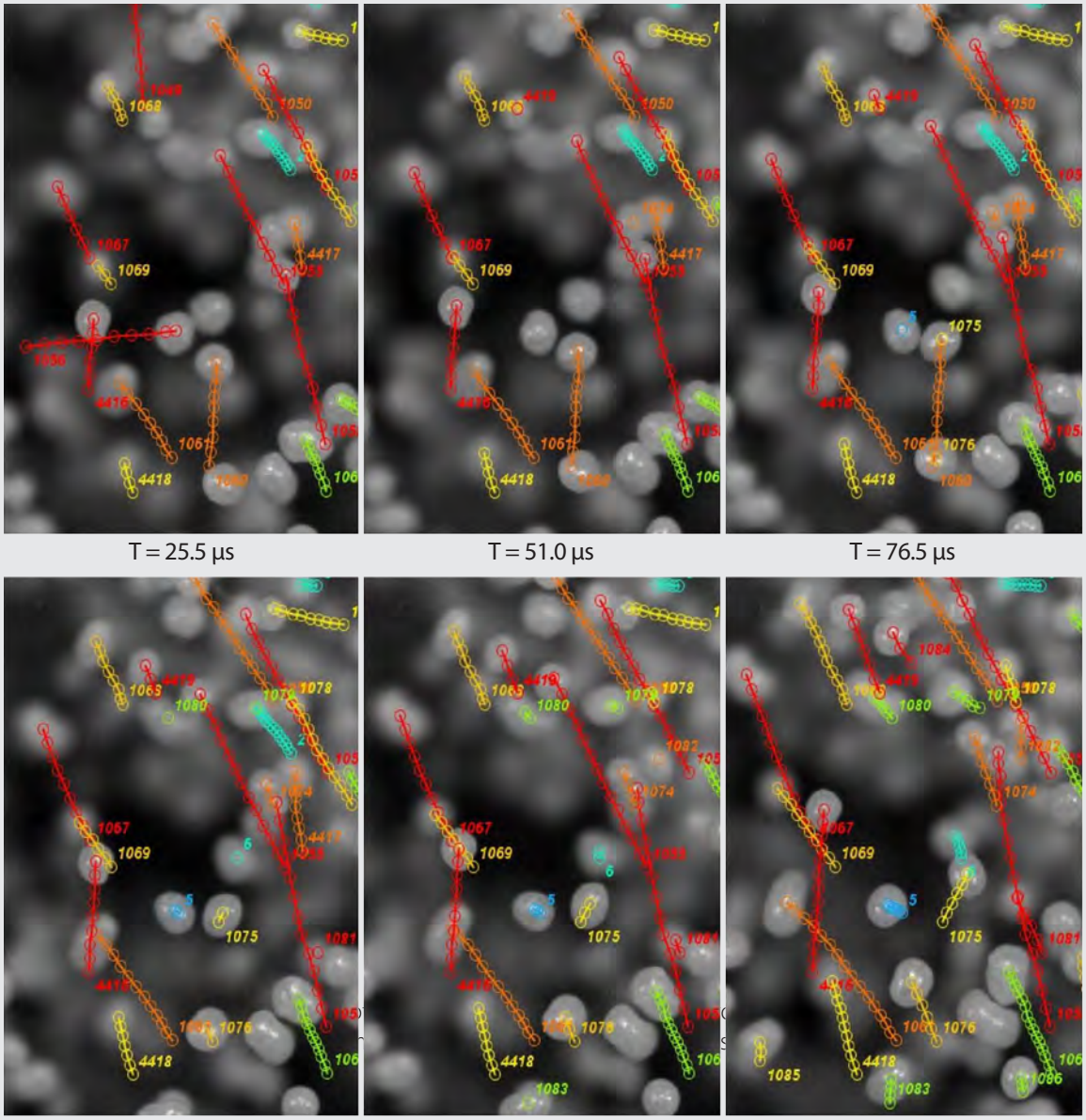
Chemical looping combustion is a new method for converting either pulverized or gasified coal into energy. Instead of feeding the fuel with air, this flameless technology employs a dual fluidized bed system in which the metal oxide in a fuel reactor releases oxygen to feed combustion. The "reduced" metal is transferred to the second bed and re-oxidized, then reintroduced to the fuel reactor, completing the loop. The by-products of chemical looping are CO_2 and water in the form of steam. Once the steam is condensed, a relative pure stream of CO_2 is produced, ready for capture.

Oxy-fuel combustion (aka oxycombustion) is the combustion of pulverized coal in a mixture of approximately 95 percent oxygen and 5 percent recirculated flue gas. Using oxygen instead of air eliminates free nitrogen from the process. Nitrogen is the largest component of ambient air and a source of NO_x emissions. Oxy-fuel combustion also decreases the net amount of flue gas and produces a highly pure CO_2 exhaust that can be captured at relatively low cost.



A sequence of camera frames in which particle motion is automatically recognized and labeled by NETL's HSPI software.

Big Role of Small Particles Is Brought to Light

It is nearly impossible for the human eye to follow a moving particle smaller than a grain of salt. Now imagine following that particle if it is one of millions moving randomly in a high-speed liquid or gas stream. NETL researchers have created a method to do just that by developing a high-speed particle imaging (HSPI) system that peers into fossil fuel processes and tracks particle dynamics.

The ability to see the motion of minute particles is of critical importance to NETL because particle motion is one of the primary factors that affect the efficiency and reliability of fossil fuel processes. HSPI is the only system that measures all critical parameters of a fossil fuel process—particle velocity, trajectory, concentration, size, and shape—and its measurements are highly accurate, with uncertainties of less than 1 percent for most applications.

One fossil fuel process that depends on flow fields of small particles is coal gasification, in which coal is turned into a low-emission combustible gas. To study particle flow fields, NETL engineers needed an imaging system with extreme light sensitivity and very high frame rates at a resolution near that of high-definition television. The HSPI system obliges with components that include a high-speed image sensor, a high-intensity light source, and an endoscope (similar to those used in surgery) to probe flow fields of fossil fuel processes. NETL developed custom particle image recognition and tracking software to automatically convert hundreds of thousands of high-speed camera frames into relevant particle dynamics data. NETL has filed a provisional patent application for the HSPI software.

The first application of HSPI was the study of flow fields in NETL's cold-flow circulating fluidized bed unit, a large cold-flow gasification experiment being conducted at the Laboratory's site in Morgantown, WV. This experiment provided the first detailed observations and measurements of the dynamic behavior of small particles (less than 1 millimeter) inside a particle flow field with very high particle concentrations. Researchers used the HSPI system to view, record, and measure the precise motion of microscopic particles that simulate the motion of coal particles in a gasification chamber.

The success of the initial study was promptly followed by an innovative transfer of the technology to industry through collaboration with Particulate Solid Research, Inc. (PSRI), an international research organization comprising over 25 member companies from the chemical and energy industries and renowned for research in fluidization. Through PSRI, the HSPI technology was made available to multiple companies. Future plans with PSRI include a series of experiments to help accurately model flow particle size and density distribution.

NETL is using the results from the HSPI system to validate computational fluid dynamics (CFD) models, such as the Laboratory's MFIX code. The new insight into the miniscule world of particle flow phenomena provided by HSPI could dramatically change the CFD models that are playing a major role in the design of coal-based power plants with near-zero emissions and other next-generation fossil fuel processes.

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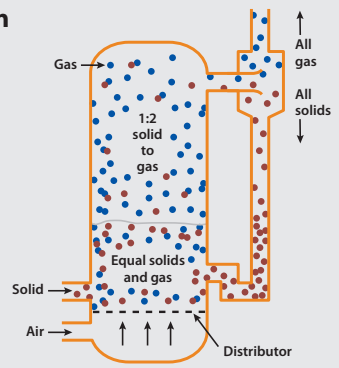
Fluidized bed combustion is a method of burning fuel in which solid fuels are suspended on upward-blowing jets of air during the combustion process. The result is a turbulent mixture of gases and solids that resembles a bubbling fluid. Fluidized beds were developed as part of the Office of Fossil Energy's Clean Coal Technology Program, managed by NETL. They have long been used for the combustion of high-quality as well as difficult fuels, such as waste coal tailings, to improve chemical reactions and heat transfer.



