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

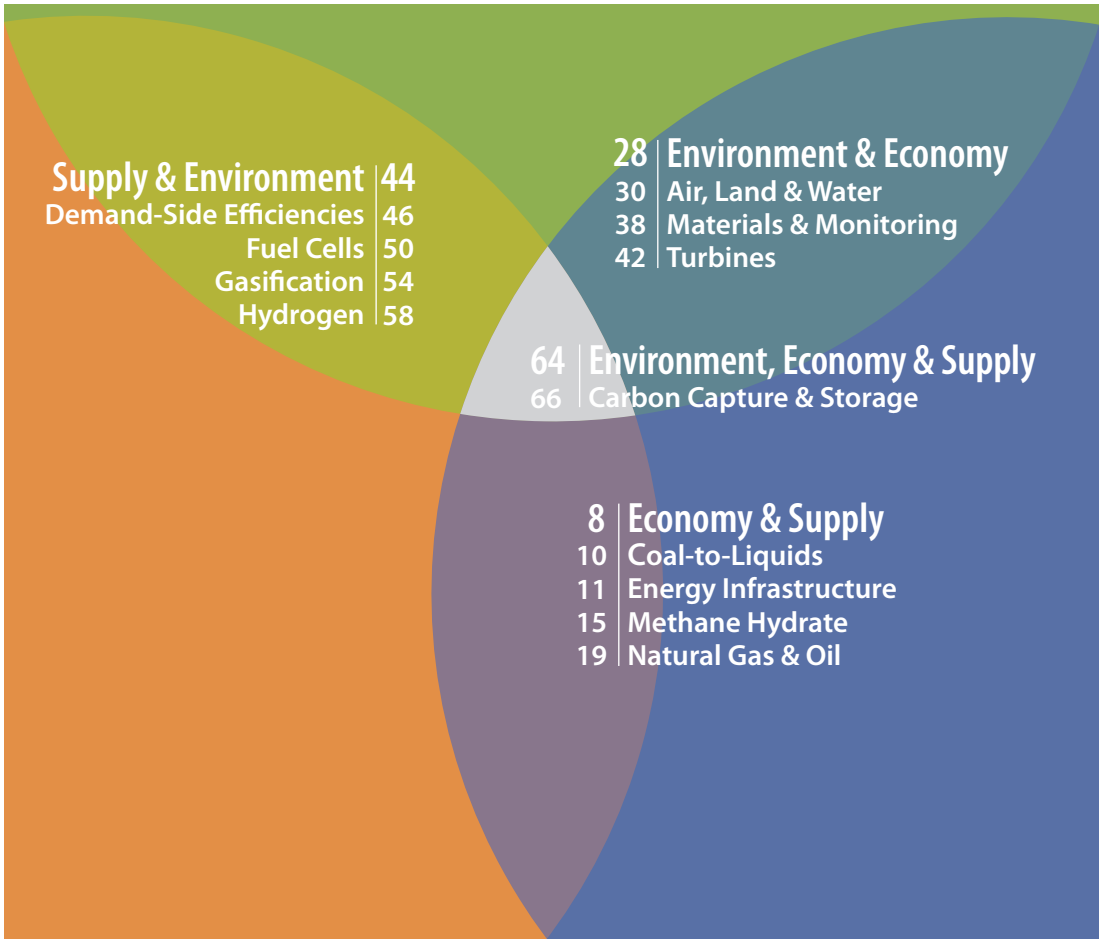
2007 NETL Accomplishments

07

Mission

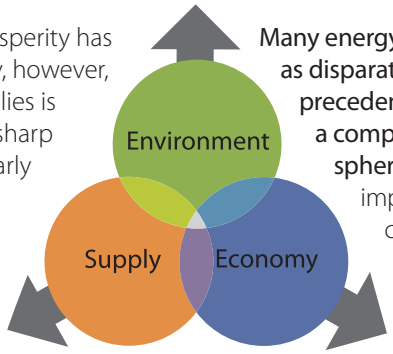
NETL implements research, development, and demonstration programs to resolve the environmental, supply, and reliability constraints of producing and using fossil resources.

Contents



Advancing Technology That Benefits Society

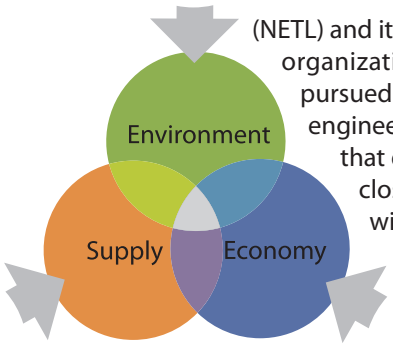
For 200 years, America's economic prosperity has been built on its energy bounty. Today, however, increased competition for global supplies is leading to constrained resources and sharp escalations in energy prices—particularly in oil and natural gas. This presents a formidable challenge to our nation. Secure, reliable energy supplies at sustainable prices are essential to U.S. stability and growth.



Energy affordability and supply security make up two of the three overarching issues characterizing today's energy situation in the United States. The third is environmental quality. As a nation, we strive to act responsibly by reducing the impact of energy production and use on our nation's air, land, and waterways.

Many energy strategists regard these arenas as disparate challenges, one of which takes precedence over the other two. This produces a competitive tension that pulls the spheres in opposing directions. Significant improvements may be realized in the chosen area, but the others are left stagnant, or even severely damaged. An effective approach to meeting our nation's energy needs depends on our giving equal attention to all three requirements, seeing them as a single issue that demands our immediate attention.

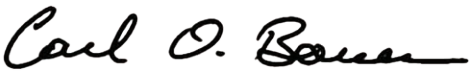
Since its inception in 1977, the Department of Energy (DOE) has consistently incorporated these areas into its strategic plans for public energy research and development. In support of the Department's efforts, the National Energy Technology Laboratory



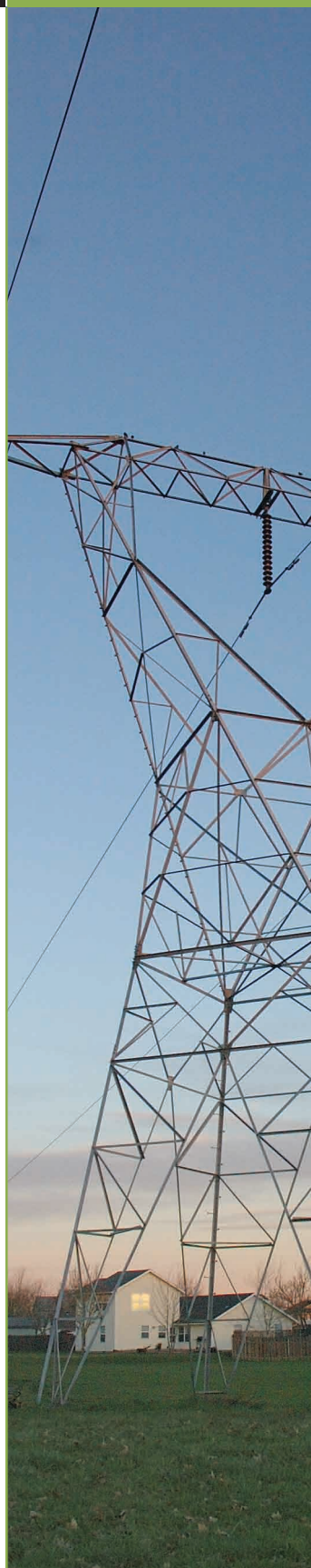
(NETL) and its predecessor organizations have pursued science and engineering solutions that drive the circles closer together, with the ultimate goal of finding tools and processes that hit the center mark by addressing all three areas concurrently.

Whether our efforts are geared toward carbon management, enhanced oil and natural gas recovery, advanced materials, energy efficiency, or methane hydrate, we are finding economical solutions to environmental challenges, the means to expand our domestic energy sources without driving up costs, and methods for extracting resources with minimal impact to the environment.

America's energy challenges are formidable, but they are also surmountable. The accomplishments NETL achieved in fiscal year 2007 have created sound building blocks with which we can 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



NETL Innovation

The National Energy Technology Laboratory (NETL) is a U.S. Department of Energy (DOE) national laboratory—one of the "crown jewels" of American science. Through basic research and technology development, the laboratory supports the Energy Department's mission to advance the national, economic, and energy security of the United States.

The laboratory has five sites that span the Nation. NETL sites in Pittsburgh, Pa., and Morgantown, W.Va., conduct a broad range of research to increase the supply of traditional energy resources, improve the efficiency and environmental performance of power generation plants, and help end users to conserve energy. Researchers at NETL's site in Albany, Ore., focus on developing advanced materials for use in the energy industry. Sites in Tulsa, Okla., and Fairbanks, Alaska, address challenges unique to those energy-rich regions. All five locations share the same goal: to advance science and technology for a clean, secure energy future.

As the only national laboratory owned and operated by the Energy Department, NETL is unique in how it conducts business and in the relationships it forms with industry, academia, research organizations, and other national laboratories. First and foremost, the laboratory conducts cutting-edge research and development (R&D) through its Office of Research and Development. About one quarter of NETL's 1,200 Federal and contractor employees are directly engaged in research with industry, government, and academic partners to solve problems that would otherwise become barriers to commercializing power systems, fuels, and environmental and waste-management technologies.

As part of the executive branch of government, NETL's research goals are exclusively determined by National needs. NETL's approach to onsite research provides—

- A flexible, focused research effort that addresses national energy R&D needs.
- Impartial evaluation of new concepts and materials and expert authoritative review of external R&D proposals.
- A venue for universities, other Federal agencies, and other research organizations to participate in collaborative research.
- In-depth expertise in technologies and research methodologies for program planning and management purposes.
- Hands-on energy technology training for postdoctoral researchers, graduate students, visiting professors, and undergraduate students.
- A wide-ranging set of collaborations with regional and national universities on energy research issues.

Complementing NETL's onsite research, the laboratory supports R&D that is conducted by other organizations. In these cases, NETL sets the direction for critical energy and environmental R&D, then solicits and selects projects for funding through a competitive process. Like NETL research conducted at the laboratory's multiple sites, these "outside the fence" projects help provide the foundation for America's national security and our way of life.

Much of this NETL-managed work is concentrated in the NETL Project Management Center. Offices within DOE, and a wide variety of other government organizations, routinely seek out the center's project management capabilities and tap into its expertise in creating public-private partnerships. Organizations that the Project Management Center supported in fiscal year 2007 included—

- DOE's Office of Electricity Delivery and Energy Reliability.
- DOE's Office of Engineering and Construction Management.
- DOE's Office of Environmental Management.
- DOE's National Nuclear Security Administration.
- U.S. Department of Defense, Defense Advanced Research Projects Agency.
- U.S. Environmental Protection Agency.
- U.S. Department of Homeland Security.

Other NETL-supported research arises through programs within the laboratory's Strategic Center for Coal and its Strategic Center for Natural Gas and Oil. The Strategic Center for Coal supports technology development to improve the performance of the existing fleet of coal-fired power plants and to build the near-zero-emissions coal plant of the future. Examples include technologies to improve power plant efficiency, reduce air emissions, recycle coal utilization byproducts, and fight climate change by capturing carbon dioxide from flue gas and storing it safely and permanently in terrestrial biosystems and geologic formations. The Strategic Center for Natural Gas and Oil invests in projects that will lead to improved natural gas and oil production and use. An example is the center's efforts to realize the potential of methane hydrate, an untapped resource that, globally, contains more energy than all of the world's coal, oil, and conventional natural gas combined.

In addition to conducting and supporting far-reaching R&D, NETL conducts studies of complex, large systems—such as industrial or ecological processes—and the interactions among those systems, including social, economic, political, regulatory, technological, design, and management institutions. This work is housed in NETL's Office of Systems, Analyses, and Planning. Published results of the studies provide strategic information and analysis to the policy makers who are responsible for providing direction and funds to ensure that America has a continuing supply of clean, affordable energy.

Evaluating a national laboratory's achievements can be difficult. Even measuring the success of a single research project or program can be elusive. Thomas Edison famously said, "If I find 10,000 ways something won't work, I haven't failed. I am not discouraged, because every wrong attempt discarded is another step forward." But ultimately, Federal energy R&D must lead to results that benefit the American people.

One measure of NETL's success this fiscal year is the seven R&D 100 Awards that NETL and NETL-supported technologies earned in 2007. These prestigious awards, which the Chicago Tribune dubbed "the Oscars of invention," are given annually to the 100 most technologically significant new products to hit the market during the year. According to R&D Magazine, which selects the winning technologies, the goal of the award is "to spotlight major breakthroughs—products and processes with the capacity to improve the standard of living for many people."

This year, three awards went to technologies developed by NETL scientists: a process to produce titanium products at significantly lower cost, software that can reduce the cost and time needed to develop and commercialize advanced coal technologies, and a surveying technique to help prepare abandoned oil and gas wells for carbon storage. Four more technologies that were honored with R&D 100 Awards were developed with support from NETL.

By almost any measure, NETL made great strides in fiscal year 2007, as the accomplishments outlined in the following pages will show. But the laboratory's scientists, engineers, economists, and policy analysts won't rest on their laurels. NETL is constantly looking to the future to anticipate energy issues that will arise and to provide analysis that will be important to the decision makers who establish our national energy research directions.

NETL's progress and successes this year establish the foundation for the laboratory's continuing efforts and new initiatives—all of which are designed to help America and the world address and solve the energy challenges we all face.

