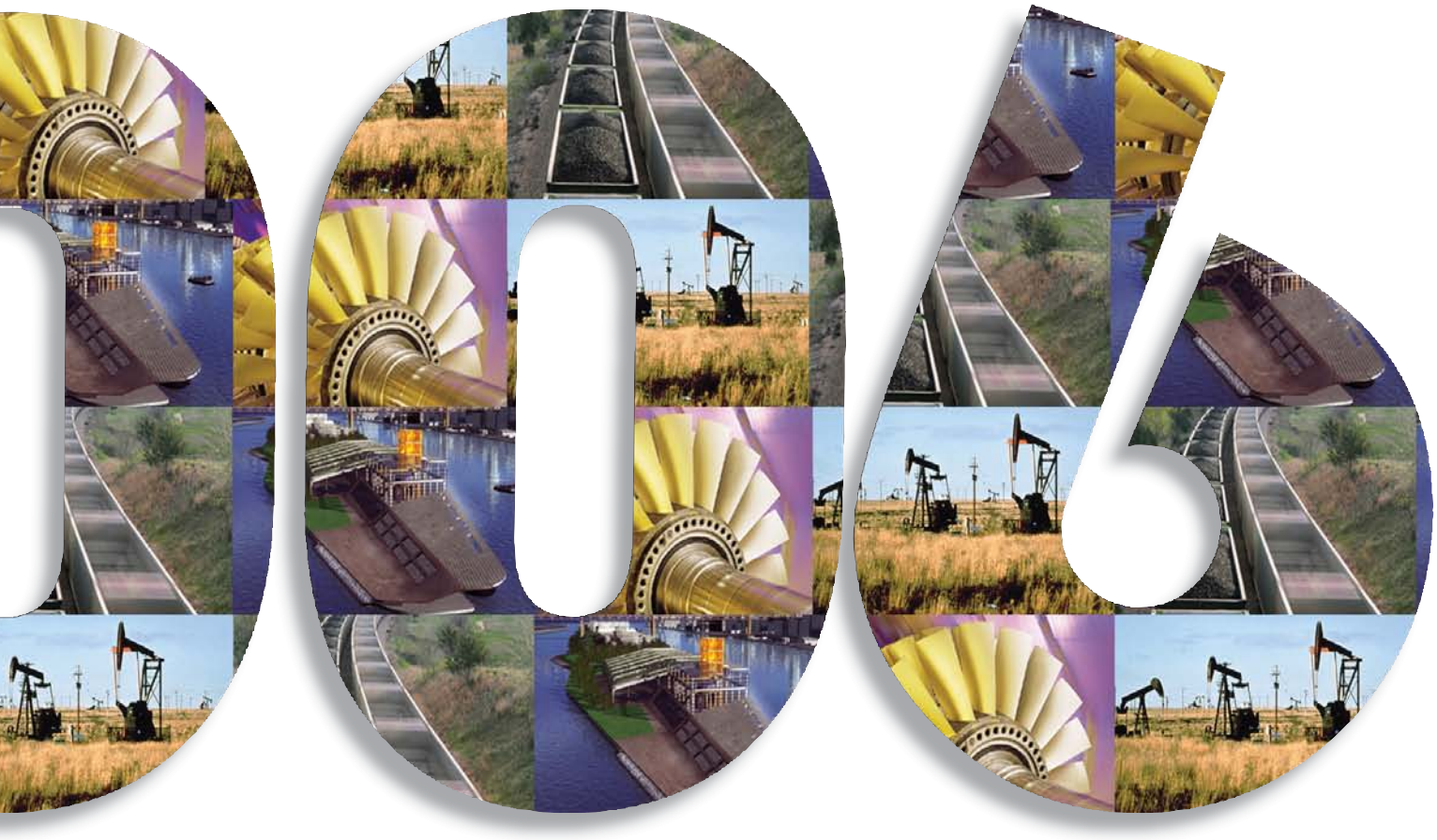
U.S. Department of Energy • Office of Fossil Energy
National Energy Technology Laboratory

ACCOMPLISHMENTS



2006

Message from the Director

For 200 years, America's energy demands have grown at a remarkable rate. As we have moved from an agricultural society, through industrial expansion, and into the current technological era, our society's transformation has depended on reliable, affordable energy supplies.

Energy reliance is not limited to the United States. The worldwide need for on-demand electricity, modern transportation, and industrial power is driving a steep rise in global energy consumption. By 2030, we will collectively consume nearly double the energy we use today.

In this climate, U.S. energy security is critical. It demands our extracting the maximum available energy from our nation's coal, natural gas, and oil supplies and realizing a higher contribution from nuclear and renewable energy. It also means producing and using alternative liquid fuels and gaining access to such emerging resources as methane hydrate.

America must couple its energy consumption with environmental responsibility. Through advanced technologies, we can slash greenhouse gases and other air emissions, minimize water consumption and pollution, and find beneficial uses for the by-products of energy production.

The National Energy Technology Laboratory (NETL) is one of three Department of Energy national laboratories that address the marketplace challenges of meeting our nation's energy demands. As the only laboratory with fossil energy as its principal focus, NETL applies basic science and engineering to resolve the environmental, supply, and reliability constraints of producing and using fossil resources.

Our onsite researchers solve complex problems in energy system dynamics, geologic and environmental challenges, advanced materials and processes, and computational and basic sciences. NETL seeks solutions to an even wider range of energy challenges through partnerships with industry, academia, and other national laboratories, and through contracted extramural research.

America's challenges in creating and maintaining a secure energy supply are formidable, but they are also surmountable. NETL continues to contribute solutions that bring positive change to our nation's energy structure. I am pleased and proud to be part of such an important endeavor and to work with exceptional colleagues who invest themselves in addressing the energy needs of the nation and the world.

Carl O. Bauer

Director
National Energy Technology Laboratory

ACCOMPLISHMENTS

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en·er·gy [énnərjee] the capacity of a system to do work

America's energy bounty runs our robust economy. Energy drives the technologies that improve our productivity. Energy empowers industry and business to produce, transport, and market the goods and services that comprise our gross domestic product. Energy supports our municipalities, underpins our infrastructure, and provides our citizens with food, shelter, employment, and leisure. This capacity to do work has built our nation into a sophisticated society in which we enjoy one of the world's highest standards of living and a position of global leadership.

The United States derives its energy from a variety of feedstocks—fossil fuels, nuclear power, and renewables such as solar, wind, hydrogenation, and biofuels. All are needed to meet America's continually growing demand for clean, reliable energy. The right mix of feedstocks, based on the needs of each area of our nation, is the most effective way to produce the power we need to maintain our quality of life.

Of these energy sources, America relies most heavily on fossil fuels. Fossil resources provide 85 percent of the energy we consume today, and tomorrow's energy picture will be much the same. Despite advancements in renewable technologies and the potential resurgence of nuclear power, projections through 2030 show only a slight increase in energy percentage from these contributors. In the foreseeable future, fossil fuels will continue their dominant role in powering our nation.

The United States is endowed with abundant fossil energy resources. Our domestic reserves include one of the world's largest oil shale deposits and potentially trillions of cubic feet of gas hydrate along our continental shelf. Combine these with our conventional coal, oil, and natural gas resources, and it becomes clear that the United States stands on a strong fossil fuel foundation.

America's fossil endowment extends significant benefits to each of its citizens, but it also poses a number of challenges. Environmental considerations, such as impacts to land, air, and water, demand that we manage our resources responsibly. Maintaining our nation's energy security requires that we strike the optimal balance between domestic and imported supplies, diversify our energy portfolio, and modernize and protect our transmission and distribution systems.

The National Energy Technology Laboratory (NETL) is contributing to U.S. successes in meeting these environmental and energy security challenges. Through applied science, NETL transforms the possible into the actual by developing technologies that produce clean, efficient energy from fossil fuels. We explore ways to maximize our nation's conventional and unconventional fossil resources, and we support national efforts to modernize and protect our energy transmission and distribution infrastructure.

Through onsite research, partnerships with industry and academia, and external projects, NETL aids today's U.S. power plants in reducing emissions, conserving water, and recycling combustion by-products. Tomorrow's energy facilities will produce some of the cleanest, most efficient energy in the world as a direct result of NETL's research into advanced materials, fuel cells and turbines, hydrogen and electricity co-production, and carbon dioxide capture and sequestration.

NETL and its research partners are also working to diversify the U.S. portfolio of domestic energy feedstocks and improve the efficiency of our nation's energy production. NETL technologies improve access to complex and challenging oil and natural gas deposits. We explore critical emerging resources, such as methane hydrate, and we research alternative liquid fuels, ultra-supercritical power plant mechanisms, and other unconventional technologies.

NETL also leverages its assets to benefit the American public by teaming with various programs within the Department of Energy to develop a more reliable energy delivery system and advanced technologies for energy conservation. Together, we are creating a shared national vision of a modern electric grid and accelerating grid modernization, aiding the nation in responding to national emergencies involving the energy infrastructure, and supporting the innovation of technologies that conserve energy in residential and commercial structures.

NETL's accomplishments are the result of research activities that foster the inventive genius of America's citizens and industries. The laboratory's successes demonstrate real and measurable progress toward national energy security, a cleaner environment, and a robust American economy. Some of the most important programs NETL implements are FutureGen, the Clean Coal Power Initiative, the Methane Hydrate Research and Development Program, and the Modern Grid Initiative.

- **FutureGen** is a $1 billion industry-government partnership to design, build, and operate a coal-gasification-based near-zero-emission electricity and hydrogen production plant. The 275-megawatt prototype plant will serve as a large-scale engineering laboratory for testing advanced power, carbon capture, and coal-to-hydrogen technologies. A direct response to the President's Climate Change and Hydrogen Fuels Initiatives, the FutureGen plant will employ cutting-edge technology to make it the cleanest coal-fueled power plant in the world.
- **The Clean Coal Power Initiative** is a cost-shared, large-scale technology demonstration program between government and industry. Its goal is to accelerate the commercialization of advanced, affordable, and environmentally sound technologies. Under this initiative, the nation's power generators, equipment manufacturers, and coal producers help identify the most critical barriers to coal's use in the private sector and select and demonstrate technologies that will economically meet environmental standards while increasing the efficiency and reliability of coal power plants.
- **The Methane Hydrate Research and Development Program** is helping the energy and scientific communities understand the nature and potential of naturally occurring methane hydrate. In a collaborative effort, researchers from industry, academia, DOE national laboratories, and other federal agencies are exploring hydrate-related hazards to conventional deepwater oil and gas exploration, documenting the role methane hydrate plays in environmental processes, and researching the potential of methane hydrate as a source of domestic natural gas.
- **The Modern Grid Initiative (MGI)** is developing a shared vision for the modernization of the U.S. electric grid and creating a flagship government-industry partnership to invest significant funds in grid-technology demonstration projects. MGI-funded projects will develop an integrated suite of technologies and processes to move the grid toward modernization. Projects will address key barriers and establish scalability, applicability, and a clear path to full deployment for solutions that offer compelling benefits. Each project will involve a full spectrum of national and regional stakeholders and multiple funding parties.

The following pages review NETL's accomplishments during the past fiscal year and illustrate our commitment to securing clean, efficient, reliable power for America's energy future.

About NETL

The National Energy Technology Laboratory is owned and operated by the U.S. Department of Energy (DOE). As the only DOE national laboratory dedicated specifically to fossil energy research, NETL's efforts are focused on resolving the environmental, supply, and reliability constraints of producing and using America's fossil fuel resources.

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 1,800 onsite and contracted activities in the United States and in more than 40 foreign countries.

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

2006

COAL—America's Most Abundant Energy Resource

America's energy bounty begins with coal. One quarter of the world's coal reserves are found within the United States, and the energy content of our nation's coal resources exceeds that of all the world's known recoverable oil. Coal also provides the foundation for our electric power industry, supplying more than half of the electricity consumed by Americans. Yet, this "black diamond" presents an environmental challenge. Concerns over greenhouse gases, trace mercury emissions, and microscopic particles are driving the development of twenty-first-century clean-coal technologies. NETL is committed to improving the economy, efficiency, and environmental impact of our nation's existing coal-based power plants and to developing the innovations that will build tomorrow's near-zero-emission power facilities.

Coal-Fired

Technologies for Existing Coal-Fired Power Plants

NETL and its research partners develop solutions to address the environmental impacts of our nation's existing coal-fired power plants. Research efforts focus on cost-effective controls for mercury, nitrogen oxides (NO_x), and fine particulate emissions, as well as beneficial uses of coal utilization by-products and innovations to minimize the impact of fossil-fuel use on the nation's water resources.

MERCURY

Mercury

NETL manages the largest research program in the country for studying fossil-combustion-based mercury emissions, providing increasingly effective mercury-control options that can meet existing and future regulations, such as the Clean Air Mercury Rule. Current research is focused on pilot- and full-scale field testing of advanced mercury-control technologies at operating coal-fired power plants, as well as the continued development of novel concepts to expand our fundamental understanding of mercury emissions and their control.

ALSTOM Completes Mercury Testing with Excellent Results—ALSTOM Power Inc. completed full-scale mercury testing at its second test site, Basin Electric's Leland Olds station in Stanton, ND, as part of an NETL-managed project. The 220-megawatt electric unit is equipped with an electrostatic precipitator and burns North Dakota lignite. Testing was conducted using ALSTOM's activated carbon-based sorbent, Mer-Clean™, which promotes oxidation and capture of mercury. Long-term test results at the site indicate that Mer-Clean achieved 90 percent mercury removal at low injection rates and relatively high flue gas temperatures. These results are particularly significant because previous activated carbon research suggested that performance decreases at higher temperatures.

Mercury-Control Field Testing Completed at TXU's Monticello Station—The University of North Dakota Energy and Environmental Research Center (EERC) and URA Corporation completed mercury-control field testing at TXU Energy's Monticello Station in Mt. Pleasant, TX. The objective of this NETL-managed project is to cost effectively oxidize elemental mercury in lignite combustion gases, followed by capture in a wet scrubber. The project involves mercury oxidation upstream of systems equipped with an electrostatic precipitator followed by wet flue gas desulfurization. Monticello Station fires a 50/50 blend of Texas lignite and Powder River Basin coals. During long-term testing, calcium bromide was added to the coal feed to enhance mercury oxidation and capture. A calcium bromide injection resulted in 65 percent mercury removal. A higher-calcium bromide injection averaged 86 percent mercury removal. Results from this project will help researchers develop technology options that will enable the current fleet of coal-fired power plants to cost effectively comply with the Clean Air Mercury Rule.

Novel Sorbent Shows Promising Mercury Results—As part of an NETL-managed project, mercury-control testing was completed at Midwest Generation's Crawford Generating Station in Chicago, IL, using C-PAC sorbent from Sorbent Technolgies Corporation, Twinsburg, OH. C-PAC was developed to control mercury emissions while minimizing negative impacts from activated carbon on the marketability of fly ash. Midwest Generation markets its fly ash, so it was important to identify mercury sorbents that would allow this revenue stream to continue. Testing was conducted on the 234-megawatt electric Unit 7, which burns subbituminous coal and is equipped with an electrostatic precipitator. Long-term results indicate that C-PAC achieved 80 percent mercury removal at an injection rate of 4.6 pounds per million actual cubic feet. The fly ash from these tests was saleable, based on an analysis conducted by Headwater Inc. of South Jordan, UT.

Sorbent-Enhancement Additives Evaluated—EERC has initiated testing to determine if sorbent-enhancement additives (SEA) will enhance mercury removal from coal combustion gases to achieve a high level of cost-effective mercury control. Bench-scale testing shows that powdered activated carbon is highly effective in capturing oxidized mercury but minimally effective in capturing elemental mercury—the dominant form produced by Powder River Basin subbituminous coals. This project, funded by NETL, tests two SEAs, SEA 1 and SEA 2, which will be tested independently and in combination with powdered activated carbon injection. The test are being conducted at Kansas City Power & Light's Hawthorn Unit 5, which burns Powder River Basin coal, and Louisville Gas & Electric Company's Mill Creek Unit 4, which burns a blend of medium- and high-sulfur bituminous coal. Although testing is ongoing, results for SEA1 show up to 74 percent mercury removal. The results of this effort will be applicable to virtually all utilities that burn subbituminous and bituminous coals in the United States.