Fuel Cells

NETL research is steadily advancing toward cost-competitive fuel cells for a variety of power needs. Through management of the Office of Energy Efficency and Renewable Energy's Solid State Energy Conversion Alliance (SECA)—a collaboration of government, private companies, and the wider scientific community—we are developing market-ready megawatt-class fuel cells for integrated gasification-fuel cell systems, which can produce reliable, efficient, environmentally friendly electric power from coal and other domestic resources. The high efficiency and unique features of these systems will allow a greater than 90 percent capture of CO_2, significantly reduce other emissions, and substantially decrease water requirements for power production. NETL also works in partnership with DOE's Office of Energy Efficiency and Renewable Energy to develop fuel cells for transportation and other small-scale applications.

NETL Research Shows Feasibility of Controlling Pressurized Fuel Cell-Turbine Hybrid—Simulation results obtained from the NETL Hybrid Performance (HYPER) test facility show that fluctuations in a pressurized fuel cell-turbine hybrid system can be managed using a control scheme based on the mathematics of H-Infinity control theory. During load upsets, the control scheme maintains fuel cell airflow input and synchronous turbine speed by using air bypass valves and an auxiliary fuel input. Developed with West Virginia University as part of NETL's Insititute for Advanced Energy Studies, the results have important implications for scaling up hybrid systems for use with large coal-based power systems. The controls research initiated at NETL by the HYPER team represents the only experimentally derived development of system-transfer functions—those functions that characterize the control of a combined fuel cell-gas turbine application.

Mobile Unit Measures Impact of Trace Species on Solid Oxide Fuel Cell Performance—A mobile platform developed by NETL has been installed at the Power Systems Development Facility at Wilsonville, AL, to support the performance testing of fuel cells operating on coal-derived synthesis gas. The skid-mounted array of 12 individual fuel cells is designed to provide data on the effects of trace coal contaminants on solid oxide fuel cell (SOFC) performance over a range of electric load conditions for extended periods of operation. Testing is supported by an analytical instrument known as a gas chromatograph inductively coupled plasma-mass spectrometer. The instrument offers parts-per-billion sensitivity to inorganic gas-phase compounds such as arsenic, phosphorous, selenium, and mercury, which are typically found in trace amounts in coal synthesis gas. The multi-cell array operated for 200 continuous hours on direct synthesis gas at the facility. It is available to support fuel cell performance testing at other coal gasification sites.

NETL Research Develops New Interconnect Materials for SOFCs—NETL researchers have discovered a titanium-containing ferritic stainless steel that can improve SOFC interconnect materials. Under specific laboratory conditions, a titanium-rich outer scale is developed on the interconnect material. The scale is thought to have a low electrical resistance, which would minimize the contamination of the SOFC's cathode by chromium. The research results were published in the May 15, 2008, issue of *Journal of Power Sources*. A follow-up paper describing the critical titanium content is anticipated.

New Processes Improve SOFC Performance and Cost Efficiency—In an interagency and industrial-partner collaboration, researchers at NETL, ATI Allegheny Ludlum Corp., and Pacific Northwest National Laboratory have successfully modified the metallic alloy AISI 441 to help achieve SOFC electrical interconnect requirements for lifetimes of 40,000 hours or more. AISI 441 is an inexpensive ferritic stainless steel. Experimental work at Pacific Northwest National Laboratory and ATI Allegheny Ludlum indicated that, with a special coating, AISI 441 exhibited very low and nearly constant area-specific resistance throughout 5,000 hours of testing. A rare earth treatment integral to the special coating and a manufacturing process that reduces silica formation have been developed by NETL and ATI respectively. In addition to these breakthroughs, the cost of commercially available AISI 441 is predicted to be considerably lower than the cost of producing state-

of-the-art high-temperature metal alloys suitable for SOFC electrical interconnect service.

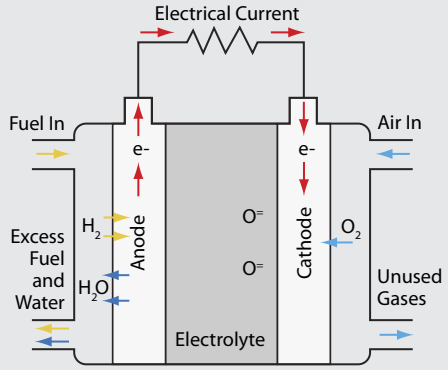
NETL Develops Improved Coating Process for SOFCs—As part of NETL's Insititute for Advanced Energy Studies, collaborators at West Virginia University and NETL developed an environmentally friendly electroplating process for protecting SOFC interconnects with a manganese-cobalt coating. Electroplating is easier to employ and lower in cost than other coating methods, and data show that a test cell with interconnects coated using the new approach exhibits a lower degradation rate than one with uncoated interconnects. Results of this research were presented at the Materials Science & Technology 2008 Conference organized by the American Ceramic Society and appear in a patent disclosure and two peer-reviewed journals.

Design Guide Documents Best SOFC Practices—The *Solid Oxide Fuel Cell Design Guide* has been prepared in a collaborative effort among NETL, Pacific Northwest National Laboratory, Oak Ridge National Laboratory, and the American Society of Mechanical Engineers. The guide recommends the best in SOFC design practices, including modeling and analysis procedures, for use by designers and fabricators of SOFCs. Developed by SECA's Core Technology Program, the guide describes analytical procedures developed to model electrochemical and thermomechanical performance of SOFCs. Additionally, it describes how these procedures and other tools can be used to design a structurally reliable and durable SOFC stack. As a living document, the guide will be updated and expanded on a regular basis to facilitate development of cost-effective, reliable SOFC designs.

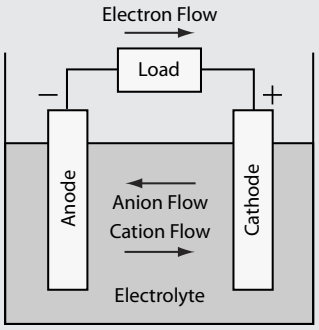
How it Works

Fuel Cell vs. Battery

A fuel cell is an electrochemical device that converts a common or specialty fuel (e.g., methane, coal-derived synthesis gas, biofuel) and an oxidant (air) into electrical energy without allowing the fuel and air to mix. A fuel cell operates much like a battery, using an anode, a cathode, and an electrolyte to generate electricity directly from the chemical energy of the fuel. This direct conversion is more efficient than producing electricity via combustion. Unlike a battery, a fuel cell will operate continuously for years while producing two to three times more power for a comparable volume. This is important to saving weight, space, and cost.



Solid Oxide Fuel Cell
(Open System)



Battery
(Closed System)

Industry Teams Test Fuel Cell Designs—SECA, managed by NETL, is developing and testing SOFC designs for use in coal-fueled central power generation. One SECA industry team, led by Fuel Cell Energy, Inc., has developed two 11-kilowatt SOFCs that have exceeded 3,500 hours of operation. A second SECA industry team, Siemens Power Generation, has tested a 9.8-kilowatt SOFC stack for more than 2,700 hours. These SOFC stack tests, using scaled cells, have demonstrated a steady-state degradation of less than 2 percent per1,000 hours of operation. The tests are an important step in proving SOFCs for use in integrated gasification-fuel cell coal plants. Testing will continue through at least 5,000 hours of operation to assess materials stability. SECA has the goal of developing fuel cell power systems with capabilities greater than 100 megawatts that will produce affordable, efficient, environmentally friendly electrical power from coal. The systems should have at least a 15 percent greater overall efficiency than today's average coal-fired power plant.