Economy & Supply

Ensuring Ample, Affordable Energy

Not only do Americans need an ample supply of energy, we need energy to remain affordable. Through a variety of programs, NETL is fostering technologies that will help maximize our domestic energy supplies, modernize and protect our energy delivery system, enhance national energy security, and keep energy costs in check. NETL is finding ways to transform our nation's vast coal resources into liquid fuels. We are designing strategies to modernize the U.S. electricity delivery system. We are developing advanced exploration, drilling, and recovery technologies for America's oil and natural gas resources. And we are conducting methane hydrate exploration in both marine and Arctic environments.

Economy & Supply

Ensuring Ample, Affordable Energy

Coal-to-Liquids—Reducing Import Reliance

As the United States seeks to reduce its dependence on imported liquid fuel supplies, the option of producing liquid fuels via coal gasification is becoming more and more attractive. Using America's most abundant energy resource in such a manner can help our nation combat rising oil prices, resolve the national security issues associated with imported fuels, and transform our vast coal reserves into a clean source of energy. A further consideration is coal-and-biomass-to liquids. This approach gasifies coal with biomass feedstock, with the added benefit of mitigating CO_2 emissions via carbon capture and storage.

Coal-to-Liquids Facilities Show Potential to Address National Concerns—An analysis conducted by NETL shows that coal-to-liquids (CTL) facilities processing America's most abundant energy resource could provide a winning option for solving economic and national security concerns related to U.S. dependence on imported liquid fuels. NETL explored the feasibility of a commercial-scale, stand-alone CTL facility that would produce approximately 50,000 barrels per day. Using coal gasification and Fischer-Tropsch synthesis, the facility would convert high-sulfur bituminous coal to diesel fuel, liquid naphtha products, and power for export to the U.S. electric grid. NETL also assessed smaller CTL plants that are similar in scale to a 600-megawatt IGCC plant and may provide better financing opportunities for developers, potentially making them more feasible for commercial development. Producing 10,000 barrels per day, both a small-scale stand-alone CTL facility and a CTL facility co-sited with an IGCC facility were evaluated. The economics of these commercial-scale and small-scale processes would provide a reasonable return on investment and payback period of about five and seven years, respectively, at full plant capacity.

Environmentally Friendly Jet Fuel Can Be Produced from Coal and Biomass—Teaming with the U.S. Air Force, NETL released a study that examines the feasibility of producing 100,000 barrels per day of jet fuel from a feedstock of approximately 4,500 tons of high-sulfur bituminous coal and nearly 630 tons of corn stover. The base-case configuration would produce nearly 7,500 barrels per day of diesel or aviation jet fuel, more than 3,500 barrels per day of liquid naphtha products, and 11.1 megawatts of electricity that can be exported to the grid. An environmentally friendly energy producer, the conceptual plant is based on best available control technology guidelines for sulfur, NO_x, particulate matter, and mercury. In addition, CO_2 will be captured and compressed for injection into a pipeline terminating at a sequestration site. Using this performance baseline, the analysis shows how a coal-and-biomass-to-liquids plant with carbon capture and storage could not only capitalize on using domestic energy resources to shelter against rising petroleum and natural gas prices, but also mitigate output of CO_2 as compared to conventional petroleum processes.

Novel Nanocatalysts Synthesized at NETL—NETL researchers have generated nanoscale iron particles and analyzed them as part of initial experiments using a state-of-the-art surface-analysis-and-imaging system that can image individual atoms to determine the elemental composition of the first few atomic layers of surfaces. Creating this nanocatalyst is significant for fossil energy applications, especially CTL, because iron is an important catalyst in that process. The fundamental project focused on fabricating iron and iron-oxide on a gold surface to produce model nanocatalysts. Success of this project can lead to better understanding of materials for Fisher-Tropsch applications, the process used to convert gasified CTL fuels.

Report Shows Feasibility of CTL Plant in Alaska—The NETL Arctic Energy Office issued a July 2007 report titled "Alaska Coal Feasibility Studies—Healy Coal-to-Liquids Plant," affirming the technical feasibility of siting a Fischer-Tropsch CTL plant at the Usibelli Coal Mine near Healy, AK. This interior Alaska site near the electric grid is serviced by rail and could supply coal for more than 50 years of plant operation. The proposed plant would process 4 million tons of coal per year, export 42.5 megawatts of electrical power to the grid, and supply Alaska refineries with 14,600 barrels per day of low-sulfur feedstock for producing diesel, jet fuel, and gasoline. Preliminary financial analysis indicates that if the plant output sold for $64 a barrel, a 12 percent return-on-investment could be realized without tax or production incentives. The project was highlighted in the October 29, 2007, issue of Petroleum News, a weekly newspaper covering the oil and gas industry in Alaska and northern Canada.

Energy Infrastructure—Providing Definitive Solutions

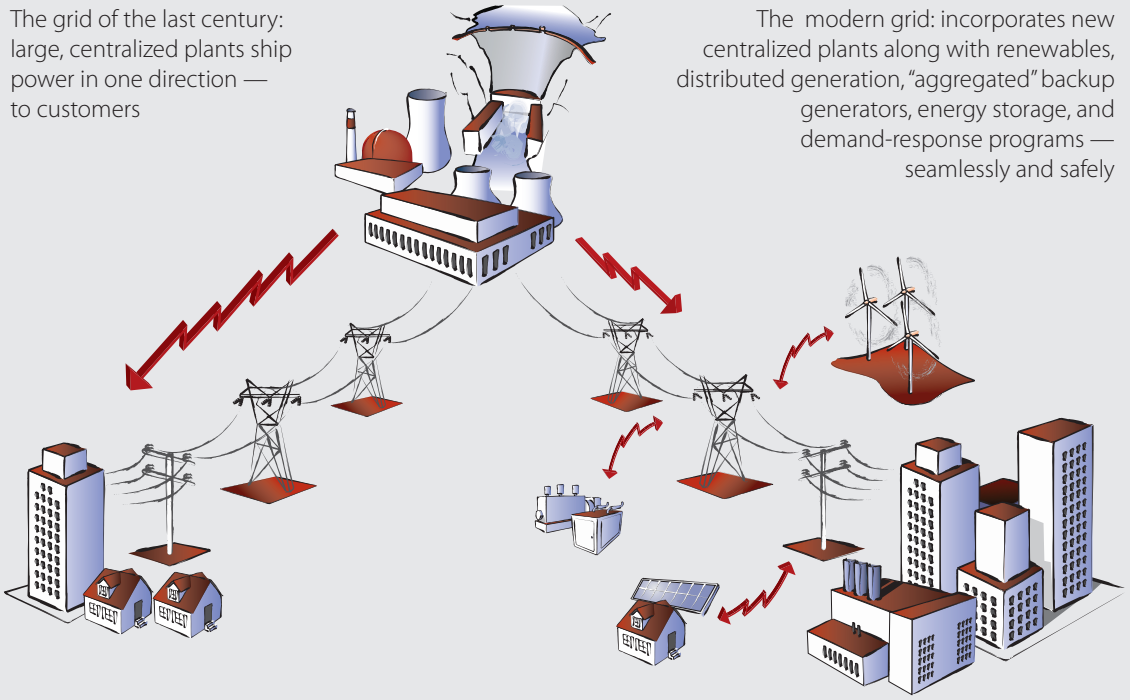
Meeting America's energy challenges demands attention to every phase of the energy cycle—not only production and generation, but also transmission and distribution. We must ensure the reliability, integrity, and security of our nation's electrical transmission grid and natural gas pipelines, and we must coordinate the federal response to natural and man-made emergencies NETL lends its expertise on public and private efforts to build and protect the complex energy infrastructure on which our economy depends.

NETL Completes SEQURE™ Survey for Gas Leaks—Utilizing a helicopter outfitted with the R&D 100 Award-winning SEQURE™ technology—developed and trademarked by NETL—more than 1,500 line kilometers of magnetic and methane data were acquired from Naval Petroleum Reserve Number 3 (NPR-3), a 15-square-mile oilfield near Casper, WY. With boom-mounted magnetometers and a sensitive detector for identifying methane and other light hydrocarbons, the aircraft looked for leaks in the 100-year-old oilfield infrastructure. Preliminary analysis pinpointed locations of numerous well-type anomalies—early indications of survey success. Final processing of the data will result in geographic information system (GIS) maps with anomalous magnetic features and methane-data overlays, for use at the Rocky Mountain Oilfield Testing Center, the survey's sponsor.

Economy & Supply

The grid of the last century: large, centralized plants ship power in one direction — to customers

The modern grid: incorporates new centralized plants along with renewables, distributed generation, "aggregated" backup generators, energy storage, and demand-response programs — seamlessly and safely



NETL's Modern Grid Strategy: Powering the Twenty-First Century Economy

Our nation's economy and security—indeed, our lifestyles—depend on the quality of our electrical grid. But our electricity transmission and distribution system is aging, and its antiquated 1950s- and 1960s-vintage design no longer meets the needs of our twenty-first century economy. In fact, unreliability in the grid causes annual business losses of about $100 billion, due to power-quality events and power interruptions—the economic equivalent of having an August 14, 2003, Northeast blackout every three weeks. The cost of electricity is increasing as well, largely due to transmission congestion and lack of diversity in fuel and power generation options. The inefficiency of our electrical grid results in increased greenhouse gas emissions as more fossil fuel is burned than should be needed to produce and deliver electricity to the customer. Furthermore, the United States is lagging behind other regions of the world that are rapidly modernizing their electrical grid, most notably Europe, China, India, and the Middle East. This poses a challenge for U.S. companies to economically compete in the global marketplace.

To counter these disturbing trends, NETL launched a Modern Grid Strategy (MGS) project in 2005 to assist the nation in accelerating the modernization of our nation's electricity grid by confronting the barriers that slow progress. The MGS project has four main initiatives addressing these barriers:

- Aligning the power industry and its stakeholders to reach a consensus on the values, functional characteristics, key technology areas, and metrics of a modern grid—also known as the "smart grid."
- Encouraging large-scale field demonstrations of integrated suites of smart grid technologies to validate the business case for moving to a grid that will benefit all of us—utilities, consumers, and society. In most cases, the benefits of a smart grid outweigh its costs by at least four to one.
- Assisting state regulators, if requested, in implementing the regulatory and policy changes that are absolutely necessary for a move to a smart grid.
- Sharing successes of smart grid implementation to encourage further deployment.

The MGS project has been initiated at the right time in our nation's history. We know that the electric power industry needs to expand the grid and replace aging components so that current and future demand for electricity can be met. Here are some of the MGS accomplishment highlights for 2007:

- The MGS team identified and facilitated the general adoption of seven functional characteristics and five key technology areas of a smart grid by the electric power industry and its stakeholders. This adoption lays the foundation for developing consensus on metrics to measure progress toward regional smart grids and toward a national smart grid.
- Through its participation in six workshops, the MGS team assisted the Public Utility Commission of Ohio in moving toward statewide implementation of an advanced metering infrastructure and demand response as a first step in achieving modernization of the grid in the state of Ohio.
- The MGS team initiated two field tests to evaluate the benefits of various approaches to achieving specific functional characteristics of a smart grid. One field test—a dynamic feeder reconfiguration system to improve circuit reliability—was initiated with Allegheny Power Company using selected distribution circuits in Morgantown, WV. The second field test was initiated with American Electric Power to evaluate "broadband over powerline" as an option for the two-way communications needed for operation of a smart grid.

Economy & Supply

Ensuring Ample, Affordable Energy

NETL Team Responds in Support of FEMA—NETL's Energy Infrastructure Team (EIT), which provides key support to DOE during natural and human-caused emergencies, responded to the activation of FEMA during events to the nation's energy infrastructure. By deploying enabling capability and contributing vital information, EIT makes it possible for DOE to thoroughly evaluate our national energy infrastructures and their interrelationships, thereby improving the ability of the energy sector to prevent, prepare for, and quickly respond to any threats to the domestic energy supply. EIT realized the following 2007 accomplishments:

- As devastating wildfires swept through California, EIT supplied products to allow first responders to monitor wildfire migration toward existing energy assets, such as power and gas lines. Contextual maps were also compiled to assist with timely evacuations.

- Throughout the six-month hurricane season, the team responded to several tropical systems that made landfall and caused disruptions to the U.S. coastal infrastructure. EIT also responded to severe hurricanes in Central America.

- When ice storms paralyzed large areas of the Midwest last winter, EIT supplied critical analysis in response to extended power outages in multiple states.

GIS Model Maps Vulnerabilities to Coal Transportation Infrastructures Across the Nation—Collaborators at NETL and Carnegie Mellon University have developed a GIS-based model for evaluating vulnerabilities of the coal transportation infrastructure as it relates to electric power generation. The model uses novel concepts to merge geospatial and non-geospatial data to quickly assess the degree of impact of natural or manmade disruptions to coal mines, rail lines, or coal-based power plants anywhere in the United States. Interactive analyses of this type can help senior department managers understand the impact disruptions can have on electricity production. A paper describing the model and its functions was accepted for a special issue of the *Journal of Computing in Civil Engineering*.

Projects Make Significant Strides in Grid Modernization Research—Through transmission line losses, the U.S. power grid loses more than 10 percent of the electricity it carries, and transmission limitations contribute to frequent blackouts in many areas of the United States. High-temperature superconductivity (HTS) holds the promise of transmitting electricity with near-zero line loss and a capacity that is 2–5 times greater than that provided by today's underground cables. Two projects managed by NETL for the Office of Electricity Delivery and Energy Reliability (OE) are making strides toward overcoming the primary technical hurdle to commercial HTS production: the ability to manufacture HTS wire that can transmit high current while maintaining that transmission over long distances.