Mercury-Control Field Testing Completed at Miami Fort Station—Amended Silicates LLC (a joint venture between ADA Technologies Inc. and CH2M HILL) completed long-term field testing of an Amended Silicates™ sorbent injection for mercury control at Cinergy's (now Duke Energy's) Miami Fort Station Unit 6 in North Bend, OH. Amended Silicates is a non-carbon-based sorbent that has been shown to be effective in capturing vapor-phased mercury from coal-fired power plants while allowing for the continued sale of fly ash for use in manufacturing concrete. Miami Fort Unit 6 is a 175-megawatt-rated unit burning eastern bituminous coal and equipped with 3 electrostatic precipitators in series. Results from long-term testing showed that both Amended Silicates sorbent and powdered activated carbon achieved about 40 percent mercury removal at injection rates of 5–6 pounds per million actual cubic feet. Testing was conducted in cooperation with NETL.

Field Testing of Sorbent Injection for Mercury Control Completed—EERC, in cooperation with NETL, completed long-term field testing of sorbent injection for mercury control at TXU's Big Brown Station located in Fairfield, TX. Three sorbent-based technologies were evaluated: injection of activated carbon, enhanced activated carbon (produced from DARCO® Hg by EERC using a proprietary process), and activated carbon with an additive SEA4 (a proprietary technology of EERC). Of these technologies, the enhanced activated carbon provided the best balance between maximizing mercury removal and minimizing the total quantity of injected sorbent. An ongoing investigation seeks to explain the mercury-removal variations and root causes for balance-of-plant effects observed during the field test.

Mercury-Control Testing Completed at Laramie River Station—ADA-ES Inc., Littleton, CO, completed mercury-control testing at Basin Electric Power Cooperative's Laramie River Station Unit 3. Laramie River Station is one of five sites being evaluated under an NETL-managed project aimed at evaluating sorbent injection for controlling mercury. Laramie River Station burns Powder River Basin coal and has a spray dryer absorber and electrostatic precipitator for air pollution control. Results identified two technologies that have the potential to significantly reduce mercury emissions. DARCO® Hg-LH injected at a concentration of 4.5 pounds per million actual cubic feet resulted in mercury removal in excess of 90 percent. When injected at a rate of 1.6 gallons per hour, KNX™ achieved mercury removal of 94 percent at a carbon feed rate of 4.5 pounds per million actual cubic feet. Baseline mercury removal prior to testing was near zero percent. Upcoming field tests are planned for AmerenUE's Labadie Power Plant Unit 2.

Water

Thermoelectric energy production is the second-largest consumer of freshwater in the United States, only slightly behind irrigation. To ensure that our nation's energy needs are met while still protecting U.S. water supplies, NETL is conducting integrated water and energy research. This research is directed at developing advanced technologies and concepts to reduce the electric power sector's use of freshwater and to innovatively manage and reuse water produced from oil extraction, gas extraction, and carbon sequestration.

NETL Completes Long-Term Assessment of Freshwater Needs for Thermoelectric Power Generation—NETL analysis shows that freshwater withdrawals by thermoelectric power plants could decline by up to 30 percent nationally between 2005 and 2030. However, water consumption, typically through evaporation into the air, could increase by as much as 48 percent in the same time period. This increase is expected to affect all regions of the United States but will be particularly significant in California, Florida, New York, the Rocky Mountains, and the southwestern desert region. Because water availability is becoming an increasingly important factor in power plant siting, findings of the study will help industry, policy makers, regulators, and others understand the potential limitations faced by the future thermoelectric fleet. This is especially important as the U.S. population and associated economic development with its demand for electricity continue to grow.

NETL Develops Novel Method for Evaluating Water Quality—NETL researchers have developed a method for more easily evaluating water quality data collected in periodic monitoring programs. The Scatterscore Water Quality Evaluation yields a quantitative score based on all measured variables. These data are often difficult to evaluate, especially if the number of parameters is high, the sampling schedule varies, and/or values differ in orders of magnitude. NETL applied its evaluation method at 20 sites that control acid mine drainage with coal utilization by-products. The method indicated improved water quality at 14 sites, random change at 4 sites, and poorer water quality at 2 sites. The methodology is described in the journal, *Environmental Monitoring and Assessment*.

Brownfield Screening Instrument Commercialized—Bacharach Inc., of New Kensington, PA, is now including the patent-pending X-Wand™ analyzer in its product line. Working in cooperation with NETL, researchers at Western Research Institute developed the portable, battery-powered device as a quick, low-cost, effective means of locating some of the most common soil and water contaminants in the United States. The novel field kit employs a heated diode sensor (commonly used to find refrigerant leaks) to detect halogenated volatile organic compounds in soil and water at a sensitivity comparable to that of gas chromatography/mass spectroscopy. The X-Wand has been approved by the American Society for Materials and Testing. The device can streamline testing at brownfields, contributing to their prompt decontamination.

AIR QUALITY

Air Quality

In light of current and future regulations to address ambient air quality concerns, advanced emission-control and related air-quality research remain important to NETL's environmental program. The goal of this research is to develop advanced NO_x-control technologies that are significantly cheaper to build and operate than current technology. Research is focused on advanced in-furnace NO_x-control technologies and related diagnostic equipment applicable to the broad range of boiler configurations and coal types currently used in the United States. In addition, research is being carried out to better understand any potential link between coal-plant emissions and ambient air quality.

Project Provides Insight on Coal's Air Quality Impact—The Steubenville Comprehensive Air Monitoring project team, led by Consol Energy of Pittsburgh, PA, and the Harvard School of Public Health, produced particulate matter data specific to Steubenville, OH, and its vicinity, including levels of personal exposure for at-risk individuals. Results of the study show that regional sources, most likely coal-fired power plants to the west and southwest of Steubenville, contribute the largest single portion (40 percent) of total particulates observed in the city, with local sources accounting for approximately 25 percent. The ability of ambient concentrations to reflect personal exposure levels depended on home ventilation and particle type. However, overall data show that ambient levels are strong proxies for corresponding personal exposures of older adults and, to a lesser extent, children. Conducted in cooperation with NETL, the study will help policy makers and the toxicological research community create science-based strategies to address air pollution.

No Adverse Biological Effects from Coal Plant Particulates in Field Experiments—The National Ambient Air Quality Standards for particulate matter are based solely on mass concentration and do not reflect that some types of particles are inherently more toxic than others. Field-test data obtained by researchers from the Electric Power Research Institute in Palo Alto, CA, and the Harvard School of Public Health show that laboratory animals exposed to particulate matter from an Upper-Midwest power plant burning very low-sulfur, low-ash coal sustained no adverse pulmonary, systemic, or cardiovascular effects. Similar tests are planned for plants burning low-sulfur and medium-to-high-sulfur bituminous coal. The work is being conducted in cooperation with NETL to help planners mitigate public health impacts of air pollution.

Novel Device for Measuring Catalyst Deactivation Nears Commercialization—A device that provides a real-time view of catalyst deactivation was successfully field-tested during the 2005 and 2006 ozone seasons on a full-scale selective catalytic reduction (SCR) unit at Alabama Power Company's William Crawford Gorgas Electric Generating Plant near Parrish, AL. SCR systems are the predominant control technology for reducing NO_x emissions from large coal-fired power plants. The in-situ catalyst-performance measurement system was developed by researchers at Fossil Energy Research Corporation (FERCo) of Laguna Hills, CA, in collaboration with NETL, Southern Company, and the Electric Power Research Institute. FERCo has applied for a technology patent and expects to begin commercial production of the device after successful testing of Internet-based data access and reporting features. The technology will help optimize catalyst management for year-round SCR operation by predicting remaining catalyst life and evaluating replacement options without requiring a unit outage to obtain catalyst samples.

Sensor on Course to Commercialization—The 18-month commercialization plan accompanying a licensing agreement between the University of Florida and Emissions-Detection Technologies Inc., part of Fuel FX Inc. in San Diego, CA, calls for the full-scale production of a low-cost, highly durable solid-state sensor that can detect and measure parts-per-million levels of carbon monoxide and NO_x. Developed by investigators under a University Coal Research grant administered at NETL, the sensor can be used in the transportation, industrial, and energy sectors to improve combustion controls as well as meet current and anticipated emissions monitoring regulations.

Coal Utilization By-products

Developing more beneficial uses for coal utilization by-products (CUBs)—the solid materials formed during coal-fueled electric power generation—will improve power generation economics, conserve natural resources and landfill space, and reduce carbon dioxide (CO_2) emissions. NETL conducts and sponsors research to support the environmentally safe, technically sound handling of CUB material, with the goal of increasing the use of CUBs in construction and other industries. Our research efforts explore the environmental impacts of CUB disposal versus utilization, the optimization of utilization methods, and the collection and dissemination of data to assist in regulatory decisions related to CUBs.

Conceptual Process Would Use Industrial Wastes to Permanently Sequester CO_2—NETL researchers have demonstrated the feasibility of reacting CO_2 with two large-volume waste products—coal-utilization fly ash and the brine wastewater produced during oil and gas extraction—to create a solid calcium carbonate material that permanently locks in the greenhouse gas. The inert material would be placed in a landfill as is, while leftover brine water would be used in enhanced oil recovery efforts. This conceptual process provides a new option for CO_2 sequestration, as well as reducing the cost and environmental impact related to the disposal of these industrial wastes. Results of the laboratory study have been published in the Elsevier publication, *Energy Conversion & Management*.

Coal Gasifier Slag Improves Foam Glass Products—Working in cooperation with NETL, collaborators at Mississippi State University and Earthstone International LLC, Richardson, TX, have found that coal gasifier slag can replace some of the glass used in mixtures for foam glass products. Foam glass blocks can be used as building insulation, abrasive sanding blocks, and, potentially, as armor for military vehicles. Use of gasifier slag in foam glass lowers the cost of production and increases abrasion resistance. As advanced gasification becomes the technology of choice, disposal of gasification slag will become more difficult. Finding beneficial uses for slag today will enhance the utilization of future gasification by-products.

Novel Coal Ash Beneficiation Technology Demonstrated—Power plant combustion of bituminous and subbituminous coals invariably produces carbon-laden fly ash. Fly ash containing more than 6 percent unburned carbon is generally thought to be unsuitable for concrete applications. However, treatment with ozone gas neutralizes the effect of unburned carbon and renders the fly ash usable for this purpose. Testing conducted at PPL Montour Plant in Washingtonville, PA, was the first power plant demonstration of an ash-ozonation technology at near full-scale (10 tons of ash per day). Estimated capital and operating costs suggest the emerging ozone technology could compete with alternative commercially available processes for treating unburned carbon. The work was completed in cooperation with NETL under the Office of Fossil Energy's Environmental and Water Resources program.

NETL Zeros in on Mercury in Wet Flue Gas Desulfurization Products—NETL researchers have discovered that, during SO_2 capture via wet flue gas desulfurization (FGD), oxidized mercury is caught and held in the iron-rich portion of synthetic gypsum—the primary by-product of forced-oxidation FGD. Evidence suggests that a portion of the gypsum becomes iron rich when limestone is introduced to the FGD slurry to neutralize and capture acidic SO_2. If so, oxidized mercury capture could be a near-zero-cost fringe benefit of the limestone neutralization process. The ability to capture and separate the mercury before using the gypsum to manufacture wallboard, cement, and soil amendments will prevent the mercury's reintroduction into the environment when these products are exposed to water. The results have been described in Elsevier's publication, *Fuel*.

NEAR ZERO

Near-Zero-Emissions Technologies

Coal is a vital asset in our energy portfolio. NETL and its research partners are conducting advanced research to forge the highly efficient, near-zero-emissions fleet that will continue to fuel the majority of our energy needs while leaving the smallest environmental footprint possible. Integrating climate-change strategies, such as carbon sequestration, into advanced systems is an essential tactic for using coal to power our nation's future.

Testing of High-Temperature Desulfurization System Initiated in Commercial Coal Gasifier—Developed at RTI International, Research Triangle Park, NC, in cooperation with NETL, an advanced gas-cleaning technology that could make integrated gasification combined cycle (IGCC) systems competitive in today's power generation market is undergoing a field test at the 1,000-ton-per-day coal gasifier at Eastman Chemical Company in Kingsport, TN. Using an R&D 100 award-winning regenerable zinc-based sorbent (RTI-3), the high-temperature desulfurization system operates at a pressure of 600 psig with an absorber temperature of 900 ºF and a regenerator temperature above 1,300 ºF. Almost halfway through the 2,000-hour planned run, preliminary results showed that the absorber removed sulfur from synthesis gas at an efficiency greater than 99.95 percent. Completion of this long-term test will be a significant step toward commercialization, eventually leading to IGCC capital cost reductions up to $80 per kilowatt electric and an efficiency improvement greater than 1 percentage point.

Oxygen Transport Membrane Technology Achieves Key Milestone for Advanced Boiler Process—As part of a cooperative agreement with NETL, process developers at Praxair Inc. of Danbury, CT, completed a series of laboratory experiments in which the complete combustion of natural gas and recycled fuel gas was achieved using a set of six Oxygen Transport Membrane tubes. The tubes feature a ceramic membrane that separates oxygen from air less expensively than conventional cryogenics. By using oxygen instead of air, this advanced boiler process will produce concentrated CO_2 that is easily captured, consume less parasitic power, and operate at lower cost than conventional boiler processes with postcombustion CO_2 capture.

Future

Technologies for Future Energy Plants

The realization of the FutureGen prototype—which will produce electricity and hydrogen with near-zero emissions—grows sharper on the horizon as NETL continues research for the power plants of tomorrow. NETL supports coal and power systems development through advanced research in materials, sensors and controls, biotechnology and bioprocessing, pollutant formation and removal, and advanced computational processes.

Heat Engines

Turbines are the heart of nearly all the world's electric generating systems. Because of their potential for higher performance and their adaptability to fossil-fuel-based power systems that capture CO_2, turbines are a prime component in providing secure domestic power production that is clean, efficient, and affordable. NETL manages a research, development, and demonstration project portfolio designed to develop near-zero-emission turbine technologies that eliminate environmental concerns over future coal use. Researchers also use NETL's unique facilities to evaluate new concepts in combustion, sensors, and turbine materials.

Commissioning Trials Successful for Ion Transport Membrane Oxygen Prototype Facility—Air Products and Chemicals Inc. of Allentown, PA, completed three commissioning trials of its Ion Transport Membrane Oxygen process at a subscale engineering prototype facility. The process achieved target performance for system pressure and temperature at an airflow rate approaching that of aggressive commercial operation. It also produced oxygen of at least 95 percent purity. Subsequent experiments assessed commercial-scale module performance through a series of scheduled process variable changes, eventually producing oxygen of more than 99 percent purity. The Ion Transport Membrane Oxygen process is being developed in cooperation with NETL to produce oxygen at one-third-lower capital cost and energy requirement compared to cryogenic processes in IGCC and other advanced power generation systems.

Hydrogen Separation Membrane Exceeds 2010 Commercial Target—Southwest Research Institute of San Antonio, TX, has developed a sulfur-tolerant metal alloy membrane that can separate hydrogen from coal-derived synthesis gas at a rate exceeding DOE's 2010 commercial target. The novel, low-cost material is much thinner than current state-of-the-art materials, allowing hydrogen fluxes that would be practical for commercial applications. The membrane is compatible with coal-gas processing conditions and can produce a gas stream that is 99.95 percent pure hydrogen. This is a significant milestone toward the achievement of viable coal-to-hydrogen production technology for FutureGen and other future coproduction plants. The work is being performed in cooperation with NETL as part of the Office of Fossil Energy's Hydrogen from Coal program.

NETL Facility Gains Recognition for High-Quality Data—NETL's Simulation Validation Studies combustor—known as SimVal—is a unique, fuel-flexible combustor that generates data sets under realistic gas turbine conditions. SimVal is gaining recognition as a valuable source of high-quality data sets suitable for model validation. It also supports NETL's goal of developing advanced turbines for IGCC applications. Three significant achievements were realized with SimVal in 2006:

- NETL researchers generated parametric pollutant-emissions data produced from hydrogen and natural gas in the SimVal combustor. This data set is one of the most complete available for hydrogen flames produced in a turbine-scale combustor at pressure up to 8 atmospheres and was utilized at Siemens Power Generation Inc. of Orlando, FL, for validating detailed computer simulations involving combustion of hydrogen-methane fuel mixtures.
- Using laser diagnostics, NETL researchers collected highly resolved images of hydroxyl radicals in flames produced from hydrogen and natural gas in the SimVal combustor at pressure up to 8 atmospheres. This work, the result of a collaboration between NETL and the Sandia National Laboratories Combustion Research Facility, will accelerate the development and validation of comprehensive combustion models that can reduce the lead time and cost of constructing future ultra low-emission high-efficiency fuel-flexible combustion systems.