Fuel Cell Reaches New Performance Level—The Delta8 SOFC designed by Siemens Energy, Inc.—one of four NETL-supported industry teams from SECA—has performed better than all previous models in the Siemens's high power density design series, with no noticeable voltage degradation. The new design has an active area greater by 58 percent than that of the largest previous cell, and has achieved 80 percent fuel utilization during a 2,000-hour laboratory test. The higher power density and larger active area combine to reduce the number of cells, cell interfaces, and raw materials required for a system of given power output. The new design represents significant progress toward meeting the SECA cost goal of $700 per kilowatt by 2010.

Milestone Reached for Central Station SOFC—In a substantial contribution toward achieving the SECA cost goal of $700 per kilowatt, Versa Power Systems, Inc., under subcontract to FuelCell Energy, has completed a successful test of a 1.3-kilowatt SOFC stack. Comprising six cells—each with an active areaof 550 square centimeters, five times that of the baseline Versa cell—the stack's performance was consistent with the performance of the baseline cell. Scaling to larger-area cells was achieved using proprietary manufacturing processes suitable for high-volume manufacturing.

Successful Fuel Cell-Gasifier Integration Encourages Private Sector Demonstration Project—In a project cosponsored by NETL and Xcel Energy, Inc., researchers at the University of North Dakota Energy & Environmental Research Center successfully completed proof-of-concept testing of a biomass power system consisting of an SOFC thermally integrated with a gasifier. In this system, the high-temperature effluent from the SOFC enables operation of a gasifier at an elevated temperature of 1,000 °C. At this extreme temperature, moisture in the biomass fuel acts as a carbon-gasifying medium, achieving complete carbon conversion and eliminating the need for gas cleanup and associated subsystems. Reduced system complexity and more stable gasifier operation can significantly lower operating and maintenance costs, making small-scale gasification economically viable. The findings led to approval of a 30-kilowatt demonstration plant for applying the thermal integration approach to a microturbine and small-scale gasifier, fully funded by Xcel Energy.

Molecular Insights Lead to Novel Electrocatalysts—Fuel cells that use coal synthesis gas as a fuel tend to experience carbon build-up (coking) on their nickel catalysts, which eventually causes them to malfunction. Now, a team led by the University of Michigan at Ann Arbor and funded through NETL has developed a unique alloy material based on a micro-level understanding of the chemical transformations that lead to coking. The new catalyst material exhibits superior tolerance to coking compared to commonly used all-nickel catalysts and represents a rare example of designing novel electrocatalytic materials based on detailed molecular insights.

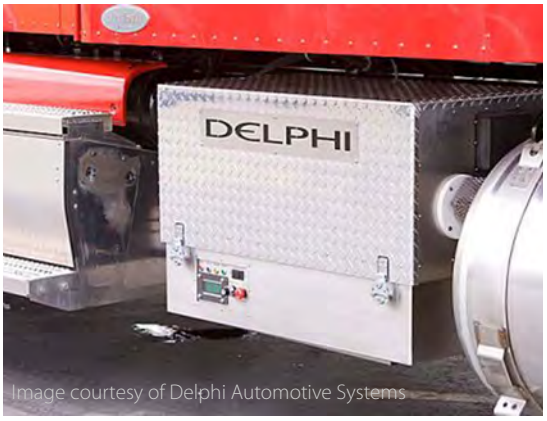


Image courtesy of Delphi Automotive Systems

Fuel cell power could make the idling of heavy trucks unnecessary.

Fuel Cell Power Unit Reduces Truck Emissions

Idling of vehicle engines is responsible for an estimated 11 million tons of CO_2 and 150,000 tons of nitrogen oxide emissions per year. Long-distance trucking contributes a significant share of these emissions, because as drivers rest for periods of 6–8 hours per day, engine idling is needed to provide heating, cooling, and electricity.

SOFCs can potentially eliminate truck-idling emissions. During a simulated 10-hour night, a Peterbilt truck Model 386 with the engine off was provided with 800 watts of power by an auxiliary power unit containing an SOFC. This was sufficient to supply the truck with air conditioning, communications, and heating.

The prototype power unit was developed by Delphi Automotive Systems, LLC, in cooperation with NETL under the Office of Energy Efficiency and Renewable Energy's SECA program. The adoption of such power units across the trucking industry would reduce annual U.S. emissions, help truck drivers meet anti-idling regulations without compromising safety and comfort, and save on fuel, as well.

Gasification

Gasification, a technology first developed in the late 18th century, is finding new uses in large-scale power generation. Gasification technologies produce synthesis gas, which can be used to generate clean electrical energy in advanced turbines and fuel cells while also yielding an easily captured CO_2 stream, ready for sequestration. NETL researchers work with computational fluid dynamics models to assist in the development of modern gasification technologies for future power plants. These technologies are expected to achieve thermal efficiencies nearing 60 percent while reducing emissions and conserving power-production resources. NETL's work is helping to reduce gasification's cost, improve its efficiency, increase its reliability, and broaden its ability to operate economically on feedstocks such as coal, biomass, and petroleum coke.

NETL Simulation Technology Optimizes Gasifier Design—Researchers have combined the power of process simulation with high-fidelity computational fluid dynamics, advanced visualization, and high-performance computing in NETL's Advanced Process Engineering Co-Simulation (APECS) software. APECS helps engineers understand and optimize the coupled fluid mechanics, heat and mass transfer, and chemical reactions that drive energy conversion processes and power plant performance. NETL has now broadened APECS so that design engineers can also optimize equipment geometry of overall plant performance. Engineers at ALSTOM Power are using the new feature to automatically scale the geometric design for the gasifier model used in a simulated integrated gasification combined cycle (IGCC) system with carbon capture.

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Gasification is the cleanest coal-based power system available today. During gasification, coal, oxygen, and steam are reacted at high temperature and high pressure to produce synthesis gas—or syngas—a mixture of carbon monoxide and hydrogen. The syngas can be used in a turbine system to generate electrical power or can undergo further refining to produce transportation fuels, chemicals, or pure hydrogen.

NETL Applies Computational Fluid Dynamics to Help Design Novel Hydrogasifier—NETL researchers used standard computational fluid dynamics and statistical tools to specify engineering design values for the hydrogen nozzles and swirl angle of the advanced coal hydrogasifier being developed at Arizona Public Service Company (APS). The analysis considered solids mixing, solids flow, and gas temperature at four different elevations in the proposed reactor design. The analysis also specified values that would maximize gas-solids mixing through the reactor while minimizing recirculation near the hydrogen nozzles. APS engineers are working in cooperation with NETL to develop and demonstrate a pilot-scale coal hydrogasification process that produces both substitute natural gas and electricity. Initial systems analyses indicate that a coproduction plant using the hydrogasifier will meet DOE goals of an overall process efficiency greater than 60 percent with at least 90 percent CO_2 capture for storage or reuse.

NETL Advances Gas Sensor Development—NETL researchers have developed theoretical calculations to explain the stability and electronic properties of different layers within the tin oxide materials important in catalysis and high-temperature sensor technologies. The analysis represents a first step toward an understanding of the properties of these materials and their surfaces at the atomic level, with direct implications for further development of high-temperature gas sensors. The achievement was presented by NETL in the January 30, 2008, issue of *Physical Review B*.

NETL Tests Yield New Concept for Hydrogen Gas Turbine Combustion—Tests conducted in NETL's simulation validation optical combustor suggest that an array-style, advanced hydrogen fuel injector could provide an alternative to premixed combustion for high-hydrogen fuels in gas turbines. The work is part of the Office of Fossil Energy's Advanced Turbines Program, which is developing hydrogen-fuel turbines that emit less nitrous oxide (NO_x) than current state-of-the-art turbines and can be used in IGCC applications with carbon capture. Test results are based on findings that a fuel tube configuration having high-velocity coaxial air flow, increased combustion pressure, and preheated air temperature of up to 550 °F will produce greater stability in the nitrogen-diluted flames and lower NO_x emission under certain conditions.