- SuperPower, Inc., made significant progress in developing second-generation HTS tape by demonstrating a critical current of 173 amps per centimeter (width) over a 595-meter wire. HTS tape functions like a wire, is about the thickness of a human hair, and can be bundled into cables and coils. In the manufacturing area, SuperPower achieved wire production rates of over 300 meters per hour.

- American Superconductor (AMSC) also achieved significant progress in developing second-generation HTS tape. Specifically, AMSC demonstrated a 40 percent increase in current-carrying capacity, achieving a critical current of 92 amps per centimeter (width) in 75-meter lengths of tape.

- AMSC has also successfully installed new HTS tape production equipment in its Devens, MA, facility. AMSC will pilot the production of 4-centimeter-wide tape, an upgrade from its former 1-centimeter-wide production capacity. Because HTS tape is split to produce multiple lengths of second-generation conductor, the new equipment allows AMSC to immediately increase its capacity to produce individual pieces of conductor material.

Methane Hydrate—Taming "Fire in the Ice"

Methane hydrate—known as "fire in the ice"—has been found in the low-temperature, high-pressure conditions existing in the seafloor subsurface along continental margins as well as in the Arctic. NETL has made tremendous strides in methane hydrate research through the DOE-led National Methane Hydrate Research and Development program, an ongoing collaboration among industry, academia, and government. The program has advanced its research focus from establishing a basic understanding of hydrates to developing technologies that will enable gas hydrate exploration in both marine and Arctic environments. NETL and its partners have addressed concerns over the perceived threat posed by methane hydrate to conventional oil and gas drilling operations by demonstrating the benign nature of typical hydrate occurrence when drilling operations are properly prepared and managed in a hydrate environment. In addition, researchers have proven the feasibility of natural gas production from Arctic hydrate and are continuing to investigate the potential of methane hydrate to expand domestic and world energy resources.

NETL Invests in Future Methane Hydrate Researchers—NETL has selected the first two recipients of the Methane Hydrate Fellowship program. The first fellowship award went to a doctoral student at the University of California at Santa Barbara, who will be characterizing the biological filter in the water column that is instrumental in controlling the amount and rate of methane flow as it reaches the atmosphere from the seafloor. The second award was made to a postdoctoral researcher at Scripps Institution of Oceanography, who will be investigating gas hydrate distribution and concentrations within the Krishna-Godawari Basin along the eastern margin of India. The Methane Hydrate Fellowship program, administered by the National Academy of Science, reflects NETL's commitment to academic research and to increasing our understanding of methane hydrate as both a potential energy resource and a part of our natural environment.

First-of-Its-Kind Seafloor Station Monitors Methane Hydrates—The geophysical team of the Gulf of Mexico Gas Hydrates Research Consortium, cosponsored by NETL, has tested a prototype geophysical sensing system that, combined with hydrophones and accelerometers, could lead to a passive seismic technology that will "listen" to natural surface and micro-seismic noise. This technology is part of a suite of novel visual, geochemical, geophysical, and biological sensors that together will comprise a first-of-its-kind methane hydrate monitoring station. When the monitoring station, with all its many parts, is tested and operational, it will provide critical information about the behavior of gas hydrates and the interaction of hydrates with the ocean, seafloor, aquatic life, and atmosphere over an extended period of time. The National Oceanic and Atmospheric Administration from the Department of Commerce and the Minerals Management Service of the U. S. Department of the Interior cosponsor the consortium.

Combined Technologies Assess Gas Hydrate Area—Researchers at Lawrence Berkeley National Laboratory, working in cooperation with NETL, succeeded in joining a hydrate reservoir simulation code (Tough + Hydrate) with a geomechanical modeling program (FLAC 3D). Combining the models provides, for the first time, the ability to assess reservoir stability, ground subsidence, and other critical issues found at gas hydrate accumulations and contributes to a better understanding of their role in the environment and as a potential energy resource.

Economy & Supply

Processing a sediment core from a methane hydrate stratigraphic test well, Mt. Elbert, Alaska's North Slope, Prudhoe Bay.

First U.S. Arctic Methane Hydrate Test Well Confirms Potential for Natural Gas

Natural gas is our nation's cleanest-burning fossil energy resource, yet the ever-increasing gap between its supply and demand is leading scientists increasingly to consider unconventional gas resources. One potential resource that may help close this gap is methane hydrate, an ice-like crystalline solid consisting of gas molecules surrounded by a cage of water molecules.

Gas hydrates form naturally in geologic reservoirs under conditions of high pressure and low temperature. Known as "fire in the ice," methane hydrates are gaining interest worldwide, for they may contain more in-place resources than all conventional fossil fuels in the world combined, according to the U.S. Geological Survey (USGS).

In September 2001, under a cooperative agreement between BP Exploration (Alaska), Inc., and NETL, researchers began the first of four phases to characterize the large in-place hydrate resource area on Alaska's North Slope (ANS). During Phases 1 and 2 of this study, a team led by the United States Geological Survey (USGS) characterized 14 discrete hydrate accumulations within the Milne Point area through analysis of BP-supplied data.

Phase 3 was highlighted, in February 2007, with the drilling of a well at the Mount Elbert site. The well encountered roughly 100 feet of gas-hydrate-bearing sandstone and enabled the acquisition of a state-of-the-art dataset, including well logging, whole core, and formation pressure-response data. Critical accomplishments from the well include—

- Demonstration of the validity of the hydrate exploration methodology.
- Confirmation of ANS hydrate resources.
- Demonstration of safe operational approaches for scientific data acquisition.
- Collection of over 400 feet of whole core—the first hydrate and first wireline-core from ANS.
- Distribution of over 100 well subsamples to U.S. and Canadian scientists.
- The first open-hole pressure-transient test conducted in a hydrate-bearing interval.
- The first demonstration of gas production from hydrate depressurization on the ANS.

Test results provided the critical information necessary for evaluating the technical and economical recoverability of Arctic hydrates. In March 2008, the project science team gathered in Denver, CO, to discuss scientific findings and to begin finalizing potential production-testing scenarios for the project's Phase 4.

Methane hydrate has an energy density approximately 164 times that of natural gas at normal surface temperature and pressure. Found beneath Arctic permafrost and under the seafloor along continental shelves, the estimated volume of methane contained in domestic hydrates is a staggering 200,000 trillion cubic feet. The Mt. Elbert well verifies the nature of one of more than a dozen prospects in the Milne Point field, which together could contain more than 600 billion cubic feet of gas-in-place.

The project is being conducted through the DOE-led National Methane Hydrate Research and Development program, which seeks to increase understanding of naturally occurring hydrate accumulations, their potential as a future energy resource, and their relationship to seafloor stability and global climate issues. Though methane-hydrate recovery poses a major technical and commercial challenge, success of the program could potentially reshape national and global supplies of energy, resulting in a profound impact on the nation's environmental quality, economic health, national security, and scientific leadership.

Economy & Supply

Ensuring Ample, Affordable Energy

Rock Physics Models Developed for Mapping and Quantifying Subsurface Methane Hydrates—Researchers at Stanford University, working in cooperation with NETL, have developed rock physics models that relate seismic attributes to the physical properties of methane hydrate in a reservoir. The models produced can be used to explore for methane hydrate accumulations in marine and non-marine subsurface reservoirs and have been tested with borehole and seismic data from three hydrate study areas: Mallik in Canada's Mackenzie Delta, Japan's Nankai Trough, and Hydrate Ridge off the coast of Oregon. In an interactive mode, the models allow the user to vary the reservoir properties (e.g., hydrate saturation, porosity, and reservoir thickness) to match the observed seismic response at a particular site. Ultimately, the models will allow hydrate researchers to estimate hydrate and free gas saturations in porous reservoirs using seismic data.

Discovery Reveals Possible Role of Methane Hydrate in Gas Production in the Barrow Gas Fields—During the first phase of a project, the North Slope Borough was able to demonstrate a possible connection between the methane hydrate zone and the free gas reservoir in two of Alaska's three Barrow gas fields. These fields, which have been operating since at least 1949, have shown little, if any, pressure reduction over their life and have had no water breakthrough, suggesting that dissociation of methane hydrates may be driving production. The success of this initial effort, which was accomplished in cooperation with NETL, resulted in a determination to continue to the next phase of the project, detailed reservoir modeling and formulating recommendations for the optimal location of a potential production test well.

Unique Laboratory Will Help Unlock the Mystery of Hydrate Formation and Dissociation—In 2007, the Oak Ridge National Laboratory, supported by NETL, significantly expanded the capabilities of the Seafloor Process Simulator (SPS), a unique experimental facility designed to conduct experiments on natural and human-made sediments. The SPS allows researchers to bridge the gap between traditional molecular-scale laboratory experiments and extensive field-based production tests and experiments. With the addition of a fiber optics-based distributed sensing system, the SPS is now capable of measuring time-resolved temperature and stress changes in three dimensions at the centimeter scale. This new tool set makes it possible to monitor rates of methane formation and dissociation within large sediment volumes by measuring a combination of high-resolution temperature data and pressure observations in the system. Sediment stability during hydrate accumulation and dissociation can also be monitored using strain measurements collected by the new tool set, permitting better assessment of the seafloor stability issues associated with hydrate production or environmental changes.

Researchers Investigate Biological Origins of Methane Hydrate and Its Role in the Global Climate Cycle—To better understand the role of methane in the global climate cycle, researchers at Oregon State University, with support from NETL, are investigating the biological production rates of methane in seafloor sediments. This work combines laboratory studies to derive a range of thermodynamic and kinetic conditions under which methane-producing microbes may be active in the sub-seafloor sediments. These data will be integrated into numerical models that describe the formation and release of gas hydrate in marine sediments.

Natural Gas and Oil—Maximizing Our Supply

U.S. natural gas and oil resources are tremendous energy assets to our nation, providing more than 60 percent of the total energy used by our industries, businesses, and citizens. However, more than two-thirds of all the oil discovered in America to date remains in the ground, in geologically and operationally complex settings that are often economically unrecoverable with current technology. About 218 billion barrels of oil—a volume approaching the proven reserves of Saudi Arabia—lie at depths of less than 5,000 feet. Continued U.S. gas and oil production depends on locating fields among obscure geologic sources and advancing technology for recovering discovered resources as economically as possible. NETL is developing advanced exploration, drilling, and recovery technologies to ensure that America's oil and natural gas resources are recovered to their fullest potential. New sensors and modeling techniques are helping to pinpoint supplies. Enhanced drilling techniques, such as the economic microhole technology, are reaching resources once deemed "not worth it." Enhanced oil recovery (EOR) technologies are helping operators place wells more strategically, identify better injection schemes, and improve reservoir management practices.

Exploring

Two NETL Studies Encourage Deep Gas Exploration—NETL has released two comprehensive reports that provide detailed geologic information of the northern Appalachian basin and northeastern Gulf Coast regions. Considered important resources of information for companies interested in exploring the regions for deep gas, these free-to-the-public reports enhance the likelihood that trillions of cubic feet of natural gas can be added to our domestic supply of energy.

- *The Geologic Play Book of Trenton-Black River Exploration in the Appalachian Basin* incorporates regional geologic, geochemical, and geophysical data into a model that will be useful for exploiting the most promising reservoirs within the Trenton-Black River geologic formations. It was produced by the Trenton-Black River Appalachian Basin Exploration Consortium.

- *Resource Assessment of the In-Place and Potentially Recoverable Deep Natural Gas Resource of the Onshore Interior Salt Basins, North Central and Northeastern Gulf of Mexico* discusses a model for expanding exploration in the region that, according to the U.S. Geological Survey, ranks in the top 8 percent of the most petroleum-rich basins in the world. This second report is the result of a study by NETL and University of Alabama investigators, who conducted a comprehensive basin analysis of the Mississippi Interior Salt Basin.

Archive of Unconventional Gas Research Gives Wealth of Information to Aid Future Development—NETL has compiled on DVD the Natural Gas Program Archive containing reports and data produced during nearly two decades of research by the Office of Fossil Energy. Prepared in response to rising industry interest, the archive makes available nearly 1,400 documents and 600 logs from 70 individual research wells. The two-DVD set covers such programs as Eastern Gas Shales, Western Gas Sands, Methane from Coal Seams, Methane Hydrate, Deep Source Gas, and Secondary Gas Recovery and represents a wealth of information that bears directly on development of future gas and oil resources to help meet the nation's growing demand for natural gas.

Economy & Supply

Ensuring Ample, Affordable Energy

Project Results Will Help Tap Huge Domestic Gas Reserve—University of Kansas researchers and collaborators at the Kansas Geological Survey and the Discovery Group, Inc., have provided comprehensive database and modeling algorithms for rock properties as a result of a study completed in cooperation with NETL. This information is critical to gas production because it supplies crucial information, such as relative permeability, capillary pressure, and electrical resistivity. The project has sparked considerable industrial interest and participation by major producers, including BP America, ExxonMobil, Kerr-McGee, Shell Oil Company, and the Williams Companies, Inc. Information in the study will help operators locate and tap the enormous unreached gas reserves—estimated at 240 trillion cubic feet—located in the tight gas sandstones of Utah, Wyoming, and Colorado.

New Technology Could Sharpen Images of Deep Gas Prospects—Working in cooperation with NETL, product developers at Paulsson Geophysical Services, Inc., of Brea, CA, have developed the first all-fiber-optic seismic-receiver system that, unlike available technologies, will operate with no downhole electronics or power. The new sensor system is expected to withstand temperatures to 400 ºF and pressures to 25,000 pounds per square inch. It includes micro-electromechanical-system (MEMS) accelerometers to sense ground motion and an optical interrogation system to measure acceleration magnitude. The combined fiber optic-MEMS approach will allow a dramatic increase in the number of sensors that can be deployed simultaneously as a borehole seismic array and should result in better image quality, making it possible to more accurately assess deep gas targets.