- Researchers demonstrated that NETL's Combustion Control and Diagnostics Sensor (CCADS) will operate in combustors with either bare metal liners or thermal barrier coating and can detect flashback during combustion of fuels containing up to 80 percent hydrogen. This demonstration highlights the broad applicability of CCADS and is an important step toward its commercial deployment. Incorporated into the fuel nozzles of a turbine combustor, CCADS sensors have a much shorter response time for flashback detection than traditional temperature sensors and could be a key to developing controls that would ensure reliable turbine operation in FutureGen applications. NETL is working with Woodward Governor Company, Fort Collins, CO, to commercialize the NETL-patented CCADS technology for facilitating improved performance and lower emissions in advanced power systems.

NETL Facility Expands Fuel Cell-Turbine Hybrid Simulation Capabilities—Researchers have successfully integrated and tested a high-speed computing platform called dSpace for NETL's Hybrid Performance Facility. The new addition is designed for "hardware in the loop" applications—simulations that incorporate actual major hardware components to allow for a more detailed study of the least-understood parts of the system. The unique facility integrates real gas-turbine and heat-exchanger hardware with fuel cell simulators to better understand how the fuel cell will interact with the rest of the system. dSpace provides the higher-speed computer platforms necessary to complete this type of simulation.

Non-intrusive Technique Predicts Remaining Life of Turbine Blade Coatings—Working in cooperation with NETL, collaborators at the Electric Power Research Institute, Southwest Research Institute of San Antonio, TX, and Turbine Technology International of Rochester, NY, developed an analytic approach for predicting thermal fatigue damage to the critical coatings that protect hot section components (e.g., liners, blades, vanes) of combustion turbines. The team developed algorithms to estimate remaining life based on stress, strain, and temperature profiles at various operating conditions and verified these predictions against actual field observations. The new technique will help optimize intervals between turbine refurbishment. It will also reduce the risk of coating failure, which can lead to catastrophic damage, costly replacement, prolonged outage, disrupted electric service, and revenue loss.

University Turbine Systems Research Project Yields Important Design Tool—Researchers at Virginia Polytechnic Institute and State University have identified computer simulation algorithms for predicting complex flows and heat transfer within the internal cooling channels of turbine airfoils. Greater accuracy afforded by this computational advancement will allow designers to specify the airflow paths and quantities that achieve more precise cooling, cutting aerodynamic losses and improving turbine performance. The work was accomplished under the Office of Fossil Energy's University Turbine Systems Research program, a government-industry-academia collaboration managed by the South Carolina Institute for Energy Studies at Clemson University under a cooperative agreement with NETL.

Fuel Cells

FUEL CELLS

NETL's fuel cell research is conducted under the banner of the Solid State Energy Conversion Alliance (SECA), a collaboration managed by NETL that brings together government, the private sector, and the scientific community. SECA is focused on developing, by 2010, commercial-grade fuel cells with a market-competitive $400-per-kilowatt manufactured cost. Concurrently, the scale-up, aggregation, and integration of SECA's technologies are leading to the validation of prototype megawatt-class products by 2012, with testing at the FutureGen facility or an equivalent site. Finally, SECA's coal-based and combined-cycle projects are developing megawatt-class fuel cell power systems that will produce affordable, reliable, efficient, and environmentally friendly electrical power from coal.

Office of Management and Budget Praises SECA as Partnership Leader—In the *Budget of the United States Government, Fiscal Year 2007*, the Office of Management and Budget (OMB) cited SECA as leading the way in government-industry partnerships. OMB's description of the SECA program helps illustrate DOE's efforts to demonstrate the future of coal, one of our nation's priorities. OMB stated: *The SECA program leverages private-sector ingenuity by providing Government funding to industry teams developing fuel cells, as long as the teams continue to exceed a series of stringent technical performance hurdles. This novel incentive structure has generated a high level of competition between the teams and an impressive array of technical approaches. The SECA program also develops certain core technologies that can be used by all the industry teams to avoid duplication of effort. The program exceeded its 2005 performance targets, and it is on track to meet its goal for an economically competitive technology by 2010.*

Industry Teams Exceed Phase I Targets—SECA system prototypes, manufactured with scalable mass-production techniques, exceeded Phase I targets for availability, efficiency, and production cost. A typical system demonstrated an availability of 90 percent compared to the SECA target of 80 percent. An efficiency of 35–40 percent was achieved in the small 3–10 kilowatt systems, surpassing the target of 35 percent. This superior efficiency in a small size demonstrates the achievability of much higher efficiencies for larger systems. Most significantly, the independently audited system costs ranged $691–$784 per kilowatt—a major breakthrough toward achieving market-competitive costs. These Phase I numbers represent aggregated results across six industry teams. NETL is operating select units for verification.

SECA Transitions to Coal-Based Systems—To address the issues of fuel cell scalability and incorporation into IGCC plants, DOE integrated SECA's cost-reduction activities into its Coal-Based Systems projects. The goal of these projects is to develop and demonstrate fuel cell technologies that will improve coal-based central power stations and provide a 10–50 megawatt power block for inclusion with FutureGen or equivalent demonstrations. Three industry teams—Siemens Power Generation of Pittsburgh, PA, General Electric Hybrid Power Generation of Torrance, CA, and FuelCell Energy Inc. of Danbury, CT—transitioned their cost-reduction projects into Coal-Based Systems and are working to develop fuel cell systems for an IGCC plant with capacities of 100 megawatts or greater. All SECA industry teams will continue their cost reduction activities through 2010 with the best fuel cell stacks available for development.

Fuel Cell Power Density Improved—One of SECA's primary goals is to enable fuel cells to produce more watts of electric power from smaller volumes of materials. This improved power density is needed to make fuel cells economically competitive with gas turbines and diesel electric generation. Several of SECA's industry teams are developing high-power-density solid oxide fuel cell (SOFC) prototypes with a net power output of 3–10 kilowatts and the potential for mass production. The following are some examples of the power-density improvements that SECA's industry teams have realized:

- Siemens Power Generation's new corrugated design increased surface density by 40 percent, and its new fuel cell stack design increases power density by as much as 52 percent.
- General Electric's prototype SOFC reduced system volume by 75 percent, enabling the power density of the SOFC system to increase by 37 percent.
- Acumentrics Corporation of Westwood, MA, doubled the power density of its SOFC unit from 2005 to 2006.

Research Team Develops and Demonstrates Commercial SOFC Interconnect Material—Allegheny Technologies Inc. of Pittsburgh, PA, Pacific Northwest National Laboratory, and NETL have identified and successfully tested a cost-effective interconnect material based on ferritic stainless steels for applications in coal-based SOFC systems. The team's development goal was to use an inexpensive metal alloy to eliminate the negative effects of metallic interconnects on electrical conductivity in SOFCs. With funding and direction from the SECA Core Technology program, Pacific Northwest National Laboratory achieved success in laboratory tests with a commercial alloy from Allegheny Ludlum Corporation of Pittsburgh, PA. More extensive investigations are in progress to determine whether, with appropriate surface treatment, an alloy of this type can fully satisfy stringent SOFC interconnect requirements.

High-Temperature Blowers Developed for SOFC Systems—Phoenix Analysis & Design Technologies Inc. of Tempe, AZ, and R&D Dynamics Corporation of Bloomfield, CT, have successfully demonstrated two distinctly different high-temperature pumps and blowers for SOFC systems. Each of the novel technologies successfully separates hot fuel cell gases from temperature-sensitive pump components, such as bearings, magnets, electronics, and motor windings. This work is key to improving SOFC efficiencies, and it supports the achievement of fuel cell systems that can adapt to diverse fuels. The efforts were conducted for SECA under a series of Small Business Innovation Research grants.

Crack-Resistant Compliant Glass Seal Identified—SOFC systems are more robust if their seals can accommodate motion in cell components and recover from stress-induced cracking. The University of Cincinnati has identified a glass composition that does not crystallize at SOFC operating temperatures and remains soft, so that cracks flow shut as the stack cools to room temperature. University of Missouri-Rolla is now working to improve the chemical compatibility of this class of flowable glass, and Sandia National Laboratories is examining composites in which ceramic filler particles improve the resiliency of the soft glass seal. Engineered materials systems that utilize novel glass formulations and composite structures hold promise for successful seal solutions.

Cathode Poisoning from Interconnect Chromium Mitigated—Chromium is a common element in cost-effective fuel cell metal interconnects. However, it often migrates from the fuel cell's interconnect to its cathode material, forming compounds that may decrease cell performance. The SECA Core Technology program has developed a "chromium poisoning" mitigation strategy through work performed at Argonne National Laboratory, Pacific Northwest National Laboratory, and Carnegie Mellon University. The approach allows SECA's industry teams to slow chromium transport with applied coatings, remove it via airflow, and capture it in cathode structures—all without significant loss in cell performance.

Carbon Sequestration

NETL explores many facets of carbon sequestration, including capture and separation technologies for CO_2; direct and indirect storage options; mitigation of non-CO_2 greenhouse gases; monitoring, mitigation, and verification for ensuring permanent sequestration; and breakthrough concepts for reducing the cost of capture. NETL also manages DOE's seven Regional Carbon Sequestration Partnerships, which collaborate with regional, state, and local governments, universities, and private companies to determine the best approaches for capturing and permanently storing greenhouse gases in each region of the country.

NETL Study Highlights Regulatory Barriers to Carbon Sequestration—In response to the Intergovernmental Panel on Climate Change's special report on carbon capture and storage, several U.S. and international efforts are underway to strengthen the regulatory environment for carbon capture and storage projects. An NETL review of these projects throughout the world highlights the major legal and regulatory issues that remain unresolved (e.g., CO_2 purity specification, access and property rights, intellectual property rights, monitoring and verification requirements, liability) and summarizes international efforts to address them. NETL prepared five case studies by contacting project developers in several countries to discuss their efforts in addressing each major legal issue and by interviewing national and international carbon capture and storage experts working to develop a regulatory framework. Findings of the study will be useful to international programs, such as the Carbon Sequestration Leadership Forum and the Asia-Pacific Partnership on Clean Development and Climate.

New Method Accounts for Coal Swelling During CO_2 Isotherm Measurements—NETL researchers have developed a unique method that more accurately quantifies the extent to which coal swells during CO_2 injection. The method combines volume and weight measurements relative to a constant temperature. Traditional techniques ignore coal swelling, despite the fact that it affects injection rates and the accuracy of CO_2 sorption measurements. The amount of swelling increases with CO_2 pressure, as do the resulting errors incurred by ignoring coal swelling. If the amount of swelling is unknown, accurate measurements of a coal seam's CO_2 sorption capacity are not possible. Details about the method appear in the March 2006 issue of *Chemical and Engineering Technology*.

New Tools Offer Breakthrough in Measuring Terrestrial Sequestration Effectiveness—Researchers at The Nature Conservancy, Arlington, VA, and Stanford University have developed a process that traces the crown diameters of treetops using geographic information system image analysis. The information generated by the procedure can be used in conjunction with other data collection tools to automatically calculate the carbon content in forests. The technology will greatly reduce uncertainties associated with the measurement and verification of carbon in forestry projects established for carbon sequestration. The process was developed under a cooperative agreement between NETL and The Nature Conservancy aimed at developing accurate, low-cost tools and models to measure the carbon stored in terrestrial sequestration projects.

Technology for Sequestering CO_2 Through Photosynthesis Licensed to Commercial Developer—GreenShift Corporation of New York, NY, obtained a license from Ohio University to commercialize a patented technology for sequestering CO_2 via photosynthesis. Developed in cooperation with NETL, this technology removes up to 50 percent of CO_2 from flue gas using photobioreactors—small, closed systems that contain algae and water. Scaling up the process to industrial dimensions would also produce value-added products, such as biodiesel fuel and fertilizer.

Hydrogen

Advanced hydrogen production and delivery technologies can supply tomorrow's energy and transportation systems with clean, affordable hydrogen power. Long term, the predominant sources of hydrogen will likely be renewables and nuclear energy. However, until these technologies are viable, fossil fuels can provide a mid-term source of hydrogen. NETL manages a portfolio of research and development projects focused on producing hydrogen from coal fuels for use in fuel cells, as merchant gas, in the petrochemical industry, and in other systems.

Hydrogen Separation Membrane Technology Exceeds Performance Targets—NETL industrial partners are developing novel membrane materials for producing pure hydrogen and sequestration-ready CO_2 from coal-derived synthesis gas at process temperatures consistent with downstream gasification-unit operations. Successful membrane development will lead to higher thermal efficiencies and lower capital and operating costs compared to conventional hydrogen separation technologies, ultimately enabling a viable coal-to-hydrogen production process.

- In bench-scale tests, novel materials engineered at Eltron Research Inc. in Boulder, CO, have already met DOE's 2015 targets for sulfur tolerance and operating conditions and surpassed those for hydrogen production rate. The cost of the technology is estimated to be approximately half that of commercial pressure swing adsorption technology.
- Researchers at IdaTech LLC, Bend, OR, have verified that a novel material engineered at Southwest Research Institute, San Antonio, TX, can separate hydrogen from coal-derived gas at a rate that exceeds DOE's 2010 commercial target. The sulfur-tolerant palladium-copper alloy can be deposited on a porous base in layers as thin as one micron to produce robust, defect-free membrane wafers. The wafers transport 99.95 percent pure hydrogen from shifted synthesis gas (a mixture of hydrogen and CO_2) and represent a significant milestone toward achieving the FutureGen project goal of developing a viable coal-to-hydrogen production technology.

Advanced Molecular Sieve Could Enable Hydrogen Production from Coal—Working in cooperation with NETL, researchers at Media and Process Technologies (MPT), Pittsburgh, PA, have developed a carbon molecular sieve that is highly selective for hydrogen and particularly well suited for coal-derived gas. Teaming with Pall Corporation of East Hills, NY, MPT successfully produced a functional porous stainless-steel base that will support the fabrication of a membrane reactor based on a carbon molecular sieve in which the hydrogen production and separation could occur simultaneously. The technology could enable economic production of hydrogen from coal using advanced coal-based power concepts being developed for the FutureGen project.

Composite Membrane Exceeds Performance Target for Hydrogen Separation—Sulfur-resistant palladium alloys normally fail when they encounter the carbon oxides present in shifted-coal gas feeds. However, researchers at the Colorado School of Mines have developed a novel alloy of palladium and gold that remains intact despite trace levels of carbon monoxide, CO_2, and hydrogen sulfide. The alloy was deposited on a Pall AccuSep commercial membrane base and tested at commercially relevant operating conditions. The membrane exceeded DOE's 2015 target for hydrogen separation by almost 70 percent. These successes, achieved by the NETL-managed University Coal Research program, represent a significant milestone in the effort to produce hydrogen from coal.

Materials

Advanced materials and processes will be vital to future power and fuels production plants, including FutureGen. Working in partnership with Oak Ridge National Laboratory, NETL's Materials program addresses the need for new materials that can withstand the corrosive, high-temperature environments of advanced power generation technologies, such as coal gasifiers, turbines, combustors, and fuel cells. Research areas include structural ceramics, new alloys and coatings, functional materials, and corrosion abatement.

Materials Program Evaluates Ultra-supercritical Conditions Components—Under NETL's management, a consortium of U.S. boilermakers has laid the groundwork for the selection and use of materials that reliably operate under harsh ultra-supercritical steam conditions (1,400 °F and 5,000 pounds per square inch pressure). Ultra-supercritical steam conditions would increase the efficiency of the current domestic fleet and enable coal-fired power plants to generate electricity at competitive rates while reducing CO_2 and other fuel-related emissions. Partners supporting this project include Energy Industries of Ohio in Independence, OH, the Electric Power Research Institute in Palo Alto, CA, and Oak Ridge National Laboratory. Significant accomplishments for 2006 follow:

- Using electron microscopic techniques to characterize microstructural changes in both aged and stressed samples of nickel-based superalloys, researchers at the University of Cincinnati can now more accurately forecast the long-term behavior of these alloys under ultra-supercritical steam conditions. Understanding the properties of high-temperature materials, including the properties of resistance to deformation and thermal fatigue, will help ensure the reliability of ultra-supercritical power plants. The project trains future materials scientists while providing valuable tools for predicting and extending the life of advanced alloys.
- Researchers at the Babcock & Wilcox Company, Barberton, OH, have found that a metal finishing procedure known as "shot blasting" significantly improves the resistance of advanced alloys to oxidation by high-temperature steam. This finding is the result of ongoing exposure tests exceeding 2,000 hours. Application of this process could provide boiler fabricators a relatively inexpensive and straightforward method for steam protection of boiler tubes.
- Foster Wheeler Inc. of Clinton, NJ, produced corrosion probes made of various new alloys, coatings, and weld overlays to evaluate the candidate materials' fireside corrosion resistance in advanced coal-fired boilers. The air-cooled, retractable probes operated problem-free in the Duke Energy high-sulfur coal-fired unit at the Gibson Generating Station in Owensville, IN, and in the Xcel Energy low-sulfur coal-fired Pawnee Station in Brush, CO. In 2007, another set of probes will be installed at the American Electric Power eastern coal-fired General James M. Gavin Plant in Cheshire, OH, for a test of an extended exposure period at the temperature expected for advanced superheater/reheater components (1,200–1,600 °F).
- Researchers at ALSTOM Power Inc., Windsor, CT, have developed a modern, simplified method for studying the effects of mechanical stress on headers made of various materials for use with advanced ultra-supercritical steam boilers. The novel procedure provides valuable information on cyclic responses and structural safety in systems that produce temperature and pressure fluctuations greater than those encountered in conventional boilers. Further development and application of the procedure, combined with detailed models of ultra-supercritical boilers, will help ensure the cycling capability of key components.