NETL Assesses Current and Future Power Plant Technologies—NETL analysts have evaluated advanced technologies for gasification-based power plants developed under the Office of Fossil Energy's Clean Coal Research and Development program. Analysts found that, without carbon capture and sequestration, power plants that incorporate these technologies can achieve higher efficiencies and lower costs than today's fossil-fuel power plants. With IGCC and fuel cell technologies, for example, potential efficiency improvements equal 11 percent and 24 percent, respectively. Capital cost may be reduced by as much as $700 per kilowatt by using warm gas cleanup, ITM air separation, and other technology alternatives, and by producing more power with advanced synthesis-gas turbines. Taken together, the improvements that were studied decrease cost of electricity by more than 3 cents per kilowatt hour overall, or 35 percent. The full report, "IGCC Technologies: A Pathway Study Focused on Non-carbon Capture Advanced Power Systems R&D Using Bituminous Coal—Volume 1," is available at www.netl.doe.gov/technologies/coalpower/gasification/pubs/market.html.

NETL Applies Raman Spectroscopy to Natural Gas and Synthesis Gas Analysis—As part of the Laboratory's Insititute for Advanced Energy Studies, a collaboration of researchers from NETL, the University of Pittsburgh, and West Virginia University has yielded a Raman spectrometer configuration that simultaneously measures the major constituents—nitrogen, oxygen, and hydrogen—of natural gas and synthetic fuel gases. The process enhances the signal power several hundred times over what would otherwise be obtainable. A description of the work appears in the August 10, 2008, issue of *Applied Optics* published by the Optical Society of America.

Bench-Scale Evaluations of Advanced Gasification Technology Completed—Working under an NETL-managed Phase I Small Business Innovation Research grant, product developers at Diversified Energy Corporation successfully completed a series of bench-scale tests of the advanced gasification technology HydroMax® using both Western and Eastern domestic coal as feedstocks. Achieving carbon conversion efficiencies of up to 78 percent and energy conversion efficiencies as high as 69 percent, the technology met or exceeded expectations for the initial evaluations. As the HydroMax process is optimized, carbon conversions exceeding 90 percent are anticipated. The patented technology, which utilizes molten metal iron and/or tin in oxidation and reduction processes, offers several critical features to industrial customers seeking to generate power in the 50–100 megawatt range or who seek to produce synthesis gas as a substitute for natural gas. Desirable features include scalability, small footprint, and feedstock flexibility (e.g., coal, biomass, waste products), which could translate to lower plant capital and operating costs. Based on results from Phase I, a Phase II follow-on grant was awarded to Diversified Energy to build a scaled-up version of the HydroMax reactor to demonstrate a continuous coal gasification operation.

Early-Entrance Coproduction Project Completed—ConocoPhillips Company researchers, in cooperation with NETL, completed a two-phase project that confirmed the feasibility of integrating methanol production and power production using gasification-based E-Gas™ technology. The work showed that ridding synthesis gas of sulfur and other trace contaminants known to poison methanol catalysts is critical to the integration process. S Zorb™) sulfur-removal technology was shown to be effective in removing hydrogen sulfide, carbonyl sulfide, and hydrogen chloride from synthesis gas in a slipstream test conducted onsite at the SG Solutions, LLC, gasification facility in West Terre Haute, IN. The capacity of the S Zorb sorbent was restored during each of six successive absorption-regeneration test cycles, and the sorbent exhibited no cumulative chemical or physical deterioration. A process and economic evaluation showed that, compared to the conventional gas cleanup process using amines, the S Zorb retrofit would result in a reduction in capital cost by as much as 40 percent in the gas cleanup section of the E-Gas process.

Warm Gas Cleanup Demonstrates Contaminant-Removal Technologies—An advanced gas-cleaning technology that could help make IGCC systems competitive in today's power generation market is being developed by RTI International, Research Triangle Park, NC, in cooperation with NETL. During more than 3,000 hours of field testing of the commercial coal gasifier at Eastman Chemical Company in Kingsport, TN, RTI's R&D 100 Award-winning regenerable zinc-based sorbent removed more than 99.9 percent of the sulfur from a coal synthesis gas slipstream at temperatures of 600–900 °F. Also demonstrated were the production of elemental sulfur by the patented Direct Sulfur Recovery Process at similar temperatures, and sorbents that remove ammonia, mercury, and arsenic at warm (greater than 400 °F) synthesis gas conditions. An independent economic analysis shows that these RTI warm-gas cleanup technologies can improve the overall efficiency of an IGCC plant by about 2.3 percent and reduce the cost of electricity by 4 percent.

Experimental Data Support Feasibility of Novel Coal-to-Hydrogen Concept—Lehigh University investigators, working in cooperation with NETL, are studying a method for simultaneously producing fuel-cell grade hydrogen and compressed CO_2 from synthesis gas. They have devised a "thermal swing sorption-enhanced" reaction in which desulfurized synthesis gas containing carbon monoxide, CO_2, water, and hydrogen is introduced to a catalytic reactor. There, in the presence of excess steam, most of the carbon monoxide is converted to CO_2, which is then removed from the reaction by a sorbent. Removal of CO_2 from the reaction zone enhances hydrogen production. This concept of producing essentially pure CO_2 and hydrogen in a single operation will allow for a smaller plant footprint by eliminating the elaborate separation equipment needed in other coal-to-hydrogen approaches. The technique should also reduce the cost of producing hydrogen from coal with carbon capture. Technical papers on the concept appeared in the January 2008 issue of *International Journal of Hydrogen Energy* and the January 21, 2008, issue of *Journal of Power Sources*.

FYi

Integrated gasification combined cycle, or IGCC, systems turn coal into synthesis gas (syngas) to produce electricity. IGCC systems "integrate" two processes: gasification and power generation. The "combined cycle" provides a dual source of power. The gas turbine generates electricity; then the turbine's waste heat produces steam, which generates even more electricity. Impurities are removed from the syngas before it is combusted, resulting in lower emissions of sulfur dioxide, particulates, and mercury.

Image courtesy of GE Energy

View of the end cover of the turbine combustion system showing the gas fuel nozzles.

Novel Turbine Concept Tested in Large-Scale, Multi-element Configuration—In cooperation with NETL, engineers at GE Energy's gas turbine technology laboratory in Greensville, SC, have developed a fuel-flexible concept for advanced premix combustion technology. The novel concept—employing advanced premix combustion technology to achieve very low NO_x emissions with high-hydrogen fuels—was successfully tested in a near-full-scale operation.

Engineers are developing technology advancements for use in IGCC applications with CO_2 capture and sequestration. When tested with pure hydrogen, natural gas, and hydrogen-nitrogen fuels, the concept achieved results consistent with those seen in earlier tests using a smaller-scale single nozzle, even when local flame temperatures exceeded requirements for extended periods.

Successful combustor operation at elevated temperatures with highly reactive hydrogen fuel is critical to achieving the aggressive efficiency goals of the Advanced Turbines Program.

Novel Sensor Proves Successful in Harsh Environment—An optically based sensor constructed entirely of silicon carbide reliably tracked temperatures during a 6-day period for a gas turbine test rig operating near 1,200 °C and 100 psig. Developed at Nuonics, Inc., Winter Park, FL, in cooperation with NETL, the sensor survived the significant thermal shocks associated with six turbine-burner "light off" events in which temperatures increased from 250 °C to more than 1,000 °C in 3 seconds. The six precious-metal thermocouples used as a comparison technology during the 28-day test sequence did not fare as well: one situated around the annulus of the turbine combustor failed on startup and two others became unstable. The fact that the new sensors survived the testing shows that a fundamental understanding of the high-temperature optical properties and vibration tolerance of the sensor design that underpins the technology could lead to a new suite of ultrahigh-temperature sensors for measuring temperature and pressure in high-efficiency fossil-based energy systems.