Novel Approaches Help Find More Oil—Researchers from the Utah Geological Survey are applying nonintrusive, cost-effective techniques to find more oil in the northern Paradox Basin region of Utah and Colorado. By examining vegetation for compositional signatures of seepage and by analyzing for any hydrocarbons contained in the air from extracted soil, the techniques—which are particularly useful to independent producers—can be used to identify or eliminate areas and exploration targets before investing significant financial resources in seismic data acquisition and environmental concerns. The techniques, developed in a cooperative agreement with NETL, have benefits that could apply to other high-risk, sparsely drilled, environmentally sensitive, or poorly researched regions where similar reservoirs may be found. A feature article covering this new approach appeared in the August 2007 issue of the American Association of Petroleum Geologists monthly, *AAPG EXPLORER*.

New Technique Makes Finding Bypassed Oil Faster and Cheaper—Working in cooperation with NETL, researchers at Texas A&M University have developed a new method for rapid history matching of high-resolution geologic models. "History matching" is the adjustment of reservoir-model predictions based on past production behavior. Used in conjunction with tracer tests that monitor the paths and velocities of certain injected gases or liquids as they move through the reservoir, this novel approach can reduce the time for history matching from several months to a week or less and save significant manpower—a boon to small independent producers, who account for a significant share of domestic crude oil supplies. This new technique has stimulated formation of an industrial research and development consortium funded by eight oil production and service companies.

State-of-the-Art Technology Targets Hidden Hydrocarbon Prospects—Collaborators at Lawrence Berkeley National Laboratory and the University of Texas have developed an innovative data-acquisition and modeling technique for integrating seismic and electromagnetic (EM) data. Successful integration of borehole sonic and EM measurements considerably improves assessments of petrophysical properties and the hydrocarbon potential of rock formations tens of meters from a wellbore, making it possible to efficiently produce oil from highly heterogeneous and bypassed hydrocarbon reservoirs. The technique was developed in cooperation with NETL.

Novel Seismic Technology Provides Way to Detect and Validate New Hydrocarbon Reserves—Collaborative research conducted in cooperation with NETL at the University of Houston and University of California at Berkeley has resulted in an innovative Frequency-Dependent AVO technique for locating new hydrocarbon reserves. The seismic-based technology correlates and quantifies hydrocarbon saturation and fluid-mobility properties as well as their spatial distribution in reservoirs. It has been successfully applied to both water-saturated sands and gas-saturated zones. By mapping fluid contacts and mobility, the technique provides a way to recognize, delineate, and validate new hydrocarbon reserves—especially important in areas that have subtle or no seismic expression. It also assists in the development of producing fields and represents a major step toward the goal of developing a seismic-based method for mapping reservoir permeability.

Projects Advance State-of-the-Art Seismic Imaging—Working in cooperation with NETL, two Houston-based research teams have developed improved technologies for imaging deep structures and detecting deep hydrocarbon accumulations—a critical capability for pre-drill evaluation of a prospect's location, size, and deep hydrocarbon charge.

- Rock Solid Images developed the Direct Hydrocarbon Indicator, which employs seismic-attenuation attributes calibrated to well logs. It is expected to be more effective than the traditional AVO (amplitude versus offset) analysis for detecting hydrocarbons in deep reservoirs.

- 3DGeo Development, Inc., developed a technology that more completely incorporates available seismic-wave information to optimize image resolution in areas of deep and complex geology. This technology has clearly improved image quality for some commercial datasets, especially for depths greater than 10,000 feet.

Results of these state-of-the-art imaging techniques were widely publicized at the 2006 annual meeting of the Society of Exploration Geophysicists held October 1–6 in New Orleans, LA.

Model for Oklahoma Oil Reservoir Shows Ways to Increase Production—Working in cooperation with NETL, University of Tulsa scientists have developed a reservoir model to explain the principal mechanisms by which oil and gas are produced from the West Carney field of the Hunton formation. One of the biggest commercial discoveries in Oklahoma in the last decade, the Hunton formation exhibits unique production characteristics, such as a large production of water, unusual gas-oil ratios, and poor geologic continuity. Results of the study, however, indicate that use of CO_2 flooding and fracture treatments will increase production so that additional oil can be recovered by applying surfactants and gravity-drainage methods. The findings and recommendations of the study should lead to the production of additional oil and/or gas from the West Carney field, as well as from similarly complex, tight reservoirs with poor porosity and permeability.

Major Oil Plays in Utah and Vicinity Help Companies Plan Oil Well Development—In an effort to increase recovery of oil reserves from existing reservoirs and from new discoveries, the Utah Geological Survey has developed play portfolios for the major oil-producing provinces in Utah and adjacent areas in Colorado and Wyoming (Paradox Basin, Uinta Basin, and the thrust belt area). The Utah play portfolios produced by this project in cooperation with NETL provide easy-to-use geologic, engineering, and geographic references to help petroleum companies plan exploration, land-acquisition strategies, and field development. These portfolios may also help pipeline companies plan future facilities and pipelines.

Economy & Supply

Ensuring Ample, Affordable Energy

Drilling

Proven Ultra-High-Speed Drilling Provides a Technical Breakthrough—Using a special rig able to withstand extreme vibrations, investigators at Salt Lake City-based TerraTek Inc. achieved a penetration rate of almost 600 feet per hour with an 0.8-inch-diameter diamond coring bit rotating at speeds up to 50,000 revolutions per minute. Surprisingly, the energy necessary to penetrate rock is much less at these record-breaking speeds than theoretical predictions, forecasting dramatic cost reductions when the technology is applied in drilling deep, directional wells to reach prolific gas reserves. The data indicate that, when drilling with a full-faced bit less than 1 inch in diameter, there is an optimum combination of drilling speed and loading (weight-on-bit) that could produce the greatest rate of penetration. This would be particularly significant to decreasing weight-on-bit drilling trajectories that are deviated, horizontal, small, and deep. With the concept proven, scale-up can proceed to ultra-high-speed drilling with bits up to 3.5 inches in diameter. Success of this project part of a cooperative agreement with NETL, could provide a technical breakthrough not only for the Office of Fossil Energy's Microhole Development program but also for the mining, geothermal, and other industries with deep and hard rock drilling applications.

Major Milestone in Technology Can Reduce Costs and Risks of Deep-Well Drilling—Product developers at Honeywell International Inc. have developed four electronic components that will help downhole instrumentation and other "smart" well-production applications to function reliably in deep, high-temperature, high-pressure environments. The suite development was guided by a joint industry partnership of petroleum service companies and operators organized by Honeywell under the NETL-managed Deep Trek program, which is aimed at reducing the costs and risks involved with characterizing, quantifying, and recovering deep domestic natural gas reserves—estimated at hundreds of trillions of cubic feet. The high-temperature suite consists of an operational amplifier, a field-programmable gate array, a first-of-its-kind electrically erasable and programmable read-only memory, and an 18-bit analog-to-digital converter.

Microhole Wireless Steering-While-Drilling System Tested Under Laboratory Conditions—INTEQ engineers, in cooperation with NETL, have produced and tested three prototype bidirectional communications and power modules designed for use with INTEQ's $2\frac{3}{8}$-inch CoilTrak® drilling bottom-hole assembly. Each module features an alternator that uses the flow of drilling fluid to generate electrical power for the other measurement-while-drilling and logging-while-drilling components of the assembly. Using pressure pulses in the drilling fluid, a module can encode and transmit data from downhole to operators on the surface. With the capability to receive and demodulate returning instructions, the technology eliminates the need for an expensive coil with an electric wire connection and enables "smart" well drilling in locations where an electric line is not affordable.

Microhole Tool with Lower Environmental Impact Demonstrated—Product developers at Western Well Tool, Inc., have completed a field demonstration of the Microhole Drilling Tractor (MDT) with a major oil company operating in Alaska. Operating inside 4½-inch tubing at depths of 800–950 feet, the MDT successfully demonstrated on-off capability, pulled with up to 1,465 pounds of force, and verified its capability to transmit torque. The MDT is designed to provide forward thrust for the drill bit at the end of a coiled tubing drill string to overcome the tendency for locking up or delivering insufficient weight-on-bit to drill ahead. The hydraulically powered device will allow producers to economically and effectively drill shallow holes with long horizontal well sections up to 3,000 feet beyond existing technology, which will require fewer wells and thereby minimize surface environmental impacts. Developed in cooperation with NETL, this technology was a finalist for *World Oil* magazine's 2007 New Horizons Idea Award.

Self-Expanding Wellbore Casing Technology Demonstrated—A project team led by Dynamic Tubular Systems, Inc., completed all essential steps in the development of an innovative technology that is applicable to microhole drilling but can also be used to case any size drilling well, production well, or borehole. As part of an NETL-managed project implemented under the Office of Fossil Energy's Microhole Technology Initiative, the split-tube casing system's technology evolved within two years from a broad concept through development and manufacture to the placement of two self-expanding tubulars in a field test. Applicable to a variety of extraction industries, the new technology has attracted industry interest as an affordable approach for maintaining borehole stability and well control and could extend the reach of traditional telescoping designs that would otherwise fall short of target.

Self-Expanding Idealflo™ Sandscreen Expected to Significantly Lower Well-Drilling Interruptions—As part of a cooperative agreement with NETL, a project team led by Dynamic Tubular Systems, Inc., developed and tested an innovative, self-expanding, control-screen technology that can be applied in producing resources from wells of all types. The technology is of particular use with micro-wells, solving the unique problems that small-diameter wellbores encounter because of the plugging and erosion caused by the increased sand movement created by high fluid velocities. The new sandscreen features a highly supported, grid-type construction of close tolerance and slotted panels that can be tuned to provide detailed control over well hydraulics and particle filtration. As a result, the tubular grid can screen sand particles of any size, thereby improving hydraulic efficiencies. It is also constructed from alloys of higher strength and wear resistance than screens available today, so it is particularly erosion-resistant. This unique sandscreen design has attracted international interest in its potential for significantly reducing production interruptions.

Automation Improves Directional Drilling Efficiency in Field Tests—As part of a joint industry project funded by NETL and the Drilling Engineering Association, engineers from Slider, LLC, increased by 60–200 percent the rate of penetration that can be achieved when using a downhole motor to drive a drill bit. Demonstrated in Texas oilfield tests, the new technology incorporates an automated rocking feature for moving the drill assembly fractionally above and below the desired drilling target to keep it from "sticking" to the formation. The achievement could save 11–23 percent of total well costs.

New Tool Helps Small Oil and Gas Producers—A software program designed for the personal digital assistants used by pumpers and well-tenders is now available online at the Oklahoma Marginal Well Commission website. The program will allow small producers to electronically record and track basic well management, reporting, and archiving information while in the field for later downloading to a main database or office computer. Developed through a grant from the Stripper Well Consortium, which is partially funded by NETL, the tool represents a dramatic improvement over the unreliable yet time-consuming hard-copy record keeping prevalent in the field. The consortium, managed by The Pennsylvania State University, offers small, independent operators the opportunity to work together with technology developers and researchers from across the country to solve production problems.

This microhole drilling bit—part of BakerHughes Inteq's CoilTrack microhole drilling system—has been integrated with a small motor and is able to drill boreholes as small as 3 ½-inches in diameter.

Microhole Drilling Rig Demonstrated Successfully

An NETL-managed project some people call "the little mouse that roared" could change the way America's oil and natural gas wells are drilled. A specially designed hybrid "microhole" coiled tubing rig was successfully demonstrated in the nation's midcontinent region. The field demonstration included the drilling of 25 test wells to penetrate a particularly intractable natural gas formation called the Niobrara in western Kansas and eastern Colorado. Today, the microhole drilling rig continues to be used to drill Niobrara wells and is being considered for coalbed methane drilling.

The effort delivered a cost savings of 25–35 percent per well drilled compared with conventional drilling equipment. As a result, about 1 trillion cubic feet of shallow gas that had been bypassed by conventional drilling have now been made economic. That volume equates to about 5 percent of America's annual natural gas consumption.

While coiled tubing rigs are frequently used to service or stimulate production in problematic oil and natural gas wells, operators have only recently begun drilling more "grassroots" exploratory and development wells with them. That effort has largely been limited to higher-cost operating areas such as Alaska and Canada.

The commercial Niobrara drilling program—in which 3,000-foot wells were drilled in as little as 19 hours from rig move-in to move-out—followed a Department of Energy-funded research project undertaken by Gas Technology Institute (GTI), Des Plaines, IL. In that effort, GTI partnered with two small firms—Advanced Drilling Technology LLC (ADT), Yuma, CO, and Rosewood Resources Inc., Dallas, TX—to demonstrate a new, high efficiency, hybrid rig (combining rotary and coiled tubing technologies) for drilling exploratory and development wells with ultra-small diameters.

The GTI project received funding from the Energy Department's Microhole Technology Initiative. Managed by NETL, the initiative seeks to develop the tools and techniques for drilling ultrasmall boreholes (generally, 1 ¾ to 4 ½ inches in diameter) and related downhole micro-instrumentation, using coiled tubing drilling rigs that are small and easily transportable. These rigs—some small enough to mount on a trailer pulled by a standard pickup truck—employ solid tubing coiled around a spool on the trailer to drill boreholes with well casing diameters of less than 4 ½ inches. Such rigs can drill shallow wells very quickly, saving substantially on daily rig costs and dramatically improving the economics of drilling.