- Long-term mechanical strength testing for several alloys under consideration for use at ultra-supercritical steam conditions has exceeded 26,000 hours—much longer than previous tests and at higher temperature (1,350 °F). The testing, performed at Oak Ridge National Laboratory, confirmed that certain alloy modifications reduce the accumulation of damage to a material over time.
- Researchers at the Babcock & Wilcox Company completed successful bending trials with two candidate construction materials for advanced high-efficiency coal-fired boilers. Both materials—one a sophisticated nickel-based alloy, the other a stainless steel composed mainly of austenite—remained intact as they were processed into 3-, 5-, and 7-inch-radius cold bends. These achievements confirm that the materials can be fabricated without cracking or pitting.
- Researchers at the Babcock & Wilcox Company produced heavy-section joints from new materials being considered for advanced boilers that are capable of operating at much higher temperatures and efficiencies than those of conventional plants. The joints were completed using the gas tungsten arc-welding technique, based on results of weld characterization studies conducted at EWI, of Columbus, OH. The technique could provide boiler fabricators with a rapid process for making steam lines and headers from the candidate high-temperature materials. The joints' mechanical strength at high temperature will be evaluated at Oak Ridge National Laboratory.
- The realization of a 1,400 °F steam power plant depends on the successful development of advanced alloys and fabrication components. Contributing to this effort, researchers at the Babcock & Wilcox Company have successfully applied prototypic manufacturing operations to fabricate a thick-walled header section which incorporates high-temperature materials, including advanced steels and nickel-based alloys.

Surface Treatment Improves Oxidation Resistance of High-Temperature Alloys—Methodologies to improve the oxidation resistance of low-cost stainless steels are paramount to the development of economical solid oxide fuel cells. Critical components, such as interconnects, are subjected to high temperatures, which can degrade the steel and subsequently the fuel cell's performance. Using cerium, NETL researchers developed a simple and inexpensive surface treatment that dramatically improves the oxidation resistance of stainless steel in laboratory tests. The patent-pending method is of interest for a wide range of power generation applications in which system performance, reliability, and affordability are significantly affected by the corrosion of structural materials in hostile environments.

Nanostructured Coatings Offer Advantage for Boiler Component Protection—In cooperation with NETL, researchers at Karta Technologies Inc., San Antonio, TX, used an advanced process to coat metal surfaces with a nanostructured aluminum alloy (grain sizes below 15 nanometers). Coatings comprised of such fine grains form protective barriers more quickly than do conventional coatings, potentially providing a less expensive approach to protecting boiler components from the harsh conditions of advanced fossil energy systems. In future testing, power plant operators with City Public Service will expose samples coated with the novel material to boiler firesides, where tube failures often occur.

DEMONSTRATION

Clean Coal Demonstration Projects

Initially established to combat acid rain, the Clean Coal Technology program is now dedicated to reducing emissions of mercury, fine particulates, and greenhouse gases. Since 1986, NETL has actively supported cost-shared demonstration projects that improve the power plant fleet and have great potential for public benefit. Demonstrations must exceed existing technologies in terms of efficiency, environmental performance, and/or economy. Many demonstrations conducted through this program have resulted in the commercial acceptance and application of innovative technologies.

Clean Coal Power Initiative Project Adds Value to Coal Ash in Field Tests—Ash beneficiation technology developed at the University of Kentucky Center for Applied Energy Research was successfully tested at the Kentucky Utilities Company's Ghent Generating Station near Carrollton, KY. The results pave the way for designing a near-commercial-scale demonstration plant capable of turning CUBs into such marketable products as recycled carbon fuel, fill material for plastic manufacture, aggregate and other construction materials, and pozzolan for concrete manufacturing. The field tests, conducted in cooperation with NETL, used a mobile pilot-scale test rig to process approximately 150 tons of pond ash. Ash beneficiation technologies help eliminate the cost and environmental liability of constructing ash-settling ponds.

Landmark Coal Drying Study Completed—Lehigh University researchers completed a 3-year investigation of a novel lignite coal-drying process. Based on models developed for low-temperature drying kinetics, the process uses waste heat to dry high-moisture coal in a fluidized-bed unit. The university's evaluation forecasts several power plant benefits, including improved boiler efficiency, reduced auxiliary power consumption, lower emissions, and reduced cooling-water usage. The study represents a significant milestone toward improving the performance of steam plants fired with Powder River Basin subbituminous and lignite coals and high-moisture biomass fuels. The process is being successfully demonstrated at the Great River Energy Coal Creek Station in Underwood, ND, in cooperation with NETL and other industrial partners.

Multipollutant Clean Coal Power Initiative Project Begins Operational Phase—Operation of the TOXECON™ process, which could offer coal-fired power plants a low-cost retrofit option for reducing mercury emissions by up to 90 percent, was initiated at the We Energies Presque Isle Power Plant located in Marquette, MI. Mercury levels before and after TOXECON treatment are monitored by a continuous emissions monitoring instrument developed at Thermo Electron Corporation in Waltham, MA, with NETL support. During initial operation, a production model of the instrument was stable and responsive to activated carbon injection and recorded significant mercury reductions. This project demonstrates the first full-scale commercial mercury-emission-control system for permanent operation at the We Energies Presque Isle Plant.

MODELING
SIMULATION

Modeling and Simulation

Modeling and simulation activities speed innovation by reducing the cost of developing new technologies and addressing problems unsolvable by traditional approaches. State-of-the-art research led by NETL incorporates high-speed computing into the laboratory's ongoing programs. This approach accelerates development and saves substantial program costs by reducing the number of experimental studies required to achieve an end.

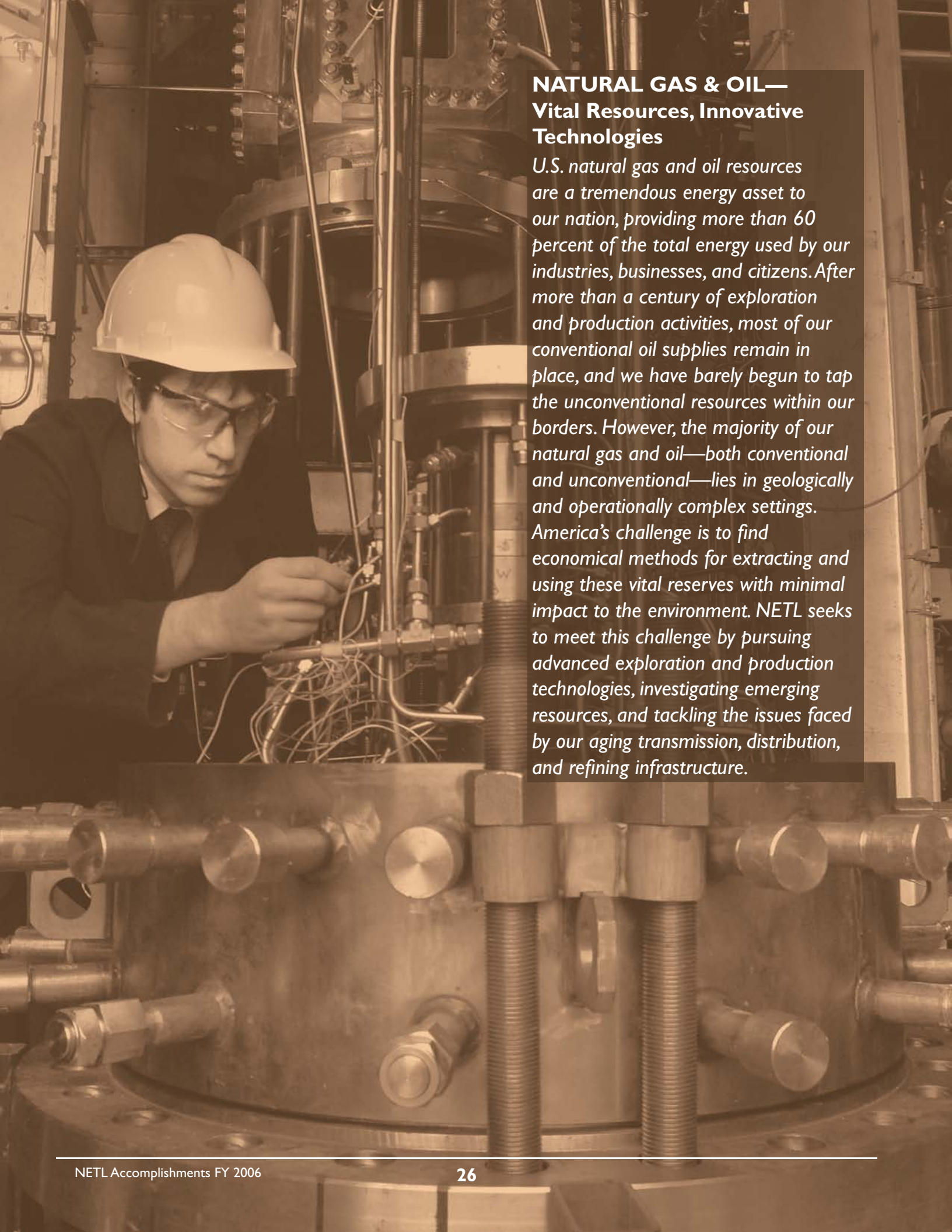
One Thousand Copies of NETL's Power Systems Financial Model Delivered—One thousand copies of the Power Systems Financial Model have been delivered worldwide to more than 900 organizations representing the financial, engineering, manufacturing, energy, academic, and governmental sectors. Originally developed within the Office of Fossil Energy and now managed by NETL, the spreadsheet-based discounted cash flow model has been provided free of charge since December 2001 as a tool for evaluating the economic feasibility of power plant investments. The most recent upgrade calculates levelized cost of electricity.

NETL Scientists Produce Prototype of Next-Generation Multiphase Flow Software—NETL researchers have developed a prototype of MFOAM, the next generation of multiphase flow software, which will greatly increase the fidelity and speed of simulating coal gasifiers and chemical looping systems. MFOAM combines the geometric fidelity available in commercial software with the source code access provided by NETL-developed MFIX (Multiphase Flow with Interphase eXchanges) software. MFOAM is based on the open-source framework OpenFOAM (Field Operation and Manipulation), instead of being developed as an entirely new program.

NETL Modeling Study Provides Insight into CO_2 Injection—A modeling study completed by NETL researchers provides insight into the "quarter-power mixing rule"—a calculation used to determine the thickness of displaced fluids—that applies when CO_2 is injected underground for enhanced oil recovery and carbon sequestration. Model simulations reveal why the longstanding empirical relation depends on properties of the injected and displaced fluids but not the underground medium. The work also contributes to a better understanding of how the characteristics of the fluid and rock interact to negatively impact the success of oil recovery or the sequestration capacity of a geological formation.

Advanced Geological Sequestration Model Accounts for CO_2-Induced Coal Swelling—Researchers at NETL developed and tested a three-dimensional swelling and shrinkage model to account for the effects of both CO_2 sorption and methane desorption on coal. The new model is an improvement over simpler one-dimensional models that consider only the effects of methane. The new shrinkage-swelling model was incorporated into a previously validated reservoir simulator, and the results showed that coal swelling can significantly reduce the amount of CO_2 absorbed by coal. Results of the study were presented at the 2006 International Coalbed Methane Symposium.

NETL Model Describes Electromagnetic Field Effects on Metal Oxides—In a paper appearing in the July 2006 *Journal of Physics and Chemistry of Solids*, NETL researchers have proposed one of the first atomistic models describing microwave-induced transport in ionic solids. The project, which was computational in nature, was performed at NETL in collaboration with the University of Pittsburgh. Microwave processing of materials, such as tungsten carbide with cobalt, produce functional materials with much higher strength and corrosion resistance than thermal- and pressure-treated materials. However, there is as yet little fundamental understanding of the underlying physics of microwave processing. This project advances the understanding of how electromagnetic fields affect metal oxide systems, which will contribute to the design of new types of materials as well as improved approaches in materials processing.



NATURAL GAS & OIL—Vital Resources, Innovative Technologies

U.S. natural gas and oil resources are a tremendous energy asset to our nation, providing more than 60 percent of the total energy used by our industries, businesses, and citizens. After more than a century of exploration and production activities, most of our conventional oil supplies remain in place, and we have barely begun to tap the unconventional resources within our borders. However, the majority of our natural gas and oil—both conventional and unconventional—lies in geologically and operationally complex settings. America's challenge is to find economical methods for extracting and using these vital reserves with minimal impact to the environment. NETL seeks to meet this challenge by pursuing advanced exploration and production technologies, investigating emerging resources, and tackling the issues faced by our aging transmission, distribution, and refining infrastructure.

GAS & OIL

Exploration and Production

The United States is the world's most thoroughly explored and developed oil and gas region. Because of this, costs associated with finding, developing, and producing our remaining domestic stores are also among the world's highest. Continued U.S. gas and oil production depends on locating fields among obscure geologic sources and recovering discovered resources as economically as possible. NETL is developing advanced exploration and production technologies to ensure that America's oil and natural gas resources are recovered to their fullest potential.

Leading Drill Pipe Manufacturer Announces Commercialization of Revolutionary Technology—Grant Prideco of Houston, TX, announced the commercial launch of its IntelliServ® Network. Developed with Novatek Engineering Inc., Provo, UT, in cooperation with NETL, the revolutionary built-in telemetry system uses an innovative coupler to transmit two-way, real-time data across pipe sections regarding conditions tens of thousands of feet below the surface. The network was also successfully interfaced with another oil and gas service company's downhole drilling- and formation-evaluation tools. Field tests showed that the network delivers critical downhole data to the surface up to 10,000 times faster than do currently available technologies.

Technology Helps America's Independent Producers and Small Businesses—Through the support of NETL's Stripper Well Consortium, Vortex Flow LLC of Englewood, CO, has developed and begun marketing seven new advanced-technology downhole and surface tools for the oil and natural gas service industry. Market sales for these tools have increased exponentially since their introduction. The Vortex Flow™ tools are based on a revolutionary fluid-dynamics system that accelerates the velocity of water and reduces the friction that causes pressure drops as fluids flow through a pipe, resulting in far greater efficiency when moving fluids. These tools have been proven to increase production and decrease maintenance costs. Over 200 Vortex Flow surface tools have been installed in gas-gathering and production-flow lines across the United States. Vortex Flow also won the Platts 2004 Global Energy Newcomer of the Year Award.

"Supercement" Project Isolates New Materials for Field Testing and Commercialization Potential—In an NETL-managed project, CSI Technologies of Houston, TX, identified two candidate supercements with a strong potential for reducing annular seal failures in deep wells (greater than 15,000 feet). Highly expansive Portland-based pre-stressed cement (patent pending) and non-Portland-based epoxy resin cement (patent pending) will both be the focus of field testing in high-temperature, high-pressure wells. The resin cement has already undergone more than 50 preliminary tests at a variety of temperatures and depths, with excellent results.

Improved Deep Seismic Imaging Technologies Offered Commercially—An NETL-managed project has yielded two new techniques for improving hydrocarbon detection in deep, complex reservoirs. Rock Solid Images of Houston, TX, developed technology that employs the degree of seismic wave lengthening or "attenuation" to track how thoroughly a reservoir is saturated with gas and the quality of the reservoir. Another company, 3DGeo of Houston, TX, developed a seismic processing methodology for ultradeep seismic imaging in the Gulf of Mexico. The methodology uses the most accurate technique—based on full three-dimensional wave equations—to optimize the seismic image quality for deep reservoirs, providing a more accurate subsurface model. These new seismic imaging and detection technologies will improve exploration success rates in deep areas of the Gulf of Mexico and in other deep environments.