Full-Scale Catalytic Injector Developed for Hydrogen Turbines—Precision Combustion, Inc., in cooperation with NETL, has optimized the design of a full-scale single injector module for megawatt-class turbines fueled with hydrogen. Featuring Rich Catalytic-Lean burn (RCL®) technology, the prototype injector is ready for testing with high-pressure hydrogen-nitrogen fuel mixtures at simulated engine conditions. RCL systems employ a catalytic reactor operating under fuel-rich, oxygen-lean conditions that are followed by a post-reaction mixing with air to produce final fuel-lean combustion conditions downstream. RCL systems have the flexibility to burn a variety of fuels, including hydrogen, synthesis gas, biogas, and natural gas. Subscale testing at increased pressure has successfully demonstrated lower NO_x emissions with stable operation. By reducing air, nitrogen, or other diluent requirements, the technology can increase the efficiency of hydrogen-burning turbines while reducing NO_x to less than 3 parts per million and eliminating CO_2 emissions.

Innovative Hydrogen Fuel Injectors Produce Stable Flames and Ultralow Emissions—Working in cooperation with NETL, product developers at Parker-Hannifin Corporation, in collaboration with combustion laboratory researchers at the University of California at Irvine, have demonstrated ultralow emissions and flame stability for turbine engines. Using innovative fuel injectors designed to rapidly pre-mix fuel with air, the system produced only 1–5 parts per million of NO_x.

Clean Oxy-syngas Combustor Developed—Working in cooperation with NETL, investigators at Clean Energy Systems, Inc. (CES), have developed an oxy-fuel gas combustor that can utilize virtually any gaseous fuel—including coal-derived synthesis gas—to power turbines with near-zero emissions. By combusting clean fuels with oxygen, almost all NO_x is eliminated. Further, the small amount of CO_2 remaining can be readily separated and used for commercial purposes, sequestered, or injected for enhanced oil and natural gas recovery. Also in cooperation with NETL, CES has since designed a 100-megawatt oxy-syngas combustor, which is now ready for manufacture. In parallel with the oxy-syngas combustor, CES designed and built a full-scale, 170-megawatt oxy-fuel combustor that uses natural gas and deployed it to the CES test facility at Kimberlina Power Plant. This combustor is being tested to validate combustion characteristics and control system responsiveness and reliability.

High-Purity Thermal Barrier Coatings Offer More Durable Protection for High-Temperature Turbine Components—Working in cooperation with NETL, collaborators at the University of Pittsburgh and Praxair Surface Technologies have found that thermal barrier coatings (TBCs) of yttria-stabilized zirconia (YSZ) with low amounts of aluminum and silicon oxides produce top coats resistant to sintering in high-temperature turbines, even after exposure to temperatures as high as 1,500 °C for 100 hours. Coatings prepared from YSZ of conventional purity generally undergo significant sintering at temperatures as low as 1,000 °C. Sintering causes undesirable structural changes in turbines, undermining the adherence and thermal protection afforded by the top coat. The TBCs were applied to traditional bond coats using the relatively low-cost air plasma spray method.

Q+A

Q What is the difference between *absorb* and *adsorb*?

A **Sorbents** are materials that take in or hold a liquid or gas. One application of sorbents is to capture CO_2 through the mechanisms of absorption, adsorption, or both.

Absorbtion is a widely used word that refers to a situation where a material is taken into a medium. One example of this is the absorption of water by a sponge.

Adsorbtion is a specialized technical term referring to a situation where molecules or particles collect on the surface of a medium. Velcro demonstrates how the adsorption process works. When placed together, the loop side "collects" on the surface of the hook side forming a seemingly lasting bond; however, the connection is only temporary and the two sides can be pulled apart into their original forms. NETL uses adsorption to capture CO_2 from gas mixtures during energy generation processes.

Technology Transfer

Communication, Collaboration, & Commercialization

Technology transfer is central to NETL's mission and to strengthening America's role as a leader in science and technology. When research makes the leap from laboratory to marketplace, it contributes to solving the complex energy challenges faced today by our Nation and the world.

NETL dedicates significant effort to transferring information and technologies domestically to maximize returns to the American people, and internationally to aid such multinational causes as the curbing of greenhouse gas emissions. Through patents, licensing, publications, policy discussions, and international partnerships, NETL is sharing its results and setting new trends in invention and innovation.

Facing page—NETL metallographer Paul Danielson reveals an in-depth complete microstructure of a metallic alloy.

Technology Transfer

Communication, Collaboration, & Commercialization

Patents and Commercialization

NETL Patents Laser Spark Plug—NETL researchers received Patent No. 7,421,166 for a novel laser spark plug ignition system developed at the Laboratory. The system uses fiber optics to transmit low-power laser pulses to the engine cylinder, then amplifies these pulses using a laser amplifier, or laser spark plug, located at the cylinder. The NETL spark plug has a compact profile and is designed to replace existing spark plugs in power production or pipeline pumping systems. Laser sparks allow these systems to operate at higher efficiency with lower emissions.

NETL Method Produces Low-Cost CO_2 Capture Sorbent—NETL also has been awarded U.S. Patent No. 7,288,136 for a method of producing amine-enriched sorbents with a high capacity for CO_2 capture. In only a few steps, and without involving expensive reactants or solvents, the sorbents can capture CO_2 at temperatures ranging 25–65 °C. The sorbents are then regenerated by heating them to 90 °C, and little or no degradation occurs. Low-cost advantages afforded by the higher CO_2 capture capacity and low energy cycle requirements make the long-lived sorbents suitable for large-scale processes, such as power plant emissions streams.

Powerspan Corporation Licenses NETL Carbon Capture Technology—Powerspan Corporation has licensed a novel NETL process that uses an ammonia-based solution to scrub CO_2 and other acid gases (primarily sulfur dioxide and nitrous oxide) from flue gas. The spent solution can be regenerated to release sequestration-ready CO_2 and then recycled to the scrubbing unit. Powerspan has begun testing a 1-megawatt electrical pilot unit constructed at FirstEnergy Corporation's R.E. Burger Plant near Shadyside, OH, to demonstrate the technology. The license supports a broader Powerspan goal of removing all components from flue gas. Compared to existing technology, the process could significantly reduce the capital cost and energy load associated with CO_2 capture.

NETL Licenses Emissions-Control Patent to Jupiter Oxygen Corporation—NETL has signed an exclusive license with Jupiter Oxygen Corporation for the Integrated Pollutant Removal (IPR™) technology, which will allow conventional coal-fired power plants to produce a CO_2-rich, sequestration-ready flue gas with greater fuel efficiency and lower overall cost. Invented by NETL and Jupiter under a Cooperative Research and Development Agreement, the patent represents a combination of Jupiter's oxy-fuel combustion expertise with NETL expertise in recovering energy from the process of CO_2 purification and compression. The IPR technology is being tested at a Jupiter facility in Hammond, IN, to collect data, demonstrate stable operation of a full-scale (15 megawatt) oxy-fuel combustion burn, and quantify energy recovered from combustion gas when producing CO_2 for sequestration. The process was described at the 9th International Conference on Greenhouse Gas Control Technologies held in Washington, DC, in December 2008.

Mercury Control Technology Commercialized—Alstom Power has provided its MerCure™ activated carbon injection system for removing mercury to five Pennsylvania coal-fired power stations operated by Reliant Energy, Inc. NETL cofunded several cooperative agreements to field-test the technology under the Office of Fossil Energy's Innovations for Existing Plants program. Employing a proprietary carbon-based sorbent for mercury control, MerCure has consistently demonstrated a greater than 90 percent reduction in baseline stack mercury emissions—with lower sorbent injection rates than comparable technologies. MerCure can be used for the full range of coal types and air pollution control systems. The sale increases by more than 10 percent the total existing U.S. power plant capacity that uses activated carbon injection systems for mercury emissions control.