GTI's microhole project was meant to pioneer the use of an experimental, "built-for-purpose" coiled tubing rig designed to drill exploratory and development wells with ultrasmall diameters in the lower 48 states. ADT and its predecessor, Coiled Tubing Solutions, Inc., designed and fabricated the rig specifically for microhole coiled tubing drilling to depths as great as 5,000 feet. Earlier Energy Department research had proven this capability to only a few hundred feet.

GTI and partners field tested this state-of-the-art hybrid coiled tubing rig by drilling a few inexpensive microbore wells to 1,200–1,400 feet in the Niobrara chalk formation along the Kansas-Colorado border. The results far exceeded expectations, with drilling cost savings averaging 38 percent. The project's success garnered nominations as a finalist for the 2005 World Oil Award and for 2005 Operator of the Year by the Colorado Oil and Gas Commission.

The project's initial success and strong commercial follow-up also demonstrated the potential for coiled tubing drilling of exploration and development wells in the lower 48 states.

Microhole coiled tubing drilling technology has the kind of game-changing potential that could be applied to bypassed resources in thousands of oil and natural gas reservoirs across the nation, particularly for shallow reservoirs in mature or even apparently depleted fields. The Energy Department estimates the volume of bypassed oil in U.S. oilfields at less than 5,000 feet subsurface at more than 218 billion barrels. Recovering just 10 percent of this targeted untapped resource equates to an amount equal to 10 years of OPEC oil imports at current rates.

Economy & Supply

Ensuring Ample, Affordable Energy

Innovative Motor Designed for Ultra-High-Speed Drilling—In cooperation with NETL, engineers at Impact Technologies LLC, have designed an advanced permanent-magnet synchronous machine that has potential to achieve rotational speeds up to 10,000 revolutions per minute for microhole and other drilling applications in deep, hard rock. In addition to the faster rates of penetration enabled by the ultra-high speeds, the sealed direct-current motor could also be used in conjunction with abrasive and/or corrosive fluids or other high-energy processes that are used to increase penetration rate. The patented design can provide a tremendous improvement in drilling and boring processes, allowing attempts at targets that are not possible or economic with today's technology.

Enhanced Recovery

New Tool Raises Output of Unconventional Natural Gas—Pinnacle Technologies, Inc., of San Francisco, CA, has demonstrated a new technology that can use hydraulic fracturing to help optimize the output of natural gas from often-grudging unconventional reserves, such as tight sandstone formations, gas shales, and coal seams. In fracturing, fluids are pumped into reservoirs under pressure to crack open new pathways for increased flow of oil and natural gas to the well. Applicable to oil or gas production, the Pinnacle technology is an advanced mapping system that delivers a more accurate picture of underground conditions than previous technologies and also allows improved alignment of induced fractures with natural fractures in ways that optimize flow. Benefits include higher quality data, fewer mapping failures, better understanding of fracture behavior in a reservoir, and improved well spacing and placement. Prototype arrays of this technology, which was developed in cooperation with NETL, were demonstrated in a Colorado coalbed-methane well and in a Barnett shale test. The technology also provided valuable information while monitoring California's San Andreas Fault during a long-term test funded by the National Science Foundation in partnership with the U.S. Geological Survey.

Groundbreaking Oil Recovery Project Revives Aging California Oilfield—Working in cooperation with NETL, Tidelands Oil Production Company operators experienced the most successful drilling in 25 years at the Wilmington onshore oilfield (owned by the City of Long Beach)—surprising in an area that had been virtually given up as depleted. The Wilmington project was instrumental in advancing technologies for modeling, reservoir characterization, horizontal well drilling, completion, and heavy oil thermal-production operations in an environmentally sensitive coastal area. If new technologies and techniques developed under the project are applied field-wide, it could boost Wilmington's ultimate oil recovery by 525 million barrels of oil. This jump in production from a single oilfield could translate to a 2.5 percent increase in total U.S. proven oil reserves.

Partnership Demonstrates Technology That Gives New Life to Marginal Oil Wells—Field demonstrations, conducted as part of an NETL-managed project awarded under the Office of Fossil Energy's PUMP III program, show that microturbines and other technologies can turn stranded gas—gas unfit for commercial pipelines or located too far from the needed infrastructure—into a resource for distributed power generation. Because electricity is one of the highest expenses in producing from marginal oil wells, the resulting improved economics at two demonstration sites—one with high-Btu gas and the other with medium-Btu gas—have returned previously idle fields back to production. In addition to reducing production cost, a third demonstration has brought a field with harsh gas (gas contaminated with high levels of nitrogen, CO_2, and hydrogen sulfide) into compliance with air emissions regulations by scrubbing hydrogen sulfide from the gas with a patented sulfur-treating system, thus eliminating the need for flaring. NETL demonstration partners include the Interstate Oil and Gas Compact Commission, California Oil Producers Electrical Cooperative, California Energy Commission, and California South Coast Air Quality Management District. Preventing the waste of valuable domestic oil resources through premature plugging and abandonment of marginal oil wells could add 75,000 barrels of domestic oil production per day—28 million barrels per year—within the next 10 years. An article coauthored

at NETL highlights the project in PennWell Corporation's November 2007 issue of *Cogeneration and Onsite Power Production*.

Project Identifies Means to Economically Recover More Oil from Utah Basin—Investigators at the Utah Geological Survey have indicated through models and calculations that horizontal wells drilled from existing vertical wells in two San Juan County fields would likely encounter bypassed oil that could be economically recovered. The study, undertaken in cooperation with NETL, examined representative cores, geophysical logs, and thin sections of rock to grade the potential for additional oil recovery using the technique. If applied to the approximately 100 similar fields in the Pennsylvania Paradox Formation spanning Utah and Colorado, the method could recover an additional 25–50 million barrels of oil.

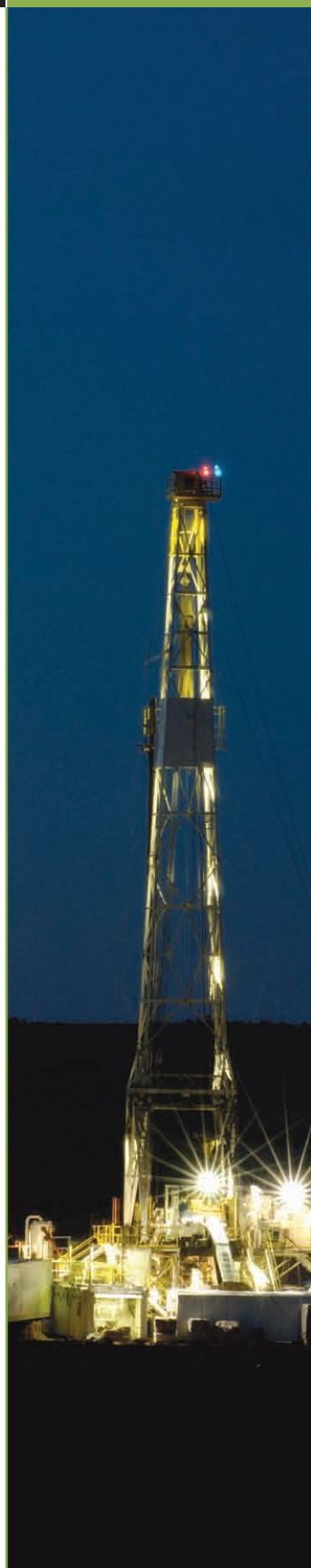
Many Industry Firsts Attained by Model for Enhanced Oil Recovery—Researchers at Stanford University, working in cooperation with NETL, are developing a novel reservoir simulator that promises to provide quick and reliable performance assessments for a wide range of reservoirs involving multiphase flows. The Stanford team achieved many "firsts," including:

- A new research tool for gas injection and two-phase compositional flow that will allow very large, complex computational simulation problems to be run on desktop computers.
- The first equations describing two-phase, four-component flow, with adsorption and volume change, that can be used to describe subterranean flue gas injection.
- Methods tailored to describe flow in space and time with efficient integration of kinetics and phase behavior in reactive porous media.

Enhanced Oil Recovery (EOR) is one of the most effective methods for recovering much of the more than 400 billion barrels of discovered oil remaining in the United States. Faster, more accurate EOR models can maximize oil recovery by helping operators place wells and surface facilities more strategically, identify better gas and water-and-gas injection schemes, and improve reservoir management practices.management practices.

EOR Research and Development Identifies Additional Recoverable Oil Reserves in Michigan—A research team led by Pittsburgh-based Schlumberger Data and Consulting Services has injected more than 500 million cubic feet of CO_2 into the Charlton 30/31 oil field, a field in the northern flank of the Michigan Basin that contains approximately 700 Silurian-age reef structures. The researchers, working in a cooperative agreement with NETL, verified a correlation between low instantaneous seismic frequency and high reservoir porosity, making possible a highly accurate reservoir simulation that can lead to greater reserve recovery while simultaneously providing for the sequestration of more CO_2. There are an estimated one billion barrels of oil remaining in Michigan's Silurian reefs and 351 billion barrels in mature fields nationwide. Stripped from locally produced natural gas (to meet pipeline quality specifications), the anthropogenic CO_2 from the project is being injected back into the reef rather than released to the atmosphere.

Microbial EOR Produces More Oil—Investigators at the University of Oklahoma, working in cooperation with NETL, have obtained positive results by using microbial-enhanced oil recovery (MEOR). In field tests at two sites operated by independent producer Arrow Holding, Inc., 330 barrels above normal production were recovered by MEOR. The investigators developed and applied technology for inoculating oil reservoirs with a mix of bacterial strains that produce viscosity-lowering surfactants. These allow oil to flow more easily out of the rock pores trapping it. The DOE Reservoir Database identifies more than 600 reservoirs representing upwards of 12 billion barrels of currently unrecoverable oil that are potential targets for the technology. These results were reported in the "What's New in Production" section of *World Oil's* August 2007 issue.



Environment & Economy

Developing Affordable Alternatives

In the foreseeable future, the United States and indeed the world will continue to rely on fossil fuels to produce the vast majority of the energy we consume. Because of this, NETL will continue to play a critical and unique role in the science and technology of affordable alternative applications for traditional fossil fuels—applications that are essential to the environmentally responsible use of America's coal, natural gas, and oil resources. NETL is developing new technologies and processes that slash emissions, make beneficial use of waste products, improve materials and monitors for advanced combustion systems, and complete the drive toward advanced power turbines—the heart of nearly all the world's electricity generation systems.

Environment & Economy

Developing Affordable Alternatives

Air, Water, and Land—Reducing Our Footprint

Air, water, and land are the most basic of America's abundant resources. The conservation of these resources is a major focus for NETL, whose research achieved singular accomplishments in 2007 in its pursuit of technologies that tackle the environmental impacts of energy production on America's air, water, and land. As Benjamin Franklin wrote in Poor Richard's Almanac, it is when "the well runs dry, we know the worth of water." However, NETL is not waiting for that to happen. NETL researchers in the Office of Systems Analyses and Planning are conducting research and analyses to reduce the electric power sector's use of freshwater. Our mercury program—the largest research program in the country for studying fossil-combustion-based mercury emissions—announced its successful achievement of the mercury-reduction goals established by the Office of Fossil Energy a decade ago. In addition, our Strategic Center for Coal and Strategic Center for Natural Gas and Oil made great strides in 2007 in research and analyses to reduce the electric power sector's use of freshwater; to better manage water produced during oil extraction, gas extraction, and carbon sequestration; and to reduce impacts to our nation's land resources.

NETL Research Reveals Sulfur Trioxide Interferes with Mercury Capture—Test results obtained at NETL suggest that mercury and sulfur oxides compete for the same binding sites on the surface of activated carbon, a widely used mercury-capture sorbent. Further, the presence of sulfur trioxide inhibits mercury capture even at the lowest concentration tested (20 parts per million). While difficult and costly to mitigate, poisoning of activated carbon by sulfur trioxide can be reduced by coinjection of alkaline sorbents along with the activated carbon, flue gas desulfurization upstream of the point of injection, and the use of alternative fly ash conditioning agents. These results have been reported in the American Chemical Society journal *Environmental Science & Technology.*

National Laboratories Investigate the Interdependency of Energy and Water— In response to a request from the House and Senate Subcommittees on Energy and Water Development Appropriations, NETL and two other national laboratories have evaluated the impact that limited water supplies could have on energy production. The report, titled "Energy Demands on Water Resources—Report to Congress on the Interdependency of Energy and Water," contains valuable background information detailing the connections between energy and water, in particular fossil-based electricity generation. It provides a summary of concerns regarding the water demands of energy production, and it discusses the science and technologies needed to address national water use and management in the context of domestic energy production and use. NETL, Sandia National Laboratories, and Los Alamos National Laboratory were the three lead laboratories that authored the report.

NETL Researchers Develop Efficient Technique for Enhancing Worth of Fly Ash—An NETL-developed method of combining mechanical sieving and an electrical separation technique called "triboelectrostatic separation" has proven effective and efficient for separating and concentrating the carbon and mineral components of fly ash. Carbon and low-carbon fly ash are saleable commodities, but high-carbon fly ash is not. Fly ash generally has over 6 percent unburned carbon, which makes it unusable for cement. Removal of minerals from the fly ash benefits the power industry, the cement and other industries, and the environment because a waste product is transformed into a useful product. The new separation method can be adjusted to the relative carbon and mineral contents of the feed material as well as for various industrial end products, such as specialty carbon or cement. The process is described in the February 2007 issue of *Chemical Engineering & Technology.*

Long-Term, Full-Scale Test Achieves 90 Percent Mercury Emission Reduction—We Energies, at its Presque Isle Plant in Marquette, MI, is demonstrating the TOXECON™ mercury and multi-pollutant control system. Operating under NETL's Clean Coal Power Initiative, the project logged 48 consecutive days that achieved 90 percent or greater reduction in mercury emissions. Total boiler load ranged from roughly 165 to 250 megawatts of electricity, and temperature generally varied in the range of 325 °F to 346 °F, with brief periods near 285 °F during low-load operations. The outlet mercury emissions measurements consistently showed a 90 percent mercury emission reduction, proving the TOXECON system's capability

for achieving the project goal of 90 percent mercury reduction during a full-scale test for a long-term duration and over the wide variation of operating conditions typically experienced at a commercial power plant.