Field Tests Demonstrate Efficiency of Microhole Drilling Technology—A project conducted by the Gas Technology Institute of Des Plaines, IL, has successfully tested a coiled-tubing drilling rig in the Niobrara Chalk formation, which includes the shallow, low-margin natural gas fields of Kansas and Colorado. The rig, developed under NETL's Microhole Initiative, demonstrated the efficiency of microhole drilling in the field tests. The U.S. Geological Survey has estimated the potential natural gas recovery from the Niobrara Chalk reservoirs at 340–2,100 billion cubic feet, with a mean recovery of 984 billion cubic feet.

Study Facilitates Longer Winter Operations on Alaska's North Slope—The Alaska Department of Natural Resources opened the lower foothills of state-owned land on the North Slope to oil and gas exploration activity on December 14, 2005—the earliest for that area since 1995. The decision was based on new snow depth and soil temperature criteria developed in the Tundra Travel Study, completed through an NETL-managed grant by the department's Division of Mining, Land, and Water. The new standard, based on snow cover and subsurface temperature measured at 16 sites, increased the winter operating season to 161 days, compared with 104 days in 2002. Data showed that early exploration activity allowed by the new standards in the prior year had no adverse impact on the tundra. Combined with improved ice road construction techniques, a longer operating season helps companies complete exploration wells within one season rather than two, significantly reducing overall costs.

Appalachian Basin Trenton-Black River Guide Completed—West Virginia University Research Corporation has developed a geological guide for the Trenton-Black River reservoirs in the Appalachian Basin (New York, Ohio, West Virginia, Pennsylvania, and Kentucky). The guide includes an integrated model for the origin of the Trenton-Black River reservoirs, with structural and tectonic analyses to identify possible favorable areas. The guide gives industry a solid basis for evaluating gas-bearing sandstone, shale, and dolomite formations targeted for potential drilling. Industry can ultimately develop these gas resources with optimum well design, location, and completion practices. Also, reservoir characterization studies completed for the Appalachian Basin can be applied to similar formations, such as the Barnett shale in Texas.

Microhole Tools Successfully Complete Field Tests—Two critical components of an advanced drilling, steering, and logging bottomhole assembly performed successfully during field tests in an Alaskan North Slope well operated by British Petroleum. The smart drill-bit steering motor—integrated with a high-performance downhole motor—and the magnetic propagation resistivity sensor that provides real-time information about the rock being drilled will aid in better directional control when drilling horizontal wells. The tools were produced by the INTEQ division of Baker Hughes Inc. of Houston, TX, as part of a cooperative agreement with NETL.

Gulf of Mexico Resource Assessment Completed—The University of Alabama completed an assessment of deep natural gas resources of the onshore interior salt basins of the north-central and northeastern Gulf of Mexico. The work was conducted at the University of Alabama in cooperation with NETL to assist in formulating advanced strategies that reduce the costs, risks, and environmental impacts associated with the exploration and recovery of deep natural gas resources. U.S. deep gas resources are considerable and have the potential to increase domestic fuel supplies in the near term.

Research Partnership Selected to Administer New Research Program—NETL has selected the non-profit Research Partnership to Secure Energy for America to administer the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Consortium. NETL's selection was made in accordance with specific directives in the Energy Policy Act of 2005 "to maximize the value of natural gas and other petroleum resources of the United States" by increasing resource supplies, improving the cost and efficiency of exploration and production, improving safety, and minimizing environmental impacts.

Success of Advanced Hydraulic Fracture-Mapping System in Texas Lowers Cost—Pinnacle Technologies Inc. of San Francisco, CA, successfully tested an advanced hydraulic fracture-mapping system with improved instrumentation that incorporates geophones and tiltmeters into one tool. The new combination tool, developed in a project managed by NETL, was placed in an observation well with conventional seismic mapping tools to monitor hydraulic fracture stimulation. The test showed that signals could be transmitted and received without interference—a breakthrough for the industry where, normally, sensors of different types must be placed in separate wells. Pinnacle Technologies plans to place the tool in a new wellbore by the end of calendar year 2007.

Measurement-While-Drilling Tool Proves Successful—Schlumberger Technology Corporation of Sugar Land, TX, has confirmed data transmission and mechanical functions of a prototype measurement-while-drilling tool in preliminary field tests conducted in Zapata County, TX. Completed in cooperation with NETL, this prototype tool represents a significant milestone in the development of a retrievable and reseatable high-temperature, high-pressure measurement-while-drilling tool with real-time continuous monitoring of inclination, seismic vibration, annular pressure, and gamma radiation. These functions equip the tool with the "look-ahead" capability needed to detect high-pressure gas zones earlier and to achieve optimum penetration rates for reduced operating costs.

Successful Telemetry System Provides Optimum Data at Great Depths—With support from NETL, E-Spectrum Technologies Inc. of San Antonio, TX, has developed and tested a wireless, electromagnetic telemetry system that could reduce the cost and risk associated with deep, high-temperature oil and natural gas drilling applications both onshore and offshore. The "through-the-earth" telemetry system matches an innovative signal receiver with an improved, high-power subterranean transmitter to provide low-cost, high-quality data without the need for a special drill pipe. Even in the noisy environment associated with well drilling, the unique receiver recovers very weak, ultralow-frequency signals from measurement-while-drilling sensors downhole near the drill bit or from wireless well logging.

NETL-Sponsored Study Prompts Interest in New Alaska Leases—Field work conducted in cooperation with NETL identified seeps in Alaska's Bristol Bay Basin as thermogenic gas, indicating the presence of oil. The project elevated interest in the first Alaska Peninsula area-wide oil and gas lease sale that drew two bids totaling $1.3 million on 37 onshore and offshore tracts. Prior to this study, most wells drilled on the Alaska Peninsula reported oil and gas shows, but none of the wells had produced. The Bristol Bay project was established to reassess this frontier basin and create a publicly available, modern basin analysis and hydrocarbon assessment. Results of this field work were published by the Alaska Division of Geological & Geophysical Surveys and presented at the Annual Convention of the American Association of Petroleum Geologists in June 2006.

High-Temperature Electronics Nearing Commercialization—Funded through NETL, Honeywell International Inc. of Plymouth, MN, accomplished a first-pass design success for a high-temperature field-programmable gate array (HT FPGA) and a nonvolatile memory capability, EEPROM (electrically erasable, programmable, read-only memory), that demonstrated its application at high temperatures (greater than 200 °C). The EEPROM concept is highly complex and, before this, had never been successfully realized. However, by coupling HT FPGA with HT EEPROM, downhole tools will no longer need to be pulled out of the well if power is lost during the drilling process or if drilling parameters change. The two chips together will reprogram the tool in place.

Design Specifications Completed for an All-Fiber-Optic Seismic Sensor—Paulsson Geophysical Services Inc. of Brea, CA, in a project managed by NETL, completed design specifications for a fiber-optic micro-electro-mechanical-system (MEMS) sensor for use in a borehole seismic array. As a one-of-a-kind sensor, the design is now ready to be built as a prototype. The MEMS sensor device is designed to operate at high pressures and high temperatures and to be manufactured with standard MEMS foundry processes and materials. The sensor device materials are matched with the interrogator-type fiber to minimize insertion losses, thermally induced stress and strain, and stray reflection losses. The sensor and uplink system are designed to operate at temperatures up to 400 °F and pressures up to 25,000 pounds per square inch to allow operation under conditions encountered in deep gas reservoirs. This design represents the first all-fiber-optic downhole seismic recording system, and unlike all other receiver strings, it would operate with no electronics in the borehole. This eliminates the need for temperature and pressure protection of the electronics, and it eliminates the need to send power downhole.

Project Yields New High-Strength, Faster-Drilling TSP Diamond Cutters—Working in cooperation with NETL, Technology International Inc. of Kingwood, TX, concluded a successful research project to develop unique thermally stable polycrystalline (TSP) diamond cutters with lower wear rates and greater fracture resistance than conventional polycrystalline diamond cutters currently used by industry. The ENDURUS™ cutters exhibit high-attachment shear strength—exceeding 50,000 pounds per square inch—and 36 percent increased impact strength, which together help maintain sharp cutting edges when exposed to hard, abrasive rock. These new cutters are expected to have a significant impact on new industry drill bits by reducing wear and lowering drilling costs.

High Water Production Problems Identified in Basin-Centered Formations—In an NETL-managed project, Advanced Resources International Inc. of Arlington, VA, worked with industry partners to sample and analyze formation water from several Mesaverde sandstone reservoirs. The data and results indicate that, due to the low saline content of reservoir waters, conventional analysis can result in false interpretations of well logs and lead to the erroneous identification of gas-bearing zones. The project developed a geochemical database of formation waters in tight gas reservoirs in western basins to aid in well-log interpretation. The final report will help the petroleum industry reduce completion costs in developing tight gas sandstone reservoirs by identifying gas-charged intervals more efficiently.

New Imaging Technology Accurately Tracks CO_2 Flooding for Enhanced Oil Recovery—Using theoretical analysis of CO_2-saturated fluid and rock properties, researchers at 4th Wave Imaging Corporation of Aliso Viejo, CA, have developed a new way to predict and quantify the effects of CO_2 on time-lapse seismic data recorded over porous reservoirs. The method can estimate injected CO_2 saturation distributions in subsurface oil reservoirs and remotely monitor injected CO_2 for safe storage and enhanced hydrocarbon recovery. Developed in cooperation with NETL, the technique is of immediate interest for extracting significant amounts of additional oil from reservoirs by improved recovery rates and optimized well patterns.

New Seismic Attenuation Methodology Locates and Quantifies Hydrocarbon Reservoirs—Researchers at Southwest Research Institute in San Antonio, TX, have demonstrated a new methodology for processing and interpreting surface and subsurface data at borehole scale to determine reservoir properties and predict hydrocarbon locations and volume estimates in complex geological environments. The technique is based on an understanding of how seismic energy dissipates through the ground. Developed in cooperation with NETL, the methodology will be of immediate interest to both small and large oil and gas producers for recovering additional resources from deepwater and other complex geological regions.

Project Improves Oil Reservoir Imaging Technology—Working in cooperation with NETL, investigators at Paulsson Geophysical Services produced a seismic data processing and interpretation framework that makes vertical seismic profiling (VSP) more accessible and usable. Built on widely used software and standard visualization toolkits, the higher-resolution VSP images will help oil companies more accurately determine known reservoir structure, locate previously overlooked reservoirs in large oil and gas fields, and lower the economic risk of producing smaller, more marginal fields.

Milestone Reached in Assessing Oil and Gas Resources in the Russian Arctic—As part of an interagency agreement with NETL, investigators at the U.S. Geological Survey, working in conjunction with Russian geophysicists, have produced a tectono-stratigraphic map as a basis for future USGS assessments. Knowledge of the potential resource base in the Arctic is necessary for industry to plan long-term investments in exploration and development. This knowledge is also useful to the U.S. government in formulating energy strategies that anticipate potential oil supply disruptions in politically unstable areas. Prospective hydrocarbon resources in the Arctic regions are immense—as much as one-fourth of the world's undiscovered oil and natural gas.

Methane Hydrate

The global storehouse of methane hydrate is vast, and, because it is widespread, methane hydrate will immensely impact the international balance of power in terms of energy supply. However, this "ice that burns" is also a threat to other deepwater drilling that passes through overlying marine hydrate deposits. Pioneering this frontier, NETL research is focused on improving our fundamental understanding of methane hydrate. With a solid knowledge base, computer models can be developed to accurately predict issues associated with climate, resource potential, seabed stability, and drilling safety.

NETL Funding, Expertise Support Discovery of Rich Gas Hydrate in Indian Ocean—The joint methane hydrate research program undertaken by the U.S. Geological Survey and India's Directorate General of Hydrocarbons discovered and closely examined one of the richest gas hydrate accumulations yet documented in the Bay of Bengal; confirmed the presence of methane hydrate-bearing systems within two major sedimentary basins in the Bay of Bengal; and documented in the Andaman Sea possibly the thickest and deepest gas hydrate stability zone yet known worldwide. The May 2–August 19, 2006, expedition included extensive drilling, coring, and shipboard data collection and analysis of methane hydrate-bearing sites. NETL funding provided equipment critical to the success of the project and allowed scientists from several national laboratories and the U.S. Geological Survey to conduct scientific analyses of samples and data. In addition, NETL staff contributed shipboard sedimentology and co-chief scientist expertise to the program.

Major Equipment Deployed at First Permanent Deep Marine Hydrate Seafloor Observatory—Researchers associated with the Gulf of Mexico Hydrates Research Consortium lead by the University of Mississippi's Center for Marine Resources and Environmental Technology completed an equipment-deployment cruise to Mississippi Canyon Block 118 in the Gulf of Mexico. The cruise was completed aboard the *Seward Johnson* with use of the manned submersible *Johnson Sea Link*. Managed by NETL, the activity deployed a major suite of novel array of visual, geochemical, geophysical, and biological monitoring sensors, a major step in establishing a first-of-its-kind, long-term seafloor hydrate monitoring station. In addition, the cruise served to provide site reconnaissance for deployment of infrastructure (system power, data collection system, and data transmission system), which, when completed, will serve as the backbone of the permanent seafloor observatory.

Computer Program Provides Insight into Gas Hydrates—An innovative simulation program developed with support from NETL's Methane Hydrate Research and Development program is helping identify future energy supplies. The first publicly available simulator of its kind, the TOUGH-Fx/Hydrate program is helping researchers and industry partners better understand the behavior of gas hydrates in the natural environment. The program models gas release, phase behavior, and flow of fluids and heat in complex geological media. The code can simulate production from natural methane hydrate deposits in the subsurface (i.e., in the permafrost and in deep ocean sediments), as well as in the laboratory. Since its public release, there has been considerable interest in the program, both domestically and abroad. Program licenses have been granted to 25 noncommercial organizations in 11 countries. Two major oil and gas companies have also purchased licenses—the first steps into industry application. Nearly 80 researchers are estimated to now have access to the TOUGH-Fx/Hydrate program.

Prestigious DOE Methane Hydrate Fellowship Program Announced—NETL has established a new fellowship program for methane hydrate researchers. Two-year appointments will support three to five fellows engaged in masters, doctoral, or postdoctoral programs that advance hydrate science either in industrial applications or academic research. The National Academy of Sciences will be responsible for creating and administering the program in close cooperation with NETL and other federal agencies participating in the National Methane Hydrate program. The fellowship program responds to requirements contained in Section 968 of the 2005 Energy Policy Act.

Research Equipment Assists in Successful Recovery of Gas Hydrate Cores and Samples—The Integrated Ocean Drilling Program, an international marine research drilling program funded primarily by the U.S. National Science Foundation and operated by Joint Oceanographic Institutions Alliance, completed a 37-day cruise off the western coast of Vancouver Island, BC, Canada. The purpose of the cruise was to investigate the occurrence of gas hydrate deposits. NETL provided infrared scanning equipment, temperature-pressure probes, x-ray linear scanners, and in-situ pressure coring devices, which were instrumental in successfully identifying and recovering gas hydrate samples for analysis. This location and similar areas off the northwest coast of the United States are known to contain significant marine gas hydrate deposits, which are under study for their gas resource potential, possible role in seafloor safety and stability, and role in climate change.

U.S. Naval Research Laboratory Completes New Zealand Cruise—The U.S. Naval Research Laboratory, in association with New Zealand's Institute of Geological and Nuclear Sciences, completed its latest cruise over the Hikurangi Margin located off the east coast of New Zealand's North Island. The purpose of the NETL-supported cruise was to characterize seafloor mound features over possible methane hydrate deposits by geochemical, thermal, and microbial analysis. Mounds were selected for sampling based on the presence of bottom-simulating reflectors, which indicated the probable presence of methane hydrate. About 30 core samples were collected for pore water geochemistry and microbial analysis, and 12 locations were sampled for heat flow.

ENVIRONMENTAL SOLUTIONS

Environmental Solutions

NETL works with its partners to protect the environment while developing efficient recovery systems to ensure adequate energy supplies. To achieve these goals, NETL develops new environmental technologies, pursues improvements to the regulatory process, and supplies the sound science needed for energy policy decisions. The results are lower costs and improved environmental protection technologies that will result in greater production of the nation's oil and natural gas. Current research is focused on produced water, federal lands access, and regulatory streamlining.

Microfiltration Proves Effective at Treating Produced Water—In an NETL-managed project, a mobile desalination unit developed by Texas A&M University holds the potential to produce freshwater from produced brinewater less expensively than transporting the water to a disposal area. The unit has been employed in several field tests on both gas-condensate wells and oil wells. Microfiltration removed all of the suspended solids while reverse osmosis removed more than 97 percent of the dissolved salts. The total projected cost for onsite desalination is less than $6 per 1000 gallons of freshwater produced, or $0.26 per barrel. By comparison, well operators pay $2.50 per barrel to transport produced brinewater to commercial disposal wells. For this demonstration, the landowner was given the freshwater at no cost. Under some circumstances, the freshwater represents income to the operator. Texas A&M expects to commercialize the technology in fiscal year 2007.