Sharing Our Expertise

NETL and United Kingdom Improve Virtual Power Plant Simulation

During a three-year collaborative effort, researchers from NETL and the United Kingdom have developed compatible software platforms for virtual process and equipment co-simulations of advanced power plants. An agreement between DOE and the UK Department of Energy and Climate Change led to the accomplishment.

NETL's Advanced Process Engineering Co-Simulator (APECS) project and the UK Virtual Plant Demonstration Model (VPDM) project capitalized on the process industry CAPE-OPEN software standard to produce plug-and-play interoperable tools that combine power plant simulation with high-fidelity computational fluid dynamics models of key equipment items, such as gasifiers, combustors, gas turbines, heat recovery steam generators, and fuel cells. (See image above.)

The technology was demonstrated by co-simulating the 2,000-megawatt conventional coal-fired power station located near the town of Didcot in southeast England. The co-simulation enabled process engineers to optimize overall power plant performance by helping them analyze complex fluid flows, heat and mass transfer, and chemical reactions that impact overall power plant design and operation. By allowing a rigorous analysis of the entire plant, the software speeds up technology development and offers opportunities to achieve aggressive environmental, performance, and economic goals for advanced fossil energy power generation systems.

NETL Researchers Lead International Collaboration on CO_2 Brinefield Sequestration—NETL researchers led a collaboration with West Virginia University, Clarkson University, and the University of Utrecht in the Netherlands that combined laboratory experiments, computations, and theory to develop more accurate and reliable equations for describing the flow of liquids through porous rock. This work will help improve the injection of CO_2 into brine-saturated geologic sequestration sites, as well as the injection of water into oilfields to increase petroleum production.

Asia-Pacific Partnership in Clean Development and Climate Participate in U.S. Peer Review—Approximately 90 delegates from Asia-Pacific Partnership (APP) member countries participated in the third U.S. Peer Review of Coal-Fired Generation in Sheboygan, WI. The NETL-supported review was part of a series during which participants shared information and experiences that will help improve the operational and environmental performance of existing coal-fired power plants within the seven APP countries: Australia, Canada, China, India, Japan, the Republic of Korea, and the United States.

U.S.-China Science and Technology Symposium Focuses on Carbon Capture and Storage—The second U.S.-China CO_2 Emissions Control Science & Technology Symposium, held in Hangzhou, China, drew 127 participants from 37 organizations representing industry, academia, national laboratories, and government agencies in the two countries. The number of participants was nearly double the expected attendance. Jointly organized and chaired by NETL and China's Ministry of Science and Technology (MOST), the event focused on carbon capture and storage under the auspices of Annex IV of the Protocol on Cooperation between DOE and MOST.

Technology Transfer

Communication, Collaboration, & Commercialization

NETL-Led Delegation Highlights Beneficial Technologies for India Power Plants—At the request of the U.S. Agency for International Development, known as USAID, NETL staff organized a delegation of 15 U.S. technology and service providers to participate in the Power Plant Summit 2008 held in New Delhi, India. The delegation identified opportunities for poorly performing utility plants in India to improve efficiencies by as much as five percent with methods having payback periods of a few months or less. If applied throughout the country, the improved plants would avoid millions of tons of CO_2 and other emissions annually while reducing costs and increasing power output.

NETL Hosts International Visitors—During the course of 2008, NETL welcomed international visitors interested in reviewing the Laboratory's research programs and discussing means for transferring U.S. energy expertise and technologies overseas.

- Ambassadors to the U.S. from Sweden, Slovakia, and Denmark participated in a tour of NETL facilities, presentations relating to energy strategies, and a round-table discussion on technology development and its implications for climate change.

- NETL key staff briefed a high-level delegation from the European Commission on the Laboratory's research, particularly programs and facilities dealing with carbon sequestration. Discussion during the meeting identified several potential areas for cooperation.

- Senior officials of the Geological Survey of Israel visited NETL for a second discussion of potential research and development cooperation related to NETL-managed coal and power programs. Israel is the only Middle Eastern country that uses significant amounts of coal to generate electric power. Israel is considering U.S. coal-based technologies—especially integrated gasification combined cycle (IGCC) power plants and carbon capture and storage—as part of a clean energy strategy to meet future electricity demand.

Noteworthy Publications

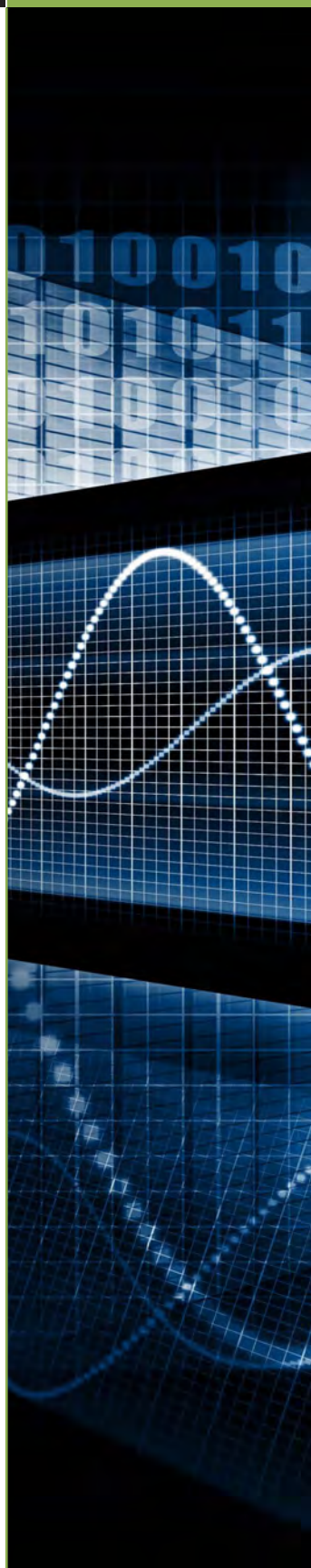
Springer Publishes NETL Reference Book on Inorganic Membranes—Springer Publishing Company has released a single-source reference text, *Inorganic Membranes for Energy and Environmental Applications*, edited by NETL scientist Arun C. Bose. The book provides information on technologies, research areas, and prospectuses associated with oxygen and hydrogen membranes for advanced energy processes. Bose coauthored a chapter describing ion transport membranes for gas separation, and other researchers at NETL and the University of Pittsburgh contributed a chapter describing the influence of gasification on metal-based hydrogen transport mechanisms and predicting corrosion and classical poisoning phenomena with thermodynamic models. Started modestly in the mid-1980s, NETL's membrane research has expanded to include a broad array of technologies. NETL's successes have gained the Laboratory international recognition in professional forums dedicated to advancing membrane science. Membrane technologies can be applied to improve the cost and performance of such advanced physical and chemical processes as gas separation and reactor operation with simultaneous product removal.

Coauthors Make Best Seller List at American Chemical Society—The book *Ultraclean Transportation Fuel*, coedited by NETL researcher Isaac K. Gamwo and former NETL researcher Olayinka I. Ogunsola, who is now a program manager with the Office of Fossil Energy, is listed among the top ten best-selling American Chemical Society (ACS) publications. Gamwo and several other NETL researchers authored multiple chapters for the book, which presents outstanding research on topics in synthetic and hydrocarbon fuels. The Publications Division of ACS maintains a list of more than 500 books and is viewed around the world by scientists as the best single source for published information on chemical research.

NETL Researchers Coedit Special Issue of *Catalysis Today*—NETL researchers Dushyant Shekhawat and David Berry served as guest editors for a special issue of the Elsevier publication *Catalysis Today* (Vol. 136, Nos. 3-4), dealing with the reforming of liquid fuels for fuel cell applications. The special issue includes 14 of the best refereed papers presented by researchers from Korea, Taiwan, Thailand, and the United States at a related symposium during the 234th National Meeting of the American Chemical Society. Liquid fuels, such as gasoline and diesel, are globally attractive feedstock for fuel cell applications because of their existing infrastructure, high well-to-wheel efficiencies, and high energy densities.