Mercury Oxidation Demonstrated Using Subbituminous Coals—Under an NETL cooperative agreement, the University of North Dakota's Energy and Environmental Research Center (EERC) completed the Large-scale Testing of Enhanced Mercury Removal project. The objective of this project was to evaluate additives alone or in combination with activated carbon to control mercury emissions from units firing Powder River Basin subbituminous coals. The results indicate that calcium chloride added to the W.A. Parish and Hawthorn stations increased mercury oxidation across the selective catalytic reduction (SCR) units. The increased amount of oxidized mercury was then captured in the wet scrubbers at each of the plants. Mercury removal at W.A. Parish increased to 94 percent when using the additives, compared to a baseline removal of 32 percent. The results are important because previous research has shown that only units burning bituminous coal can oxidize mercury across the SCR. Additional research must be conducted to determine if the calcium chloride additive could cause corrosion issues over an extended test period.

Spectroscopic Methods Have Potential to Improve Performance of Mercury Monitors in Flue Gas—In separate projects conducted in cooperation with NETL under the Office of Fossil Energy's Advanced Research program, Sandia National Laboratories, and Purdue University have demonstrated the potential of applying spectroscopic techniques to measure mercury in flue gas from coal-fired power plants. These techniques eliminate error introduced by the extensive sample-conditioning required with conventional methods by placing the instrument near the sampling probe for rapid analysis under conditions comparable to process conditions. Under laboratory conditions at Sandia National Laboratories, a detection limit of one part per billion of mercuric chloride—the most abundant form of oxidized mercury emitted from coal-fired boilers—was demonstrated in the presence of sulfur dioxide (SO_2) using photo fragment fluorescence. Purdue researchers, using two diode lasers on a pilot-scale combustor, demonstrated detection of atomic mercury to the part-per-billion level in the presence of SO_2. Laser light sources have the potential to positively impact the overall performance of continuous-emissions mercury monitors for coal-fired power plants.

Test Site Chosen for Water-Saving Technology for Power Plants—SPX Cooling Technologies, Inc., developer of Air2Air™, a patented new water-recovery technology, has partnered with PNM, the operator of the San Juan Generating Station in New Mexico. PNM has given SPX permission to use a part of the generating station's 1,800-megawatt coal-fired plant's Unit 4 cooling tower to perform full-scale testing of the novel technology in actual field conditions. The Air2Air Condensing Module, developed under the NETL-sponsored Innovations for Existing Plants program, has the potential to reduce the water usage of an evaporative cooling tower by 20 percent, which could result in saving 600,000 gallons of freshwater per day for a typical 300-megawatt coal-fired power plant. A traditional evaporative cooling tower at a thermoelectric power plant uses the latent heat of water vaporization to transfer heat. By evaporating a small portion of the circulating water flow through the tower, the remaining water is cooled. The Air2Air water conservation cooling tower has been developed to recover part of the evaporate by condensing it with relatively cool ambient air and retaining water that would otherwise be lost to the atmosphere. Throughout an annual cycle, the testing at San Juan Generating Station will validate water savings and/or collection, the durability of the modules to withstand hot and cold temperatures, and the preservation of thermal performance integrity of the wet cooling portion.

We Energies, at its Presque Isle Plant in Marquette, MI, is demonstrating the TOXECON™ mercury and multi-pollutant control system.

NETL Concludes Its Successful Mercury Control Program

Coal-fired power plants, municipal waste combustors, and medical-waste incinerators—those are just some of the manmade sources of mercury emissions that have raised environmental concern for decades. Scientists have known for some time that those sources emit mercury into the atmosphere that can eventually be converted into methyl mercury, posing a significant threat to people and animals.

The threat arises when mercury accumulates in the food chain, moving from plants to small animals to large animals and finally humans. Human exposure largely derives from the consumption of fish with high levels of mercury, as evidenced by the fact that at least 43 states at one time or another have issued food advisories regarding high levels of mercury in fish.

Recognizing the potential implications of mercury for fossil-fuel-based power generation, DOE embarked on a comprehensive research program a little more than 15 years ago to develop and demonstrate cost-effective technologies to control mercury emitted from the nation's coal-fired power plants. This program, which has been the premiere mercury research and development initiative for coal-fired plants in the world, was carried out as part of NETL's Innovations for Existing Plants research area that is directed at improving the overall environmental performance of the current fleet of coal-fired power plants. With a portfolio of successful mercury control

technologies developed under the NETL program and the establishment of a federal mercury regulatory framework well underway, future enhancement of mercury capture technology has been transitioned from government to private sector leadership.

Over the 15-year period, NETL cooperatively worked with the U.S. Environmental Protection Agency (EPA), the Electric Power Research Institute (EPRI), power plant operators, state and local agencies, as well as academic institutions and a host of research organizations, to identify factors associated with mercury speciation and capture in the coal combustion process, then develop a successful suite of technologies to address the problem.

The collaborative effort has led to the accomplishment of the goal of DOE's program to bring technology to a commercial readiness that can achieve high levels of mercury removal at costs considerably less than 1999 baseline estimates. The achievement of this goal culminated with the success of DOE's recent field-testing effort initiated in 2000. Coal type and other plant-specific factors determine what percentage of each form of mercury—element, oxidized, and particulate— will be released and how it will be controlled. Therefore, it was critical that the field-testing effort encompass a broad suite of power plant configurations and coal types, particularly those plants burning lower-rank coals that produce the more difficult to capture elemental form of mercury. In response, DOE conducted large-scale field testing of the most promising advanced mercury control technologies on more than 40 coal-fired boilers burning a range of coal types, including bituminous, subbituminous, and lignite, and equipped with a variety of air pollution control devices.

A major focus of DOE's field testing was on the development of activated carbon injection (ACI) technology. ACI involves injecting powdered carbon into the flue gas to grab hold of the mercury. The activated carbon is then captured and removed from the flue gas using the plant's particulate control device. The field program also tested technologies that would enhance the capture of mercury in a power plant's SO_2 control system.

The success of DOE's mercury research and development program is best demonstrated by the fact that over 80 full-scale ACI systems have been ordered by U.S. coal-fired power generators. These contracts include both new and retrofit installations and represent over 41 gigawatts of coal-based electric generating capacity. Approximately 30 gigawatts of existing electric generating capacity (about 9 percent of total U.S. coal-based capacity) will be retrofitted with ACI to control mercury emissions. This includes DOE-developed halogen-treated carbon systems that can capture the elemental form of mercury. The ACI systems have the potential to remove 70–90 percent of the mercury in most applications, at a cost that can dip below $10,000 per pound of mercury removed. By comparison, the cost of technology to capture mercury available in 1999 was estimated to be about $60,000 per pound.

In addition to the commercial success of the technologies developed by DOE's external research teams, researchers at NETL developed and patented two new methods for controlling mercury. In the first patent, researchers extracted partially combusted coal from a boiler and used the unburned carbon as a mercury sorbent. The second patent uses ultraviolet light to convert elemental mercury into an oxidized form that can be captured more readily by existing air pollution control devices.

NETL has taken seriously its role as manager of the federal government's mercury control program over the past 15 years and successfully guided it toward the goal of bringing low-cost capture technologies to the marketplace. Now the "baton" has been passed on to the private sector to continue to improve performance and reduce costs as the nation moves forward in controlling emissions of mercury from coal-fired power plants.

Environment & Economy

Developing Affordable Alternatives

Condensing Heat Exchangers Indicate Potential to Recover Water from Coal-Fired Power Plant Flue Gas—As part of a cooperative agreement with NETL, Lehigh University has developed new designs for condensing heat exchangers to recover water from power plant flue gas while concurrently evaluating the heat rate and emissions co-benefits of installing the exchangers at coal-fired power plants. Initial tests were completed using a smooth-tube heat exchanger bundle with flue gas from an oil-fired boiler located at Lehigh University's powerhouse. The boiler generates flue gas with approximately 14 percent water vapor and sulfuric acid concentrations of approximately 18 parts per million. Data revealed that the sulfuric acid and water vapor condensation processes occurred separately in different exchangers, which indicates that it could be possible to customize the design of each heat exchanger, allocating some for acid removal and others for water vapor condensation. The technology developed in this project will provide coal-fired utilities with a means of producing freshwater from flue gas that would normally be evaporated from the stack. The produced water would be available for power plant operations with an additional potential to remove emissions and increase boiler efficiency by utilizing the rejected heat in the turbine cycle.

State-of-the-Art Technology Makes Produced Water Usable—As part of a cooperative agreement with NETL, collaborators at the University of Texas, Los Alamos National Laboratory, and the New Mexico Institute of Mining and Technology have developed an integrated treatment process that removes more than 90 percent of the organic acids in produced water. The process combines a filtration-and-sorption step using an innovative medium produced from naturally occurring zeolites and a commercially available surfactant combined with a biodegradation step to treat off-gas from medium regeneration. The greatly reduced level of dissolved organics enables downstream demineralization by economical reverse osmosis, making the produced water clean and suitable for power utilities and many other uses.

Produced-Water Management Information System Launched—Argonne National Laboratory, working in partnership with NETL, has created a comprehensive new Web tool that will help oil and natural gas producers tackle produced water challenges. Produced water accounts for 98 percent of all waste generated by U. S. oil and natural gas operations. Since much of the produced water contains high levels of mineral salts, it is unsuitable for beneficial uses or even as surface discharge. The new website contains three modules, one of which directs inquirers to water regulations for more than 30 states and three federal agencies; a second module contains 25 fact sheets describing different technologies used to manage produced water; and the third module contains a question-and-answer tree where yes-and-no answers to questions direct the user to technologies that would be most useful to the inquirer's work site. During the first three weeks the program was open to the public, 57,000 hits were logged, along with nearly 3,300 visitor sessions. This project will enable the oil and gas industry, DOE, and other stakeholders to be aware of water and waste regulatory issues and assist them in responding to these concerns.

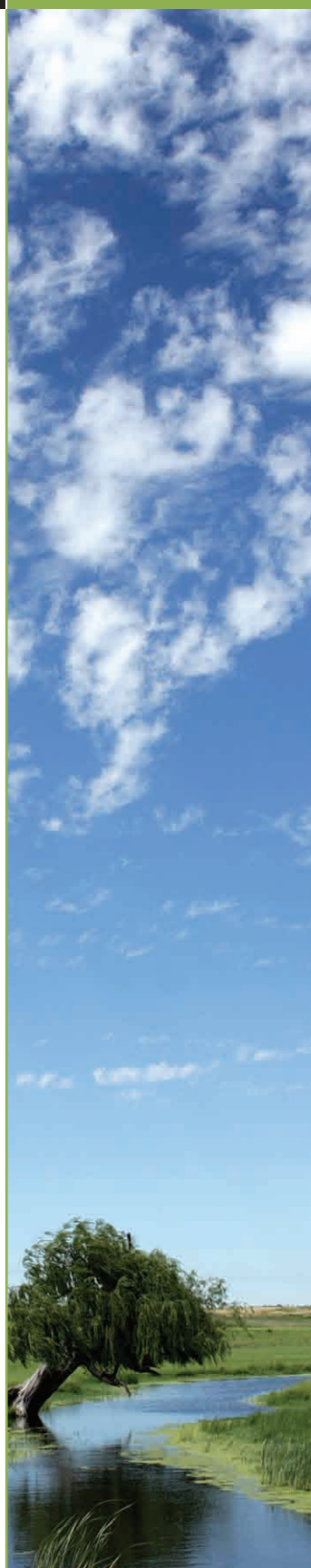
Milestone Reached in Produced-Water Reclamation Technology—A significant milestone has been reached toward the goal of developing an economic membrane system that can reduce the salt content of oil-field produced water to the extent that it is suitable for agriculture and other beneficial uses. The new process for improving the synthesis of hydrophilic zeolite membranes was developed in cooperation with NETL at the Petroleum Recovery Research Center in Socorro, NM. A two-step hydrothermal crystallization process resulted in a highly efficient membrane with good reproducibility. Test results show high efficiency for produced water samples, both actual and simulated. A patent application was filed for the breakthrough technology.

Moisture from Flue Gas Could Provide Power Plant Cooling Water—As part of a cooperative agreement with NETL and industrial partners, investigators at EERC have demonstrated at pilot scale the recovery of water from flue gas using an aqueous solution of calcium chloride as a desiccant (moisture-removing agent). The liquid desiccant dehumidification system recycles a desiccant solution between an absorber tower (packed bed or spray) for contacting the desiccant with the flue gas, and a vacuum flash vaporization and condensation stage for recovering water and re-strengthening the solution. Test results show that the amount of water recovered could allow air-cooled plants to operate at 100 percent capacity during peak periods with sufficient high-quality water for misting the coolers, boiler makeup, and other plant requirements.