Process Enhances Quality of Water Produced with Coalbed Natural Gas—In a project funded by NETL and the Colorado School of Mines, Argonne National Laboratory and the Gas Technology Institute have used an integrated electrodialysis process for water treatment. The process is being evaluated for its potential to economically demineralize the large volumes of water associated with coalbed natural gas production, with the objective of generating water for beneficial use. The use of special membranes may allow the removal of problematic sodium while retaining needed minerals, such as calcium and magnesium. Results have shown greater than 90 percent produced-water recovery efficiency, 92 percent removal of dissolved solids, and modest energy input.

Onshore Platform Reduces Environmental Impacts—In conjunction with Texas A&M University and Noble Drilling Inc. of Sugar Land, TX, NETL is demonstrating the environmental benefits of an onshore drilling platform. Using offshore technology to minimize surface disturbance, the onshore platform will also minimize disturbance to wildlife and other key environmental resources. The project will document these reduced impacts in an effort to demonstrate that access to oil and gas resources in sensitive environmental settings can be developed without harm to ecosystems. The platform was first used on Alaska's North Slope to drill an experimental methane hydrate well.

ENERGY INFRASTRUCTURE

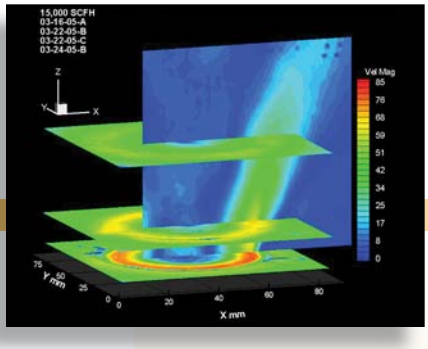
Energy Infrastructure

An extensive network of pipelines transports America's natural gas. As demand for natural gas increases, our current pipeline infrastructure will need to be technologically enhanced. The pipeline-compressor system must be sustained, but advanced delivery systems must also be developed. NETL's research is developing economical and environmental solutions to upgrade the nation's critical gas network as it adapts to rapidly changing natural gas markets.

NETL Generates Storage-Base Gas Report for the White House—NETL staff provided a report to the White House on the potential of drawing down storage-base gas in the wake of Hurricanes Katrina and Rita. Storage-base gas is the gas that must remain in storage to deliver the working energy needed by consumers at required rates and pressures; operators do not typically remove this gas. However, with the concern about possible gas shortages during the winter due to the impact of the hurricanes in the Gulf of Mexico area, NETL was charged with determining how much base gas could be used.

Prototype Gas Line Repair Tool Successfully Demonstrated—Product developers at Timberline Tool of Whitefish, MT, demonstrated a novel repair tool for permanently patching damaged or defective polyethylene natural gas pipelines laid underground. The demonstration, held at facilities owned by Southwest Gas Corporation in Tempe, AZ, and NICOR in Naperville, IL, produced a long-term evaluation of repaired pipe samples and revealed no adverse effects to the pipe. The results have generated offers from nearly a dozen U.S. utilities to host additional demonstrations of the prototype process. Developed in cooperation with NETL, the single-operator repair tool requires minimal excavation and would reduce to about 2 hours a repair that currently can take up to 14 hours to complete.

Newly Developed Tools Enable Operators to Identify Well Damage—Supported by NETL, Schlumberger Holditch-Reservoir Technologies of Pittsburgh, PA, developed software modules that use wellhead electronic flow measurement data to plot trends in well damage over time. Understanding when damage develops can help identify its cause so that operational changes can be made to prevent recurrence.



MODELING
SIMULATION

Modeling and Simulation

Modeling and simulation technologies play an important role in natural gas and oil recovery. Computer simulators refine models of oil and gas reservoirs to better predict how much oil and gas can be produced. Increasing a field's production involves numerical modeling to minimize the risk involved in development or enhanced recovery decisions. Additionally, modeling and simulation exercises provide some assurance to operators that investing in technologies such as chemical flooding or in-situ combustion will result in a successful venture.

Project Produces Advanced Well-Hole Drilling Simulator—Working in cooperation with NETL, researchers at Terralog Technologies USA of Arcadia, CA, produced a computer model and its associated algorithms that more accurately simulate the interactions between drill bit and rock formation, as well as the removal and transport of rock fragments by drilling fluids. By encompassing percussion and rotary motion in a drill bit, faster penetration with a straighter hole can theoretically be accomplished. The advanced simulator provides a tool for modeling a bit design that may change the theory into a reality and provide for more efficient and lower-cost drilling and exploration of hard-rock reservoirs.

NETL Models Fuel Variability Anticipated for U.S. Natural Gas Infrastructure—Using a combination of semianalytical formulas and computational fluid dynamics, NETL researchers are modeling how two gas streams with differing compositions will mix. The technique is being applied to understand how variations in pipeline gas composition resulting from gas supply changes or the introduction of liquefied natural gas may affect the operation of natural gas turbines and other end-use equipment, especially those tuned to produce very low emissions.

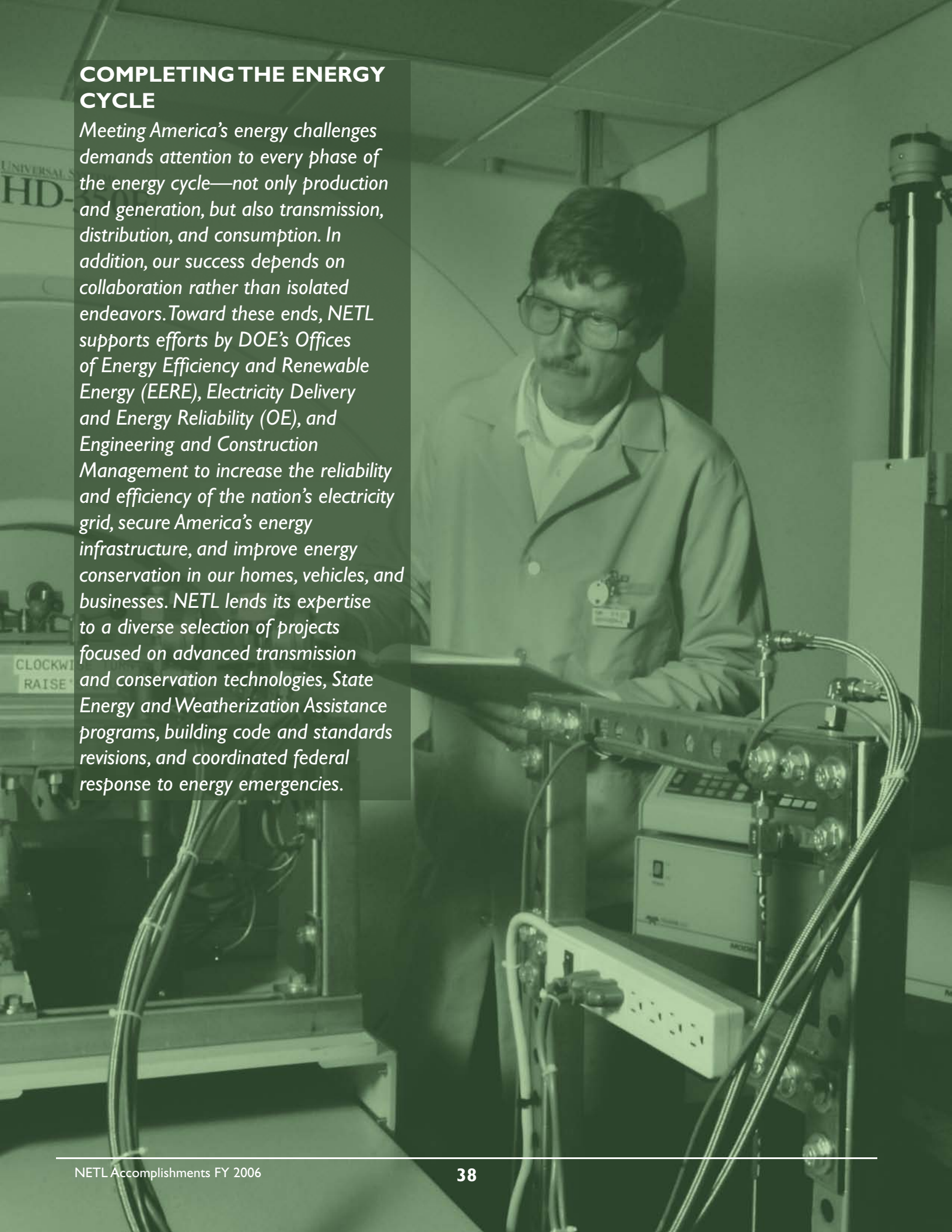
South Central Alaska Demand Study Completed—A final report assessing the potential natural gas demand from an Alaska spur pipeline was released publicly in June 2006. Produced by NETL, the report projects anticipated natural gas demand from existing and new industrial, commercial, and residential users in the Alaskan interior and south central Alaska. The demand would make economically viable the installation and operation of a spur pipeline extending from a proposed North Slope-to-Lower 48 natural gas pipeline. The study will serve as a basis for estimating potential in-state natural gas demand and evaluating the viability of locating heavy-gas-use industries in Alaska.

New Reservoir Simulation Software Released—The latest version of Miscible Applied Simulation Techniques for Energy Recovery (MASTER 3.0) is now publicly available for modeling enhanced oil recovery processes. The new version includes a foaming option for the Water Alternating with Gas process and makes overall usability improvements. Developed at the New Mexico Institute of Mining and Technology in cooperation with NETL, MASTER is a widely accepted computer simulator used to model a depleted oilfield and the production expected to result from the injection of water, CO_2, natural gas, solvents, or other liquids or gases of known physical properties.

Internal Revenue Service Uses Software Developed at NETL—Internal Revenue Service agents are using Geo-Engineering Modeling through Internet Informatics (GEMINI) software developed in cooperation with NETL at the Kansas Geological Survey where it is publicly available. The GEMINI website receives approximately 12,000–18,000 visits per month by domestic and international engineers who utilize the interactive programs designed to model and interpret rock properties, wireline logs, seismic data, and reservoir performance for predicting remaining petroleum reserves. The production decline curve module is of particular interest at Internal Revenue Service field offices that are conducting oil and gas reserve audits.

COMPLETING THE ENERGY CYCLE

Meeting America's energy challenges demands attention to every phase of the energy cycle—not only production and generation, but also transmission, distribution, and consumption. In addition, our success depends on collaboration rather than isolated endeavors. Toward these ends, NETL supports efforts by DOE's Offices of Energy Efficiency and Renewable Energy (EERE), Electricity Delivery and Energy Reliability (OE), and Engineering and Construction Management to increase the reliability and efficiency of the nation's electricity grid, secure America's energy infrastructure, and improve energy conservation in our homes, vehicles, and businesses. NETL lends its expertise to a diverse selection of projects focused on advanced transmission and conservation technologies, State Energy and Weatherization Assistance programs, building code and standards revisions, and coordinated federal response to energy emergencies.



OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY

Mining Project Demonstrates Improved Recovery of Fine-Size Coal in Commercial Coal Preparation Plant—Researchers from CQ Inc., Blairsville, PA, demonstrated commercial viability for the GranuFlow™ coal-fines-recovery process in tests conducted at the Jim Walter Resources Inc. No. 7 Coal Preparation Plant in Brookwood, AL. GranuFlow was developed to capture high-quality fine-sized coal that normally would be landfilled or impounded. The process, patented by NETL, uses a bitumen emulsion to displace water from fine coal, agglomerating the coal prior to dewatering, thereby improving coal recovery. In addition to improved energy recovery and reduced waste at the plant, economic estimates forecast an increase in annual profits from $600,000 to $3,000,000 (for coal market values ranging from $50–$100 per ton). The work is being conducted as part of EERE's Mining Industry of the Future.

Improved Particle Separation Reduces Coal and Mineral Processing Costs—A project team led by researchers from Virginia Polytechnic Institute and State University demonstrated the enhanced capabilities of new hydraulic separator designs for mineral classification and concentration. The designs are based on fluidized-bed technology, and data show that they substantially improve the performance of sizing and concentration circuits for both mineral and coal producers. This results in significantly higher plant production, improved product quality, lower operating costs, and reduced environmental impacts. Full-scale prototypes were installed and commissioned at one coal site and two phosphate sites. Based on the performance improvements, phosphate producer The Mosaic Company, Plymouth, MN, procured four additional units, and KenAmerican Resources Inc. installed a unit purchased for its coal cleaning plant near Central City, KY. The feasibility of retrofitting the technology to existing column flotation cells at relatively low cost is under evaluation. The project was undertaken in cooperation with NETL as part of EERE's Mining Industry of the Future.

Nanoscale Building Blocks Yield Breakthrough for Organic Light-Emitting Diodes—In cooperation with NETL, researchers at Pacific Northwest National Laboratory have devised a method for building inherently small blue-light-emitting organic molecular fragments into larger molecules that can be processed into stable thin films. The objective of this research is to improve the performance of blue organic light-emitting diode (OLED) devices, the limiting factor in OLED device performance. The breakthrough will enable development of an entirely new class of higher-efficiency OLED devices appropriate for solid-state lighting applications. Use of this fabrication method produced an OLED that demonstrates record short wavelength light emission (335 nanometers) at a remarkably low operating voltage as well as a record performance for blue OLED devices. This research was reported in the weekly journal *Applied Physics Letters*.

White OLEDs Achieve Record Efficiency—Working in cooperation with NETL, collaborators at the University of Southern California, the University of Michigan, and Universal Display Corporation in Ewing, NJ, developed a new OLED that achieves lighting efficiency 50 percent greater than a standard incandescent light bulb and 20 percent greater than the previous OLED record (24 lumens per watt at a face brightness of 500 candelas per square meter). The new device employs a combination of red-and-green-phosphorescent and blue-fluorescent dopants that overcome many of the shortcomings (e.g., short lifetime and poor color stability) of standard OLEDs.

New Benchmarks Achieved in Light-Emitting Diode Efficiency and Brightness—The new white XLamp® 7090 power light-emitting diode (LED) released by Cree Inc. delivers 85 lumens per watt, providing brightness and efficiency suitable in general applications, such as street, industrial, and parking garage lighting. This next-generation XLamp is the first device based on Cree's breakthrough, a gallium-nitride-based EZBright™ LED. The XLamp and EZBright product lines were developed at Cree's Santa Barbara Technology Center with NETL support.

Advancements Lead to Record White OLED Milestone—Through Small Business Innovative Research grants administered at NETL, Universal Display Corporation and its partners at Princeton University and the University of Southern California demonstrated WOLED™—a white OLED with a power efficacy of 40 lumens per watt at 1,000 candelas per square meter (similar output to a 100-watt incandescent bulb). The team is targeting a 100-lumen-per-watt white OLED by 2010, which is well in line with the DOE multiyear projection for white OLED light sources. Warm white emission from the new OLEDs has a color-rendering index of 70, closely resembling the color of incandescent lamps, which WOLEDs are targeted to replace in the lighting industry.

NETL Helps Industry Lower Solar Cell Cost—A cooperative effort between NETL and Dow Corning, Midland, MI, has realized a milestone in the development of solar energy technology—a solar-grade silicon derived from metallurgical silicon that exhibits good solar cell characteristics. NETL scientists worked with Dow Corning to develop a method for producing solar-grade silicon from low-cost feed sources. Since January 2006, a number of tests using low-cost silica, higher-purity carbon briquettes, and woodchips have been performed to produce acceptable, high-purity silicon for photovoltaic use. The process developed was very efficient in producing silicon with excellent power and electrode consumption.

Laser Ignition Multiplexing Demonstrated—As part of an NETL-managed project under EERE's Distributed Energy program, Colorado State University researchers successfully demonstrated the multiplexed fiber-optical delivery of laser ignition sparks in laboratory tests. Spark distribution occurred among 6 channels at 1,800 revolutions per minute—an important milestone toward multicylinder engine applications. Researchers are building a system for installation on a full-size multiple-cylinder engine.

Heavy Duty Truck Engine Project Reaches Major Milestone—In cooperation with NETL, product developers at Cummins Inc. of Columbus, IN, demonstrated steady-state operation of its 15-liter, 6-cylinder ISX diesel engine at 50 percent brake thermal efficiency while producing no more than 0.2 grams of NO_x or 0.01 grams of particulate matter per brake horsepower-hour. These low emissions, achieved through advanced combustion techniques, comply with 2010 levels set by the U.S. Environmental Protection Agency for class 8 vehicles. In addition to this success, the engine also extracts and converts otherwise wasted thermal energy into electricity via an expansion turbine/generator. The electricity is then used to power an electric motor connected to the vehicle's driveline or flywheel to improve the engine's thermal efficiency by approximately 16 percent.