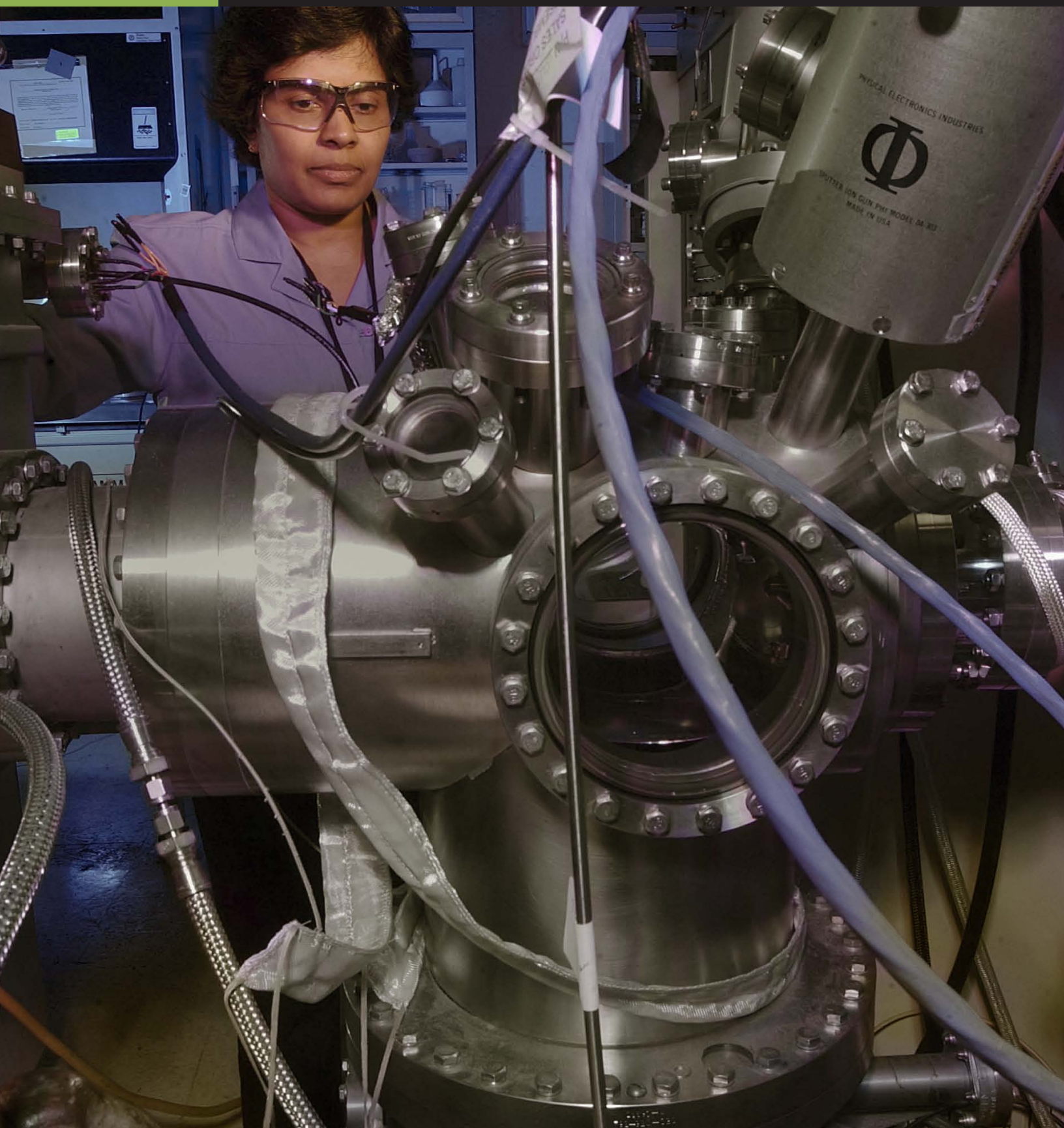
NETL Researcher Serves as Guest Editor of Scientific Journal—Evan Granite contributed the preface and served as guest editor for a special issue of *Main Group Chemistry* (Vol. 7, No. 3), dedicated to the cleanup of mercury and other trace elements in fuel gas and postcombustion emissions. The issue captures the best papers presented during four sessions dealing with the topic at the 235th National Meeting of the American Chemical Society. Co-organized and cochaired by Granite, the sessions covered the control of the trace elements mercury, arsenic, and selenium in coal-derived gas streams, the fate of arsenic and selenium in flue and fuel gas, and the online detection of mercury in flue gas. Other NETL researchers contributed a paper describing the results of an investigation into the ability of palladium-alumina sorbents to adsorb mercury from fuel gas. Mercury absorption was greatest at 204 °C when there were low amounts of palladium, and absorption was lowest with a higher temperature and a higher palladium concentration.

American Scientific Publishers Enlists NETL Expertise on Nanotechnology—NETL researcher Christopher Matranga authored a chapter in the American Scientific Publishers publication, *Chemistry of Carbon Nanotubes*. "Gas Interactions with Carbon Nanotubes" describes the use of carbon nanotubes for separating CO_2 and hydrogen. The three-volume publication includes state-of-the-art reviews by leading experts from across the globe. Matranga and others at NETL have been actively applying nanotechnology to improve synthesis gas conversion catalysts and CO_2 separation membranes for fossil energy systems.



Awards & Recognition

Celebrating Success



NETL's tradition of excellence and record of accomplishments were widely recognized in 2008. NETL, its staff, and its partners were acknowledged for scientific contributions, technology development, and excellence in communication. NETL is proud that our work is making substantial and beneficial contributions to America's energy economy.

Facing page—NETL scientist Ranjani Siriwardane working with a CO_2 sorbent in one of the Laboratory's two x-ray photoelectron spectrometers.

Awards & Recognition

Celebrating Success

NETL Technology Transfer Achievements Recognized—The Federal Laboratory Consortium presented three 2008 Excellence in Technology Transfer Awards to NETL for successfully making available new commercially relevant technologies to the marketplace:

- At the national level, NETL received an award for licensing its patented high-temperature, palladium-based catalyst formulations to Johnson Matthey. The catalysts will be used to capture mercury, arsenic, and selenium at various stages in the integrated gasification combined cycle (IGCC) process.

- NETL won a second award at the national level in recognition of the Laboratory's sharing of a patent-pending chemical engineering software—the Coal Chemistry Model—for modeling gasification processes. The module is available through the commercial software FLUENT. It was most recently used for gasifier design in collaboration with Southern Company and Kellogg Brown & Root.

- The patented Thief Process, which won the award at the mid-Atlantic regional level, has been licensed to Nalco-Mobotec for commercial development. The Thief Process extracts partially combusted coal from the furnace of a coal-fired power boiler for re-injection downstream into flue gas ductwork. Pilot-scale tests have shown that the technology's sorbent capacities are comparable to those of commercially available activated carbons, but because they are significantly less expensive, the novel sorbents promise to reduce the cost of mercury removal from flue gas.

Two NETL Technologies Earn R&D 100 Awards—NETL researchers accepted two 2008 R&D 100 Awards in Chicago, IL, on October 16, 2008. The first award recognized NETL's suite of palladium sorbents designed to capture mercury, arsenic, selenium, and phosphorus from high-temperature fuel gas. NETL has licensed the sorbent to Johnson Matthey for application in the IGCC process. The second award recognized the Advanced Process Engineering Co-Simulator (APECS)/ANSYS® Engineering Knowledge Manager™ (EKM). APECS/EKM decreases the time, cost, and technical risks associated with developing technologies for future high-efficiency, near-zero emission plants. NETL developed APECS/EKM in partnership with ANSYS, ALSTOM Power, Aspen Technology, and Carnegie Mellon University.