Methodology Improves Accuracy Assessment of Toxicity in Coal-Tar-Contaminated Soil—As part of a joint venture with NETL, collaborators at RETEC (which later merged with ENSR) and the University of North Dakota's EERC have demonstrated that the predicted toxicity of polycyclic aromatic hydrocarbons (PAHs) in soil is more accurately determined when based on PAH concentrations in pore-water measurements rather than in sediments, as currently practiced. A paper concerning the findings appeared in the Society of Environmental Toxicology and Chemistry's September 2007 publication of Environmental Toxicology and Chemistry. The method could lead to an improved U.S. Environmental Protection Agency (EPA) standard as well as a standard method from the American Society for Testing and Materials for predicting and measuring the effectiveness of remedial approaches for coal-tar-contaminated sites, such as those where aluminum, steel, and manufactured gas are produced.

Recommendations Incorporated into Environmental Guidelines—Following the initial presentation of the EPA's draft guidelines for pilot-scale geologic carbon sequestration activities, the Ground Water Protection Council, working in cooperation with NETL, formed a small work group of state regulatory officials to review the guidance draft and collect stakeholder input. EPA incorporated several stakeholder and council recommendations into final guidance, demonstrating that input from multiple stakeholders can successfully affect the regulatory process and lead to more cost-effective regulatory approaches.

NETL Partners Make Gains in Electronics Recycling—The Mid-Atlantic Recycling Center for End-of-Life Electronics (MARCEE) has announced its collection of more than 500,000 pounds of electronics waste across the state of West Virginia in 2006 and 2007. Operated by West Virginia University and the National Center for Electronics Recycling and supported by NETL, MARCEE develops methods for separating plastics from end-of-life electronics, examines separation economics, and evaluates the performance of plastic artifacts extruded from recycled plastics. In West Virginia, it has spurred the local recycling industry and increased public awareness of the need for electronics recycling. MARCEE's activities are part of a wider nationwide effort to establish viable electronics recycling options. According to the Consumer Electronics Association, each U.S. household contains more than two dozen pieces of electronics equipment, many of which contain hazardous components. Without programs like MARCEE, most of these products will be discarded in landfills where they leach hazardous waste into the soil and water supply.



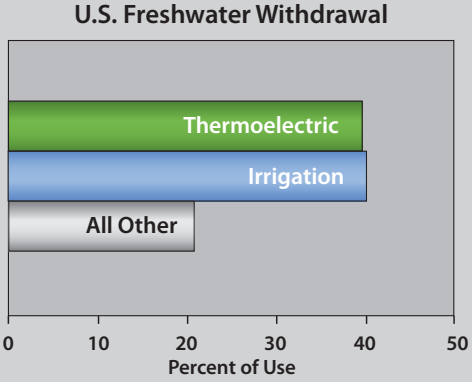
Environment & Economy

Freshwater withdrawal is essential to power production for cooling and other processes. Although the majority of withdrawn water is returned to its source, power plants can have a profound impact on local and regional supplies.

NETL Conducts First-Ever Analysis of the Impact of Carbon Capture Technologies on Water Use

During the last week of September in 2007, with nearly 60 percent of the nation facing drought conditions and cities from California to Florida facing water rationing, NETL released an update to its groundbreaking 2006 report, "Estimating Freshwater Needs to Meet Future Thermoelectric Generation Requirements." The update was the first-ever examination of how technologies to combat climate change could place further pressures on freshwater demand.

Water is a pivotal issue in the nation, since economic development hinges on the availability of freshwater. Public water systems, agriculture, power generation, and other industries all compete for limited water supplies.



Power plants are second only to irrigation in the percent of annual withdrawal in the United States. "Other" withdrawal is made for public supply, industry, mining, etc.

In the United States, the power industry is responsible for a surprising 40 percent of the water withdrawn from freshwater sources each year—about as much as the farming industry uses for irrigation. While the vast majority of this water is eventually returned to its source, power plants still have a profound effect on local and regional water supplies. In several recent cases, construction of new plants has been shelved because water-use permits were not available, and existing plants have been "de-rated," reducing their power output due to low river flows brought on by drought.

The updated NETL report examined what may happen if future policies to combat climate change result in the addition of carbon capture technologies to coal-fired power plants. Since these technologies often require additional water, the report included case study scenarios to predict how much more water could be needed.

Four of the five cases presented in the report predict that, without carbon capture, total water withdrawals by the power industry across the nation will decrease by 2030; however, water consumption—water withdrawn but not returned to the source—is predicted to grow by about a third. With carbon capture technologies added, water withdrawals by coal-fired power plants are projected to increase slightly, while water consumption could nearly double.

The report provides input for future research and development aimed at reducing water use by the power industry. Recognizing the importance of water to the economy, power generation, and life itself, NETL has joined with Sandia National Laboratories to advance research and development leading to the commercialization of technologies to reduce freshwater usage by thermoelectric power plants and minimize the plants' impact on water quality.

Environment & Economy

Developing Affordable Alternatives

Materials & Monitoring—Making Advanced Systems Possible

Advanced materials and processes will be vital to future power and fuel-production plants. Researchers in NETL's Advanced Research Materials program, in partnership with Oak Ridge National Laboratory, address the need for new materials that can withstand the corrosive, high-temperature environments of advanced power-generation technologies such as ultra-supercritical power plants, coal gasifiers, turbines, combustors, and fuel cells. The strides NETL is making in system monitoring and nanoscience are also critical to bringing these systems to fruition.

Reduced Costs Possible with Model That Predicts Corrosion in Gasifier Refractory Material—Collaborators at NETL and Oak Ridge National Laboratory have developed a thermochemical model for predicting corrosion in slagging coal gasifier refractory materials. The average service life of these materials is approximately one year, with some failures as soon as three months. Understanding the corrosive attack mechanisms existing between coal slag and gasifier refractories will help researchers design refractory linings with improved lifetimes, thereby reducing the costly downtime needed for refractory replacement. Initial results were presented at the 21st Annual Conference on Fossil Energy Materials in Knoxville, TN.

Five-Month Field Test of NETL-Designed Corrosion Probes Completed—NETL scientists employed four air-cooled probes of their own design to monitor real-time fireside corrosion in a boiler environment at a commercial waste-to-energy combustion facility owned and operated by Covanta Energy, in Brooks, OR. Results from the five-month field-test demonstrated the following:

- Corrosion rate sensors were able to follow changes accompanying process operations.
- Corrosion rates can be calibrated to mass change measurements.
- Corrosion rates of a nickel-base alloy can be calibrated to corrosion rates of carbon steel.

This technology could allow plant operators to identify process conditions that result in lower wastage of critical boiler components and ultimately facilitate more efficient scheduling of maintenance shutdowns.

Work in Computational Chemistry Promises Far-Reaching Results—Computational and experimental work at NETL, in collaboration with the University of Pittsburgh, has produced the first solid microscopic evidence of "gold-adatom-mediated" bonding in the self-assembly of chemical compounds containing sulfur and alkyl groups on a gold surface. This is a type of bonding where some of the metal molecules—in this case gold—actually insert themselves into the sulfur-sulfur bond of the organosulfur compound. The discovery—achieved through the combined use of low-temperature scanning tunneling microscopy and density functional theory calculations—holds great promise for the development of the field of heterogeneous catalysis and nanoscience. The bonding properties of organosulfur compounds, and in particular of the self-assembled molecular monolayers, are of interest in many areas of fossil energy research and development, such as improved lubricants, chemical sensors, nanocatalysts, and molecular electronics. The finding was presented in a paper published in the October 6, 2006, issue of *Physical Review Letters*.

New Technology Has Potential to Significantly Impact Nanoscience—Collaborators at NETL and the University of Pittsburgh achieved a record spatial resolution in imaging chemical species—10 nanometers—which is a thousand times better than previously possible. By being able to identify the chemical nature of these nanoscopic objects from their spectral "fingerprints," this breakthrough can have significant impact in fossil energy applications, advancing the understanding of chemical and morphological changes in materials composed of diverse ingredients, such as fossil sediments. Researchers used advanced apertureless near-field scanning infrared microscopy to identify iron

carbonyl isomers by imaging bridging carbonyl vibrations induced by a carbon dioxide (CO_2) laser in nanoparticles. By using these results to model the spectral properties of much larger organic and organometallic systems, the technique will potentially further the development of nanoscience, especially microbiology and nanoelectronics. A paper describing the research appeared in the American Chemical Society's February issue of *Langmuir.*

New Alloys Offer Lower-Cost Alternative to Nickel-Based Superalloys for Advanced Coal-Fired Boilers—A family of inexpensive, highly stress-resistant stainless steels composed mostly of austenite has been developed by researchers at Oak Ridge National Laboratory in cooperation with NETL. The alloys develop a protective scale formation that was achieved when the development team reduced their aluminum content by substituting niobium carbide for the usual strengthening agents of titanium and vanadium. Smaller amounts of aluminum permitted stabilization of the matrix structure while providing excellent stress resistance. As described in the April 20, 2007, issue of *Science* magazine, these alloys offer a lower-cost approach to substantially increasing temperature limits for structural components operating in the aggressive oxidizing environments encountered in energy-conversion systems.

New Micro-Indentation Method Requires Only Small Samples to Determine Alloy Properties—Researchers at West Virginia University, participating in the University Coal Research program managed by NETL, have developed and validated a simple micro-indentation test method that characterizes material hardness using small samples in situ. The technique was developed as part of a project aimed at enhancing the ductility of molybdenum- and chromium-based alloys by the addition of metal oxide dispersions. The novel method eliminates the need for sophisticated displacement sensors for indentation depth measurement and could provide the basis for a portable micro-indentation instrument for onsite component inspection and surface mechanical property evaluation while the component is in service.

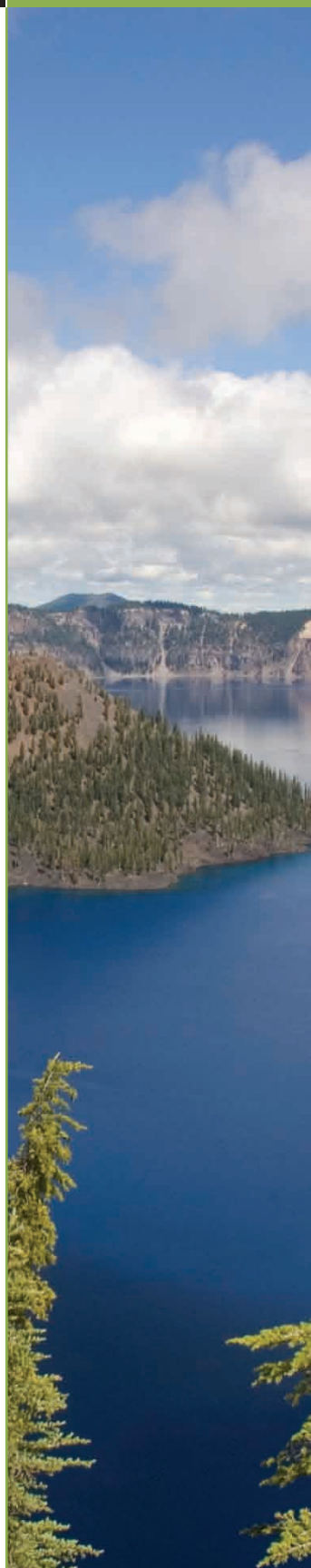
NETL-Administered Grants Yield Advances in Sensor Technology Development—Research in sensor technology, conducted under NETL-administered grants for the Office of Fossil Energy's University Coal Research/Historically Black Colleges and Universities program, was successfully concluded at four universities:

- A project team at the University of Alabama, Birmingham, developed an online capacitance-based corrosion-monitoring technology for rapid determination of fireside corrosion rates in coal-fired boilers.

- The Pennsylvania State University researchers developed and patented an intelligent distributed sapphire fiber optic sensor system for real-time monitoring of boiler furnace temperature.

- Morgan State University researchers designed and tested a novel temperature measurement system featuring a thermocouple coated with a protective intermetallic ceramic coating and uniquely equipped with high-pressure oxygen cleaning and ultrasonic dirt-peeling capabilities to improve performance and longevity.

- A research team at the University of Connecticut examined the feasibility of using sapphire fibers for optical sensing when placed directly in the harsh environment of advanced coal conversion processes.



Environment & Economy

Pouring a cast steel P-900 hatch for the Bradley Fighting Vehicle.

U.S. Army Using Cast Steel Armor to Protect Troops

To protect U.S. soldiers and military vehicles from improvised explosive devices (IEDs) and explosively-formed penetrators, the Department of Defense is purchasing ten million pounds of a unique cast steel armor called P-900, developed over the past two decades by NETL researchers. This cast armor will retrofit certain military vehicles to protect the soldiers riding in them. A number of foundries will need to produce over 100,000 castings within the Defense Department's specified period.

Over the course of the last 20 years, NETL scientists have worked with the Army Tank and Automotive Command (TACOM), one of the Army's largest weapon systems research, development, and sustainment organizations, and the Army Research Laboratory (ARL) to develop and continuously improve P-900. The research team has used a modified steel casting process called the "lost foam process" to produce cast-slotted steel armor. Recently, NETL scientists and technicians have produced castings for ARL using a new heat treatment to optimize ballistic performance against IEDs. When ARL engineers performed ballistic testing and evaluation on a series of test plates, they proved so successful that TACOM immediately put out the market call.

TACOM and NETL contacted foundries throughout the United States to produce the armor. To lay the groundwork for full-scale production, NETL met with various Defense Department offices to ensure that selected foundries meet program goals and to help the Department prepare the specifications.

Because the need for the armor is pressing, NETL has helped some foundries qualify to produce large quantities of castings by providing technical expertise and polystyrene patterns for making test targets. NETL is also helping jump-start the production process by furnishing TACOM with pattern tooling to make additional patterns while the foundries await full-size patterns.