Projects Will Reduce Petroleum-Based Fuel Consumption—NETL awarded more than $26 million in cost-shared projects for reducing national transportation fuel consumption by up to 30 million gallons per year. Sixteen new projects will be managed by NETL under the Clean Cities program of the EERE Office of FreedomCAR and Vehicle Technologies:

- Thirteen projects were awarded to install blending and refueling infrastructure for dispensing E85, biodiesel, and other alternative fuels at more than 200 new or converted service stations in 28 states and Washington, DC.
- A single project for placing highway-certified propane-powered vehicles in service was awarded under the program's Incremental Cost for Alternative Fuel Vehicles area.
- Two projects in the program's Idle Reduction Training and Awareness for School Districts were awarded for the development and implementation of comprehensive school bus driver, student, faculty, and parent education and awareness programs designed to reduce or eliminate engine idling.

Weatherization Assistance Program Grants Total $100 Million—NETL manages 23 Weather Assistance Program grants to state agencies for conserving energy while improving health and safety in homes of low-income citizens. Federal appropriations for fiscal year 2006 resulted in the weatherization of approximately 36,000 homes and reduced heating bills by 31 percent and overall energy bills by an average of $358 per year. Each dollar of DOE investment in weatherization returns $3.71 in energy- and non-energy-related benefits. Across the nation, the Weatherization Assistance Program generates 8,000 jobs and decreases U.S. energy use the equivalent of 15 million barrels of oil annually.

OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY

NETL Assists OE in Responding to National Energy Emergencies—NETL supports OE in emergency preparedness and response by leading the Visualization and Modeling Working Group (VMWG), a national laboratory consortium that conducts predictive and actual impact analyses during exercises and emergencies. These analyses enable decision makers to position staff and energy resources in advance of an anticipated catastrophic event. Over the fiscal year, the team provided support to headquarters for forest fires, floods, and tropical storms, as well as permit locations for electrical transmission line border crossings of both Canada and Mexico. VMWG's efforts included these specific examples:

- In response to 2006 hurricane season national emergencies, NETL federal staff were deployed to Washington, DC, and impacted areas in the Gulf of Mexico to provide DOE's Emergency Support Function 12 (ESF 12) assistance. ESF 12 helps restore the nation's energy systems following a major disaster, emergency, or other significant event requiring a federal response. ESF 12 also provides direct coordination with all other departmental response elements.
- State Energy Assurance Guidelines were prepared and published to assist state and local governments in responding to emergencies involving energy assets and infrastructure. Addressing petroleum, electricity, natural gas, and other energy sources, the guidelines serve as a benchmark for states when preparing or updating their Energy Assurance Plans, which then may be incorporated into the states' Emergency Response Plans.

NETL Responds to Energy Emergencies and Infrastructure Disruptions—NETL's Energy Infrastructure and Security Research Group (EISRG) coordinates DOE's response to energy emergencies and assists with recovery efforts from disruption in the energy infrastructure. EISRG also integrates the infrastructure analysis expertise of various DOE laboratories during emergency operations associated with disaster response efforts. By deploying resources and providing vital information, EISRG improves the ability of government agencies and the energy sector to prevent, prepare for, and respond to hazards, emergencies, natural disasters, or any other threat to the nation's energy supply. EISRG realized the following 2006 accomplishments:

- Developed and deployed geographic information system capability to senior-level ESF 12 responders, enabling the responders to quickly evaluate locations and attributes of the energy infrastructure. This capability was also implemented at OE Headquarters.
- Performed an in-depth analysis of the Gulf of Mexico focused on production and delivery system connectivity. The analysis resulted in an increased capability for recovery response after a disruption as well as the building of a predictive capability for shut-in production up to 36 hours ahead of a hurricane.
- Initiated development of an Energy Infrastructure Library to assist in national and regional analysis of energy supplies; national emergencies involving energy assets and emergency preparedness, training, and exercises. NETL also developed 42 Asset Summaries for the library. The summaries include essential data and analyses for the nation's most important energy infrastructure facilities.
- In collaboration with Carnegie Mellon University, began developing a model to evaluate the transportation of fuels used in power generation. Phase 1 will provide the team with a capability to track coal from source to generation. Although the model is under development, the team was able to provide analysis and expertise on the nation's coal infrastructure for rail congestion in the Powder River Basin and perform high-level analyses for the impact of the "stand-down" order issued in West Virginia due to a series of coal mining fatalities.

Modern Grid Initiative Team Commences Field Tests and Holds Regional Summits—To accelerate modernization of the nation's electricity grid, NETL and OE have established the Modern Grid Initiative (MGI). MGI aims to develop a shared national vision of a modern grid's principal characteristics and key technologies by analyzing performance and technology gaps, developing a national concept of the grid, encouraging industry consensus, and coordinating regional technology integration projects. The MGI team realized two primary accomplishments this fiscal year:

- Began field-testing integrated suites of advanced grid technologies using part of Allegheny Power Company's electric grid in Morgantown, WV. The main focus of the test is to deploy advanced sensors, switches, and control technologies to either prevent outages or, if outages do occur, isolate them to a smaller number of customers than would be affected under current grid conditions. Additional results are expected to demonstrate significantly improved reliability and power quality as well as better protection of the region's electricity distribution circuits. Successful integration would also more fully utilize the capacity of existing infrastructure, leading to significant overall cost savings.
- Conducted five regional summit meetings to engage a broad range of stakeholders in creating a shared vision of the future electricity grid in the United States and to identify key issues with each region's electricity grid. Results of the summits show general acceptance of the approach the MGI team is taking and the principal characteristics and key technology areas it has identified as critical to achieving grid modernization. Stakeholder feedback focused on the need for changes to state regulations, a clearer federal policy, improved consumer education, stronger business cases, and the establishment of performance metrics for the grid.

Low-Swirl Injector Technology Demonstrated for Industrial Turbines—Low-swirl injector combustion technology was demonstrated in a Solar Taurus 70 natural-gas-fired industrial turbine in a project managed and sponsored by NETL. Patented at Lawrence Berkeley National Laboratory, the low-swirl injector is a simple, robust, cost-effective device that can increase system efficiency while maintaining ultralow emissions of NO_x and carbon monoxide. The technology is already commercialized for industrial heaters.

Novel Injector Emits Ultralow NO_x—Combustion testing on the scale of a model C65 microturbine from Capstone Turbine Corporation, Chatsworth, CA, indicated that the injector produced NO_x levels below those specified in the California Air Resources Board 2007 regulation. NETL manages the project in support of OE's Distributed Energy program.

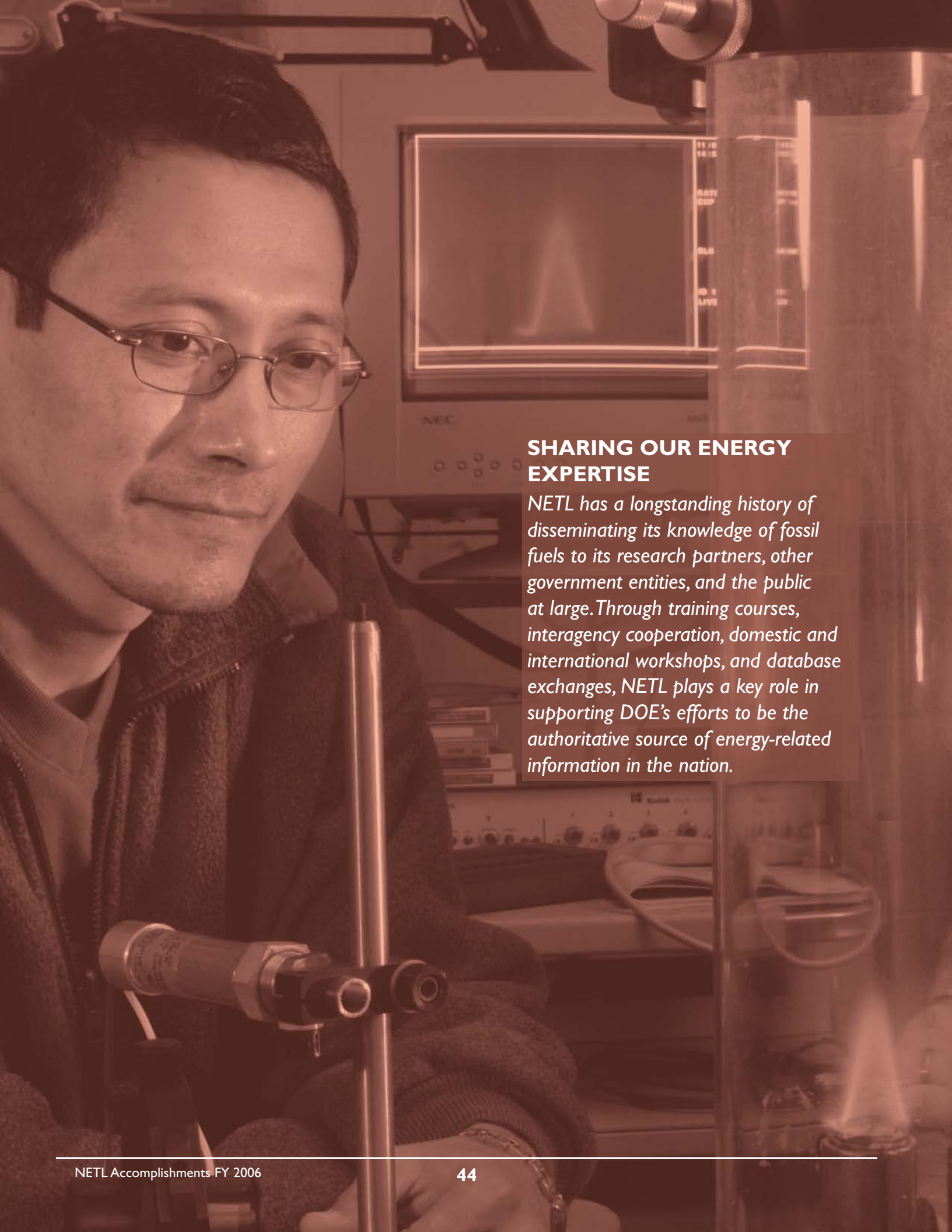
Composite Material Significantly Improves Gas Turbine Performance—Installation of a full set of silicon carbide-based shrouds in the first stage of a GE Energy F-class gas turbine has resulted in significant performance improvement at a JEA utility in Jacksonville, FL. The project was undertaken to assist GE in developing a more energy-efficient turbine with industrial applications. Invented at the GE Global Research Center in Niskayuna, NY, the Melt-Infiltrated Ceramic Matrix Composite permits a higher operating temperature compared to that of metal components, enabling higher gas-turbine power output and efficiency with lower emissions and longer intervals between scheduled maintenance outages. The project is managed by NETL in support of OE's Distributed Energy program.

Combustor Liner Achieves Longevity Milestone—Solar Turbines Inc. of San Diego, CA, has achieved a record 23,000 hours of operation in ongoing tests of an oxide-based ceramic matrix composite outer-combustor liner. The liner was developed by GE Global Research Center in Niskayuna, NY, and is installed on a Centaur 50 industrial gas turbine at a Chevron Corporation cogeneration site in Bakersfield, CA. Solar Turbines is interested in using advanced combustor liners to increase the lifetime of gas turbine components that operate at the higher temperatures necessary to build on the 38.5 percent efficiency now achieved in Solar Turbines's Mercury 50 product. The project is managed by NETL under a cooperative agreement between GE and DOE.

Advanced Reciprocating Engine Systems Offered Commercially—Caterpillar Inc., Peoria, IL, and Waukesha Engine in Waukesha, IL, are offering their Advanced Reciprocating Engine Systems for commercial sale, and Advanced Reciprocating Engine Systems technology totaling 2.3 gigawatts is operating in the field. The technology was developed through research and development support from NETL's Advanced Reciprocating Engine Systems program. With 44 percent efficiency, advanced reciprocating engine systems offer greater overall efficiency than standard reciprocating engines, which operate at 38 percent efficiency.

OFFICE OF ENGINEERING AND CONSTRUCTION MANAGEMENT

External Independent Reviews Conducted—NETL provided technical oversight and contracting for 39 external independent reviews for various programs and projects within DOE at a cost of $9.7 million. External independent reviews are required for DOE projects with a value over $100 million and are conducted by teams of external subject-matter experts who provide evaluations and recommendations on the projects.



SHARING OUR ENERGY EXPERTISE

NETL has a longstanding history of disseminating its knowledge of fossil fuels to its research partners, other government entities, and the public at large. Through training courses, interagency cooperation, domestic and international workshops, and database exchanges, NETL plays a key role in supporting DOE's efforts to be the authoritative source of energy-related information in the nation.

SHARING

Study Shows Promise for Using Coal to Support Industrial Activity in Alaska—In July 2006, NETL completed its "Beluga Coal Gasification Study (Phase 1)." Among the study's findings, economic replacement of natural gas with coal-derived synthesis gas can provide an alternative feedstock for the petrochemical industry. This technology could provide industry with an incentive to consider development of Cook Inlet, AK—the last tidewater coal asset in the United States open to year-round shipping. The Beluga study used Agrium Inc.'s nitrogen facility in Kenai, AK, as a case study for investigating the feasibility of integrated gasification combined cycle technology. Based in part on NETL's study, which complemented Agrium's concurrent investigations into the same technology, Agrium plans to develop a world-class low-emission coal-gasification facility to supply feedstock to its Kenai facility. Excess CO_2 from the facility would be used for enhanced oil recovery in Cook Inlet, potentially doubling oil production from the area.

NETL Assists in Solving HUMVEE Rollover Problem—NETL is collaborating with the Army Research Laboratory, Picatinny Arsenal, International Titanium Powder of Rockport, IL, and vehicle manufacturers to develop a weight-reducing modification that would help prevent armored HUMVEEs from overturning during combat maneuvering. The modification would replace steel-based armor with a combination of titanium alloy and transparent alumina, making the vehicle less top-heavy by halving the weight in the turret area and simultaneously providing the turret gunner greater protection from roadside bombs. NETL scientists produced prototype titanium plates from a low-cost powder manufactured using a novel process invented at Argonne National Laboratory. These plates were then ballistically tested at the Army Research Laboratory's Ballistic Research Laboratory located in Aberdeen, MD. Results from this classified testing were forwarded to the Picatinny Arsenal for use in the fabrication of the transparent alumina/titanium armor prototypes for field testing.

NETL Assists in Meeting Challenge Posed by Improvised Explosive Devices—A cast-steel armor produced by a lost-foam method variation first developed by NETL in the 1990s holds great promise for protecting heavy convoy vehicles and personnel from improvised explosive devices and other roadside bombs. The material is already used for applications at the U.S. Army Tank and Automotive Command located in Warren, MI. Army Research Laboratory personnel in Aberdeen, MD, have used the castings on targets during ballistics tests, and new castings were produced with fabrication modifications to enhance the ballistic performance of the plates.

NETL Provides Critical Information During Hurricane Recovery—NETL personnel served as members of the DOE Hurricane Recovery Monitoring Team. The team monitored the operational status of the natural gas supply industry within the Gulf of Mexico region as the industry recovered from the effects of Hurricanes Rita and Katrina. Specific emphasis was placed on generating a daily status report used to brief the White House relative to the damage assessments and repair schedules for platforms, processing plants, and pipelines. The team also provided an estimate of the combined daily Gulf of Mexico gas production, based upon analysis of the best available information from Gulf of Mexico operators.

NETL Staff Member Supports Iraq Study Group—NETL engineer Thomas L. Ochs served on an advisory panel that provided a report to the Iraq Study Group with ideas and recommendations for developing the oil, natural gas, refining, transportation, power generation, and electrical distribution components of Iraq's economy. Ochs has worked for more than two years, first with the Coalition Provisional Authority and then with the Iraq Reconstruction Management Office, to advise and support the Iraqi Ministry of Electricity. He continues to support the Iraq Reconstruction Management Office and the State Department.

SHARING

NETL Joins U.S. Department of State in Training Foreign Service Officers—For the seventh consecutive year, NETL staff organized a week-long course that equips Foreign Service Officers and other U.S. governmental foreign-affairs employees with a basic understanding of coal- and power-related technologies and associated issues. This cradle-to-grave training covers coal formation, mining, preparation, combustion, gasification, emissions control, by-product utilization and disposal, and carbon capture and storage. Natural-gas-based power generation using gas turbines and distributed energy systems was also covered. Participants attended a variety of speaker seminars and toured several facilities, including coal mines, coal- and natural-gas-fired power plants, and a solid-oxide fuel cell research and production facility. In addition to the Department of State, this year's participants represented the National Geospatial Intelligence Agency and the U.S. Departments of Commerce and Energy. The course complements a similar one on oil and gas exploration and production organized by the Petroleum Equipment Suppliers Association with support from the Office of Fossil Energy.