NETL Researcher Recognized with Percy W. Nicholls Award—The American Society of Mechanical Engineers (ASME) has selected NETL researcher George Richards to receive its 2009 Percy W. Nicholls Award for "notable scientific or industrial achievement in the field of solid fuels." The award is presented jointly each year by the Fuels and Combustion Technologies Division of ASME and the Coal Division of the American Institute of Mining, Metallurgical, and Petroleum Engineers. Richards conducts research in thermal science and energy production, with emphasis on combustion dynamics. As an NETL Focus Area Leader, he provides technical direction for research groups investigating turbine combustion, CO_2 capture, high-temperature fuel cells, fuel processing, and stationary reciprocating engines. The presentation will take place during the 34th International Technical Conference on Coal Utilization & Fuel Systems in Clearwater, FL.

Atlas Wins 2008 Grand Award for Publication Excellence—NETL's *Carbon Sequestration Atlas of the United States & Canada* was among 120 Grand Award winners selected from nearly 4,500 entries in 2008 by editors at Communications Concepts, Inc., publisher of *Writing That Works*, an authoritative monthly newsletter on practical writing, editing, and communications. Winners in this 20th annual Grand Award for Publication Excellence (APEX) competition were selected based on excellence in graphic design, editorial content, and overall communications effectiveness. Judged a "first-rate effort" in the One-of-a-Kind Publications category, the *Atlas* won kudos for richness of data and exceptional visuals, including effective info-graphics and clear, understandable copy. The *Atlas* represents a coordinated effort by experts from industry, academia, and local, State, and provincial governments working as participants in the Regional Carbon Sequestration Partnerships to assess U.S. and Canadian carbon sources and potential sinks.

American Chemical Society Applauds Field Screening Instrument—The American Chemical Society, the world's largest scientific society, has honored developers of the X-Wand™ analyzer with its 2007 Western Region Industrial Innovation Award. Developed at Western Research Institute in cooperation with NETL, the device detects common soil and water contaminants and is the first low-cost, portable field instrument that can quickly detect halogenated volatile organic compounds with a sensitivity comparable to that of laboratory instrumentation. The X-Wand can be used to perform ASTM International's Method D 7203, a standard test method for screening both water and soil for trichloroethylene, a chlorinated hydrocarbon. A patent is pending for X-Wand and discussions to license the technology are currently underway to commercially offer the product.

Partnership Receives Prestigious Award for Environmental Stewardship—On November 17, 2008, the Energy & Environmental Research Center at the University of North Dakota received a Chairman's Stewardship Award from the Interstate Oil and Gas Compact Commission (IOGCC) for leadership in technology development as part of the Plains CO_2 Reduction (PCOR) Partnership, one of seven Regional Carbon Sequestration Partnerships managed by NETL. PCOR field tests will demonstrate the effectiveness of using CO_2 for enhanced hydrocarbon production, exhibit cost-effective use of oil reservoirs and lignite coal seams for safe CO_2 storage, and establish a means by which carbon markets can facilitate more recovery of oil and gas from the region. Representing the highest IOGCC honor conferred for exemplary achievement in environmental stewardship, the award was presented by Chairman Brad Henry, Governor of Oklahoma, at the IOGCC Annual Meeting in Santa Fe, NM. The IOGCC is a multistate government agency that promotes the conservation and efficient recovery of domestic oil and natural gas resources while protecting health, safety, and the environment.

IntelliServe Network Wins World Oil Award—The IntelliServe Network won the Best Drilling Technology Award at the World Oil Awards Ceremony in Houston, TX, on October 17, 2007. Incorporating IntelliPipe®, a revolutionary drill pipe with built-in telemetry developed at Novatek Engineering, Inc., Provo, UT, and Grant Prideco, Inc., Houston, through a cooperative agreement with NETL, the technology enables operators to obtain real-time downhole data at unprecedented speed and send commands to measurement-while-drilling tools. The Best Drilling Technology Award recognizes tools and processes that have had a significant impact on industry either onshore or offshore.

NETL Partner Wins Inaugural India Power Award—The Indian Council of Power Utilities, an umbrella organization of India's power utilities, presented a 2008 India Power Award to officials of the Centre for Power Efficiency and Environmental Protection (CenPEEP) for outstanding efforts leading to the reduction of greenhouse gas emissions from India's coal-fired power plants. Established in 2008, these awards recognize significant achievements and contributions by organizations and individuals in India's power sector. To date, CenPEEP has sustainably reduced and/or avoided a total of approximately 75 million tons of CO_2 emissions from the sector. CenPEEP functions as a resource center for acquisition, demonstration, and dissemination of state-of-the-art technologies and practices that optimize the performance of power stations in India. NETL provides technical assistance to CenPEEP as part of the Greenhouse Gas Pollution Prevention Project implemented under the 1994 Protocol between India and the United States by the New Delhi Mission of the U.S. Agency for International Development. CenPEEP previously received a 2003 Climate Protection Award from the U.S. Environmental Protection Agency and a 2002 Climate Technology Award from the Climate Technology Initiative for significant accomplishment in promoting climate-friendly technologies.

Awards & Recognition

Celebrating Success

NATCARB Produces "Best Paper of the Year"—Researchers at the University of Kansas, who led development of the National Carbon Sequestration Relational Database and Geographic Information System (NATCARB) in cooperation with NETL, received the 2008 Geoscapes Best Paper of the Year Award from the *Journal of Map and Geography Libraries*/Geoscapes. The journal editors chose the paper, titled "The NatCarb Geoportal: Linking Distributed Data from the Carbon Sequestration Regional Partnerships," for its public policy implications and relevance to the energy issues facing the world today.

Project Produces Best Paper at Society of Exploration Geophysicists—A paper describing the use of multi-component seismic data for mapping gas hydrate accumulations in the Gulf of Mexico was selected for the Society of Exploration Geophysicists' (SEG) Best Paper Award. The technical paper was one of hundreds published by the SEG in *The Leading Edge* during 2006. Representing cutting-edge hydrate research being performed under the Office of Fossil Energy's Methane Hydrate Research and Development program, the new technique, developed in cooperation with NETL at the University of Texas's Bureau of Economic Geology, combines ocean-bottom cable, chirp-sonar, and new rock physics models to estimate the concentration of hydrates in near seafloor sediments and ultimately to assess future hydrate resource potential. The award was presented at an honors and awards ceremony during the 77th Annual Meeting of the SEG in San Antonio, TX.

Tool Measures Permeability, Garners Two Major Awards—Dr. Cynthia Dinwiddie received the 2007 Rossiter W. Raymond Memorial Award from the American Institute of Mining, Metallurgical, and Petroleum Engineers and the 2007 Alfred Noble Prize from the American Society of Civil Engineers for her paper describing a portable tool designed to measure the permeability of various types of geologic strata in situ. Developed as part of an NETL-managed project at Clemson University, the device measures permeability while inserted into a small hole drilled into a rock outcrop. The tool is particularly useful where outcrops cannot be sampled for traditional permeability measurement techniques in the laboratory.

About NETL

The National Energy Technology Laboratory is owned and operated by the U.S. Department of Energy. NETL's efforts are focused on advancing energy options to fuel our economy, strengthen our security, and improve our environment.

To accomplish this mission, NETL draws on 1,200 Federal and support-contractor employees to implement and manage a broad spectrum of research programs. NETL conducts more than 1,300 research activities in the United States and in more than 40 foreign countries.

NETL is a single organization comprising three research facilities located in Albany, OR; Morgantown, WV; and Pittsburgh, PA. NETL also has offices in Fairbanks, AK, and Sugar Land, TX. The Laboratory's activities are primary funded through DOE's Office of Fossil Energy, but NETL also conducts work for other DOE offices and Federal agencies.

About This Report

2008 NETL Accomplishments is a collection of the most significant activities completed by the Laboratory's Federal and support-contract researchers between October 1, 2007, and December 31, 2008.

Previous accomplishments reports have documented the Laboratory's activities on a fiscal year basis. Beginning with the 2008 report, NETL has adjusted its reporting period to reflect the calendar year. Starting in 2009, accomplishments realized between January 1 and December 31 of the reporting period will be included.

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08

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