SPOTLIGHTING OUR CONTRIBUTIONS

As a testament to its effectiveness in advancing fossil energy technologies, NETL and its researchers received awards and recognition from a wide variety of stakeholders in 2006. Our research findings were featured in leading technology journals, and our scientists earned patents for their innovations and breakthroughs. This external recognition affirms NETL's commitment to overcoming America's energy challenges.

SPOTLIGHT

AWARDS

Three Products Earn Prestigious R&D 100 Awards—Three technologies developed with support from NETL were selected by an independent judging panel and the editors of *R&D Magazine* as among the 100 most technologically significant products introduced into the marketplace over the past year. Dubbed the "Oscars of Invention," R&D 100 awards are recognized by industry, government, and academia as proof that a company has commercialized one of the most innovative ideas of the year. An R&D 100 award provides an important boost to technologies just entering the marketplace.

- Sandia National Laboratories, High Power Battery Systems Company in Nizhny Novogorad, Russia, and General Atomics in San Diego, CA, developed a solid-state battery containing fluoride instead of lithium for high-temperature (250 °C) operation. Unlike lithium batteries, which are considered a hazardous waste and have a high risk of explosion when used in high-temperature oil and natural gas drilling operations, the fluoride-based battery is operationally and environmentally safe, even at temperatures exceeding conventional design limits. Sandia National Laboratories and General Atomics teamed up to develop a manufacturing process and packaging for this proven battery technology. The device can greatly improve the reliability of power supplied to electronic components used in measurement-while-drilling tools. The project was part of a federal laboratory partnership funded through NETL.
- The Data Transmission System™, developed by Stolar Research Corporation of Raton, NM, upgrades conventional and coiled drilling equipment with a two-way data-communications capability using modulated radio waves inductively coupled to the skin of the drill pipe through loop antennas. By relaying to surface operators a more complete picture of drill-hole conditions in less time than competing technologies, drilling efficiency and accuracy are increased and operational costs are reduced. The technology was developed in cooperation with NETL with support from the Office of Fossil Energy and the Industrial Technologies program of EERE.
- The NETL-funded EXPLORER pipeline inspection robot is a long-range, tetherless, self-powered robotic system for the live, visual inspection of natural gas and other pipelines of 6–8-inch diameter. The system was created through research by NETL, the Robotics Institute at Carnegie Mellon University, NYSEARCH/ Northeast Gas Association, Polytechnic University, California Institute of Technology's Jet Propulsion Lab, and ULC Robotics in Deer Park, NY. Because the system is wireless, it can negotiate around bends, trees, and other obstacles. It is the first robotic system capable of providing semiautonomous visual inspection, as well as nondestructive evaluation of the natural gas pipeline infrastructure. It also requires only a minimum number of access points into the pipeline. Additional enhancements, currently underway, will permit the platform to carry advanced sensors capable of long-range inspection of many currently inaccessible natural gas distribution pipelines.

Technology Transfer Achievements Recognized—The Federal Laboratory Consortium (Mid-Atlantic Region) presented 2006 Excellence in Technology Transfer Awards to two NETL researchers for innovative efforts in transferring new commercially relevant computational tools to the private sector. The awards were presented to Dr. Stephen Zitney for the Advanced Process Engineering Co-Simulator (APECS) and to Dr. Madhava Syamlal for Multiphase Flow with Interphase eXchanges (MFIX). Both of these software packages were developed at NETL by federal researchers in collaboration with private industry and the university community. The awards were presented at the Consortium's annual Mid-Atlantic Regional Meeting on September 21, 2006, in Cumberland, MD.

Manager Chosen as Fellow of The Electrochemistry Society—Dr. Mark Williams, NETL Fuel Cells Technology Manager, was elected Fellow, The Electrochemistry Society, for his work in electrochemical energy conversion technology development, especially fuel cells. The society conferred its highest honor, and the first-of-its-kind for NETL, October 19, 2005, at the 208th Meeting of The Electrochemistry Society in Los Angeles, CA. Dr. Williams helped establish the Office of Fossil Energy's Solid State Energy Conversion Alliance and the High-Temperature Electrochemistry Center located at Pacific Northwest National Laboratory. These programs are expected to become major funding sources for high-temperature electrochemistry research over the next decade. With a membership of more than 8,000 scientists, engineers, and corporations worldwide, The Electrochemistry Society has become the leading society for solid-state and electrochemical science and technology.

SPOTLIGHT

Project Receives the Generation Technology Transfer Award from the Electric Power Research Institute—Great River Energy of Elk River, MN, along with several industrial partners, received the Generation Technology Transfer Award for coal-drying technology demonstrated at its Coal Creek Station in Underwood, ND. Based on lignite-drying research sponsored by NETL, the technology uses the power plant's waste heat to reduce lignite moisture so that more power can be produced with less fuel. The 54-month demonstration was conducted in cooperation with NETL. This coal-drying technology could potentially be applied to more than 100 gigawatts of installed capacity of units burning high-moisture coals, offering efficiency improvements and emissions reduction to the U.S. power industry.

Project Selected for EPA Award—An ash-beneficiation technology developed in cooperation with NETL at the University of Kentucky's Center for Applied Energy Research was presented with the U.S. Environmental Protection Agency's (EPA) "Special Recognition Award in Innovation." The technology, developed through DOE's Clean Coal Power Initiative, was tested at the Ghent Generating Station in Carrollton, KY. The award was presented by the EPA's Coal Combustion Products Partnership in Atlanta, GA, at the Annual Congress of the National Recycling Coalition in October 2006.

Project Earns Society of Petroleum Engineers Award—The Society of Petroleum Engineers presented Dr. Hao Cheng with the Cedric K. Ferguson Medal in recognition of his significant contribution in hydrocarbon distribution simulation. Dr. Cheng's work draws on research to identify the location and distribution of remaining and bypassed hydrocarbons—a resource that could amount to 100 billion barrels of recoverable oil in domestic oilfields. The research was completed in cooperation with NETL at Texas A&M University's Texas Engineering Experiment Station at College Station, TX. The medal is awarded to members under age 33 who conducted significant technical research the previous year. The Society of Petroleum Engineers presented the medal at its annual meeting and banquet on September 25, 2006, in San Antonio, TX.

NO_x-Control Technology Among Kirkpatrick Award Finalists—Oxygen Enhanced Combustion, developed by Praxair Inc., Danbury, CT, was among five finalists for the prestigious Kirkpatrick Chemical Engineering Achievement Award. Developed in cooperation with NETL, the technology replaces a small part of burner combustion air with oxygen, which is injected into the critical area of the flame. The technology can lower the cost of NO_x control by as much as 40 percent compared to selective catalytic reduction, and can accomplish this without substantial boiler modifications or the hazards of ammonia. The technology is operating in two pulverized coal boilers at Pulpwood Glatfelter Company's manufacturing facility in Spring Grove, PA. It is particularly well-suited for retrofitting older, space-constrained units with capacities of 300 megawatts or less, which represent 66 percent of U.S. boilers.

NETL Wins Best Paper Awards—The American Society of Mechanical Engineers selected two technical papers authored by NETL researchers Eric Liese, George Richards, Edward Robey, and David Tucker for Best Paper Awards. The papers were prepared for the International Gas Turbine Institute Meeting held in conjunction with the 2005 American Society of Mechanical Engineers Turbo Expo in Reno, NV, and the awards were presented in Barcelona, Spain, at the May 2006 American Society of Mechanical Engineers Turbo Expo. The awards recognize leadership in combustion-dynamics and hybrid-systems research and development demonstrated by NETL researchers in collaboration with West Virginia University.

Collaborator Receives Society for Mining, Metallurgy, and Exploration Award—Dr. Gerald Luttrell received the 2006 Percy W. Nichols Award for notable achievement in the field of solid fuels. Dr. Luttrell is a professor at Virginia State University and Polytechnic Institute. He is also associated with the Center for Advanced Separation Technologies—a university consortium cooperating with NETL in long-term, high-risk research and development of technologies that can be used by the U.S. mining industry to create new products, reduce production costs, and meet environmental regulations. Named for a pioneer in the science and technology of fuels utilization, the Percy W. Nichols award is presented annually to a member of the American Society of Mechanical Engineers or the Society for Mining, Metallurgy, and Exploration.

Collaborator Honored—Alaska Engineering Societies named Shirish Patil the 2005 Engineer-of-the-Year at the annual award banquet for the Alaska Society of Professional Engineers in February 2006. The University of Alaska Fairbanks professor is a key principal investigator for several projects managed by NETL in viscous oil production, carbon sequestration, and methane gas hydrates. Collaborating with industry and academia, the NETL-University of Alaska Fairbanks partnership seeks to overcome technical, economic, market, and environmental barriers to the deployment of efficient, clean, and affordable energy production systems in arctic climates and sparsely populated areas in Alaska.

NOTEWORTHY PUBLICATIONS

Project Produces Leading Paper for National Science Publication—The leading manuscript for the January 2006 *American Association of Petroleum Geologists Bulletin* discusses the distribution, character, and relative age of fractures in the Brooks Range of northern Alaska as yielding important clues toward discovering hydrocarbons there. The peer-reviewed paper is based on a study completed in cooperation with NETL at the University of Alaska Fairbanks to increase the knowledge of fluid migration and trap formation in the Colville Basin—the next logical area for exploration as Prudhoe Bay ages.

Research Provides Cover Story for Scientific Publication—The cover of the December 1, 2005, issue of *The Journal of Physical Chemistry B* features an image developed by computational and experimental work performed by NETL in collaboration with the University of Pittsburgh. The accompanying article describes the chemical adsorption of alkanethiol onto a gold surface at ultralow temperatures. The alkanethiol-gold system holds great promise for tailoring the chemical functionality of a surface. Such systems are of interest in a variety of fossil energy applications, including improved lubricants and fuel cell applications.

Metallography Featured in *Chemical & Engineering News*—The work of NETL metallographer Paul Danielson is highlighted in the May 2006 issue of *Chemical & Engineering News* as part of an article titled "The Gorgeous Inside Stories of Metal." The cover featured one of Danielson's images, and a gallery of his work was presented on the *Chemical & Engineering News* website. Utilizing a combination of polishing and chemical-etching techniques, Danielson produces spectacular color images of alloy surfaces as viewed through an optical microscope. These images reveal a wealth of scientific information about localized changes in chemistry and structure resulting from manufacture or use.

Researchers Author Chapter for *Catalysis*—NETL researchers Dushyant Shekhawat, Dave Berry, and Todd Gardner, in collaboration with Dr. James J. Spivey of Louisiana State University, have authored a chapter for *Catalysis*, Volume 19, published by the Royal Society of Chemistry. The chapter provides a comprehensive review of the available literature in the area of catalytic reforming of liquid hydrocarbon fuels for fuel cell applications. Other chapters in this volume cover biofuels, Fischer-Tropsch and nitride catalysts, kinetic theory, and methane decomposition. The book series publishes worldwide reviews of current interest in various fields involving catalysis.

Computational Study on Flexible Carbon Nanotubes Published—A paper published by NETL authors Karl Johnson and David Sholl in the February 9, 2006, *Journal of Physical Chemistry B* demonstrates that membranes containing single-walled carbon nanotubes could transcend the current limits of flux and selectivity. The study shows that flexibility (thermal vibrations) would not impact transport diffusion in carbon nanotubes as significantly as expected, providing impetus to continue development of membrane materials that incorporate nanotubes as the active transport component. Such membranes could be the key to the noncryogenic production of oxygen or nitrogen from air, hydrogen separation technologies, and the economic capture of CO_2 from power plant flue gas.

Catalytic Production of Hydrogen Research Published—A paper detailing computational chemistry performed at NETL on catalytic decomposition of hydrogen sulfide was published by Elsevier in its August 2006 issue of *Surface Science*. Authored by researchers Erik J. Albenze and Abolghasem Shamsi, the work focuses on hydrogen sulfide dissociation on bimetallic nickel-molybdenum catalysts as a way of producing hydrogen from the hydrogen sulfide associated with natural gas, oil, and brine water.

Thermal Imaging Research Published in Scientific Journal—A paper by NETL authors Stephen Beer, Steven Woodruff, T. Mike Dera, and Mark Tucker describing an infrared thermal imaging system for temperature measurement was published in the February 2006 issue of the peer-reviewed journal *Review of Scientific Instruments*. Compared to commercial imagers, the system is less expensive and more accurate for combustors, fuel cells, and other high-temperature devices with optical access.

Research on Hydrogen-Storage Material Published—NETL researchers have found that nitroprussides—a class of easily produced micro-porous powders with stable crystalline structures and high surface areas—have a higher affinity for hydrogen than physical adsorbents, such as carbons. This research, which contributes to the development of structures with still higher heats of adsorption and greater hydrogen capacities, is summarized in a paper appearing in the April 27, 2006 issue of the *Journal of Physical Chemistry B*.

Combustion Expert Coauthors Article for *Mechanical Engineering*—Editors of *Mechanical Engineering* approached NETL to learn how researchers are addressing the combustion intricacies associated with a growing diversity of fuel choices driven by market and regulatory forces. In response, NETL's George Richards, along with Tim Lieuwen of the Georgia Institute of Technology, authored the article "Burning Question," featured in the March 2006 issue of the magazine, a monthly publication of the American Society of Mechanical Engineers. The article highlights the search for cleaner ways to tap the nation's vast coal resources while meeting ever-tightening environmental requirements, including a reduction in CO_2 emissions.

PATENTS

Metal-Based Sorbent Method Captures Mercury in High-Temperature Gas Streams—NETL scientists Evan Granite and Henry Pennline were issued a patent for a process that facilitates mercury extraction from flue/fuel gas utilizing regenerable metal-based sorbents at both elevated and ambient temperatures. Metals such as iridium, ruthenium, palladium, and platinum can be dispersed on an inert support to increase surface area per gram of active sorbent. Alloys of these metals can be formulated to capture mercury from many industrial effluent gas streams that are highly corrosive. The process is particularly suited for coal gasification because it is effective for capturing mercury at various process stages with negligible effect on thermal efficiency.

New Process Recovers Energy from Cool Compressed Gas—A newly patented method could help offset the cost of capturing and transporting CO_2 emitted from power plants—a procedure which currently increases the cost of gas-stream processing. NETL researchers Thomas Ochs and William O'Connor patented an invention that exploits the waste gas stream in power plants for energy recovery by using economical heat sources. The innovation uses the hot exit cooling water from a power plant condenser (or other comparable low-quality heat source) to heat the high-pressure waste gas stream. The compressed warm gas is then recycled back through multiple turbines to produce additional energy.

Innovative Hybrid System Combines a Direct-Fired Reciprocating Engine with a Fuel Cell—By reversing the usual sequence, the high-temperature fuel cell in this NETL-developed system processes fuel that has been sufficiently reformed in a heat engine to obtain synergistic benefits, such as significantly improved fuel efficiency, power density, and environmental performance of the engine, as well as startup, load-following, and portability characteristics of the fuel cell. The system was invented by Rodney Geisbrecht and Norman Holcombe of NETL.

NETL Patents Ultrasonic Method for Analyzing Three-Phase Slurries at Elevated Pressure and Temperature—NETL researchers Yee Soong and Arthur Blackwell invented a way to measure the concentration and particle-size distribution of a slurry in a reactor operating under conditions of high temperature and pressure. The approach uses a cooling chamber to maintain environmentally sensitive ultrasonic transducers at ambient conditions while attached to opposite sides of the reactor. Slurry parameters can be determined from the velocity and attenuation of sound waves between the transducers, which are isolated from the hostile conditions within the reactor yet experience no signal distortion or loss.

Patent Issued for Combustion Sensor Codeveloped at NETL—Capitalizing on the wealth of information provided by flame ionization, NETL researchers Kelly Benson, Jimmy Thornton, George Richards, and Douglas Straub, in collaboration with Woodward Governor Company of Fort Collins, CO, invented and patented a novel sensor to detect combustion instability. The aim of the project was to develop a sensor for monitoring the hydrogen combustion and deployment of NETL-patented combustion control and diagnostics technology. Deployment of this novel sensor technology is expected to facilitate improved performance and lower emissions in advanced power systems.

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

2175 University Avenue South
Suite 201
Fairbanks, AK 99709
907-452-2559

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

One West Third Street, Suite 1400
Tulsa, OK 74103-3519
918-699-2000

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681

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