Once the selected foundries are deemed qualified, the Army will proceed with full-scale production at a rate of 100–600 castings per day at each foundry. Foundries using NETL's lost foam process will produce a significant portion of the 100,000-plus initial castings required by the Department of Defense.

Environment & Economy

Developing Affordable Alternatives

Turbines—Targeting Ultra-Low Emissions

From the in-depth understanding of flame dynamics to the design and engineering of leading-edge turbomachinery, NETL researchers are at the forefront of the science and technology of turbines—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 will remain 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 high-performance, near-zero-emission turbine technologies that eliminate environmental concerns with future coal use. Researchers at NETL also have the use of—and make available to others—their unique laboratory facilities and equipment to evaluate new concepts in combustion, sensors, and turbine materials.

Dilute-Combustion Concept Demonstrated at NETL—A dilute hydrogen-diffusion combustion concept is being developed as an approach for reaching the Office of Fossil Energy's nitrogen oxide (NO_x) emissions target level of 2 parts per million. Initial test results showed that combining nitrogen-diluted hydrogen fuel with diffusion combustion—a process in which the fuel and air are not premixed before combustion—lowers the flame temperature, thus appreciably reducing NO_x formation and emissions. Researchers conducted the tests in NETL's Simulation Validation optical combustor, which uses high-fidelity optical instrumentation and high-speed video imaging to observe combustion phenomena at realistic turbine operating conditions.

Next-Generation Combustion Control and Diagnostics Sensor Enables Improved Turbine Control—NETL's Combustion Control and Diagnostics Sensor, a first-generation flame ionization sensor, detects flame flashback and lean blow-out (flameout due to insufficient fuel) by measuring resistance across the flame inside the turbine combustor. The newest-generation sensor, the Time Varying Combustion Control and Diagnostics Sensor, uses the flame capacitance to provide an improved estimate of the fuel-to-air equivalence ratio—a key parameter for ultra-low emissions performance. Both sensor systems provide real-time in situ monitoring of combustion to allow sustained ultra-low emissions performance with flame stability over a wide operating margin and will enable improved control for turbines operated with coal-derived synthesis gas and hydrogen fuels.

Laser Spark Plug Prototype Successful in Proof-of-Concept Tests—Using a natural gas-fired single-cylinder test engine, researchers at NETL have shown that a miniaturized laser can function as a rugged spark ignition source. This project was aimed at producing an ignition source that could extend the operational limit of traditional spark plugs. Early tests with a lab-scale laser system demonstrated that using a laser as an ignition source can greatly reduce NO_x emissions by utilizing a leaner fuel and air mixture. Thermal efficiency of the engine can also be increased by increasing the working pressure. The laser igniter overcame severe ignitability issues that traditional spark plugs face in operating under lean-burn and high-pressure conditions. NETL researchers focused on the optical design of the laser spark plug to provide spark performance that exceeds that of a traditional spark plug, with comparable input power levels. Since the initial tests, the research group has developed and is presently testing a more rugged design that improves spark consistency. The group is also developing a spark distribution system for multicylinder engines and is currently looking for and working with commercial partners.

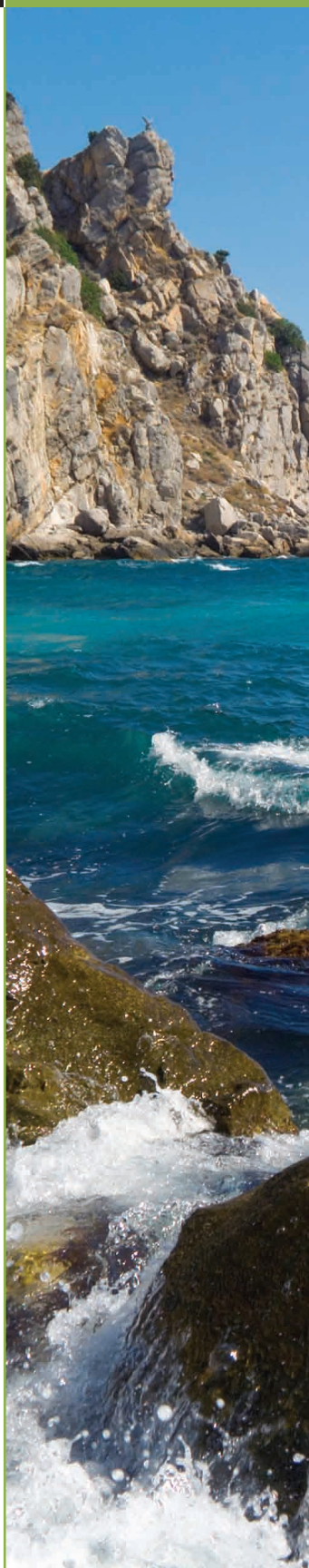
Fuel-Flexible Gas Turbine Passes the Test—In cooperation with NETL, engineers at the GE Energy gas turbine technology laboratory in Greenville, SC, demonstrated stable performance and low NO_x emissions in a full-scale combustor test rig running on a fuel mixture of 90 percent hydrogen and 10 percent nitrogen. This first-in-a-series test confirmed that the low NO_x levels previously achieved by a single-nozzle combustor running on high-hydrogen fuels can be replicated at full scale. The success of the test represents a significant milestone in

developing fuel-flexible integrated gasification combined cycle (IGCC) applications.

Revolutionary Compressor Concept Demonstrates World-Record-Breaking Performance—As part of a cooperative agreement with NETL, engineers at Ramgen Power Systems, Inc., of Bellevue, WA, have demonstrated a simpler, more efficient air compressor design based on supersonic flight intake technology. "Ramjet shock wave compression" can achieve pressure ratios near 8:1, which is twice the world record for a single-stage axial design. Developing higher-pressure ratios per stage decreases aerodynamic loss, project costs, and number of stages. At approximately 5 percent the size, 33 percent the cost, and with higher heat recovery than current designs, the novel design offers significant support of national goals for low-cost, high-efficiency carbon capture.

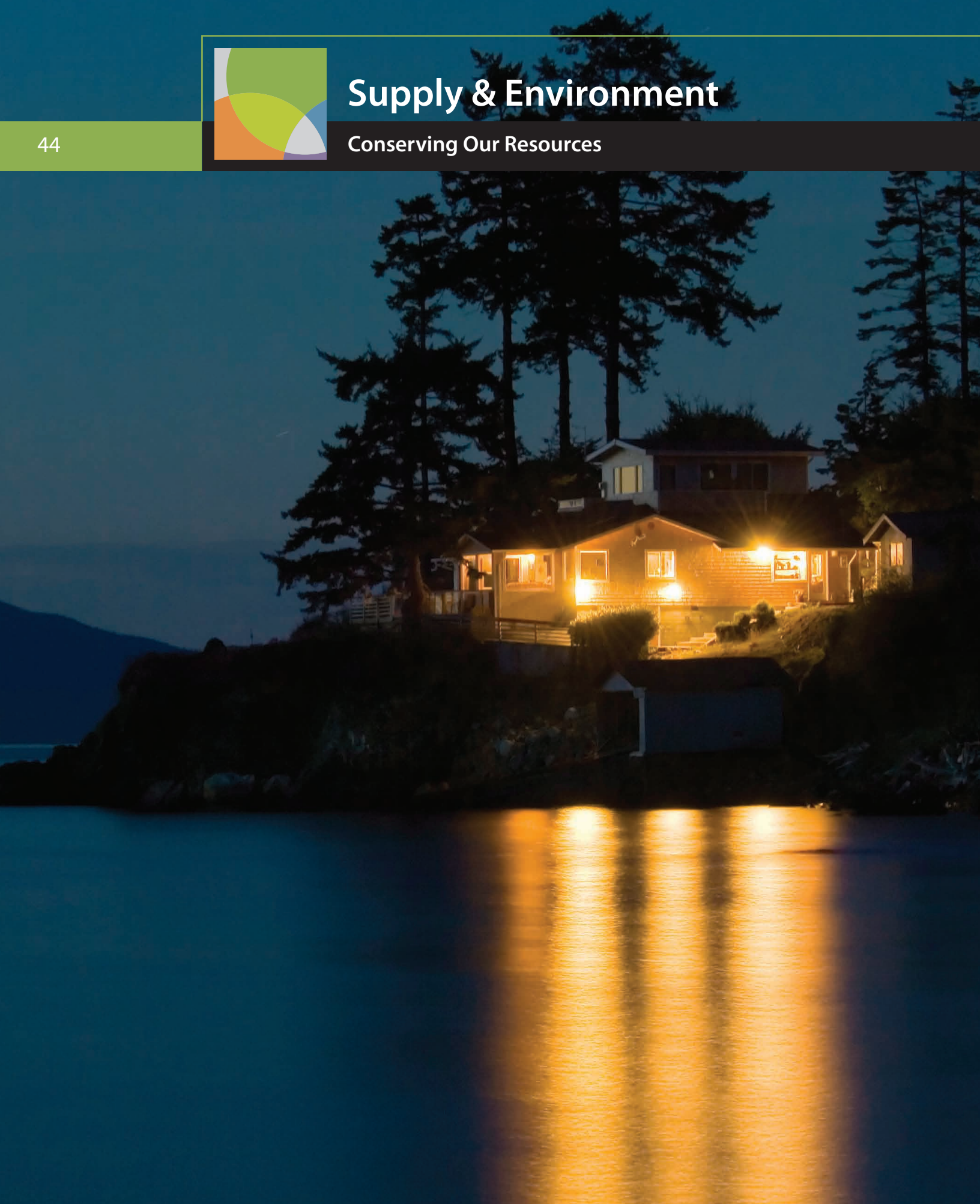
Wireless Sensors Prove Themselves in Industrial Gas Turbines—As part of a Small Business Innovation Research grant managed by NETL, MesoScribe Technologies, Inc., Stony Brook, NY, created an innovative method for embedding wireless temperature and strain sensors in the thermal barrier coatings that protect intricate turbine parts from extremely harsh operating conditions. The method attracted the attention of Siemens Power Generation, Inc., which joined with MesoScribe to demonstrate the sensors in industrial gas turbine engines. The technology provides industry an improved process for remotely monitoring the structural health of turbine blades in real time. Its deployment will increase the time between maintenance intervals, thereby reducing overall maintenance costs.

Modification Allows Commercial Microturbine to Burn Very Low Btu Fuel Successfully—Investigators at the University of North Dakota's EERC fired a modified version of a Capstone MicroTurbine™ C30 on gases having a low heating value—below the 350 Btu per standard cubic foot that is the manufacturer's lower limit. As the fuel-energy content decreased, NO_x emissions also decreased, but unburned hydrocarbons remained below 0.2 parts per million. Although carbon monoxide emissions increased, catalytic converters can be applied to remove it where that is a concern. Breaking the lower-energy barrier unlocks many opportunities not previously considered feasible, such as using normally flared waste gases associated with oil production to produce valuable electricity for oilfield operations while releasing considerably less NO_x. Part of a larger cooperative agreement, this subtask is managed by NETL.



Supply & Environment

Conserving Our Resources



Every study and forecast shows that supplying America's growing power demands will—in the foreseeable future—rely on fossil fuels. Around 80 percent of the world's energy is expected to come from fossil fuels until at least 2030. How will we supply our growing energy needs while protecting our environment? One way is through moderating energy use by improving energy conservation in our homes, vehicles, and businesses. NETL lends its expertise to a diverse selection of projects focused on advanced conservation technologies, state energy and weatherization assistance programs, and technologies that supply clean power from fossil energy. Another way to conserve our resources is by developing energy-efficient and emission-free ways to use abundant U.S. coal resources, including coal gasification and fuel cells that run on coal-derived synthesis gas.

Supply & Environment

Conserving Our Resources

Demand-Side Efficiencies—Helping Consumers Save Energy

NETL pursues a broad array of methods to help consumers conserve our national energy supply. Economic and effective methods to reduce power consumption and save costs are at the forefront of the laboratory's research. These methods range from helping low-income families reduce heating bills to supporting companies that provide breakthrough technologies to burn diesel fuel more efficiently. An additional benefit of NETL's focus on assisting consumers is the generation and maintenance of thousands of jobs through direct and indirect employment. Involving consumers in the energy conservation process is a win-win situation for all involved.

Advanced Tractor Trailers Use Less Fuel—With support from NETL, the Truck Manufacturers Association has developed a variety of unique aerodynamic devices and concepts that significantly reduce aerodynamic drag on commercial-line tractor trailers. The association achieved a 23 percent reduction in drag and an 11 percent improvement in fuel economy by outfitting demonstration vehicles with advanced mirrors, underbody trays, tractor-trailer gap devices, trailer tails, and trailer side skirts. Association members involved in the project, including Freightliner, International Truck, Mack, and Volvo, focused their efforts on modifications that are practical, serviceable, and effective in order to maximize their potential for incorporation into production vehicles.

Cummins Improves Diesel Engine Efficiency—Cummins Inc., in cooperation with NETL, is making great strides toward improving diesel engines for tractor-trailers and pickup trucks. In its 6.7-liter light-duty ISB diesel engine, Cummins demonstrated a greater-than-target 10 percent efficiency improvement and met the U.S. Environmental Protection Agency's 2010 target of 0.2 grams per mile NOx emissions without after-treatment. Cummins also saw 7 percent efficiency improvements and met the EPA target of 0.2 grams per brake-horsepower-hour with its 15-liter ISX heavy-duty diesel engine. Advanced turbocharging and cooling systems that recirculate exhaust gas have been the primary enabling technologies for achieving these outstanding results. Cummins estimates that, through the design of additional subsystem technology, it has achieved additional efficiency improvements of up to 5 percent for both engines. These improvements will be evaluated in subsequent engine testing.

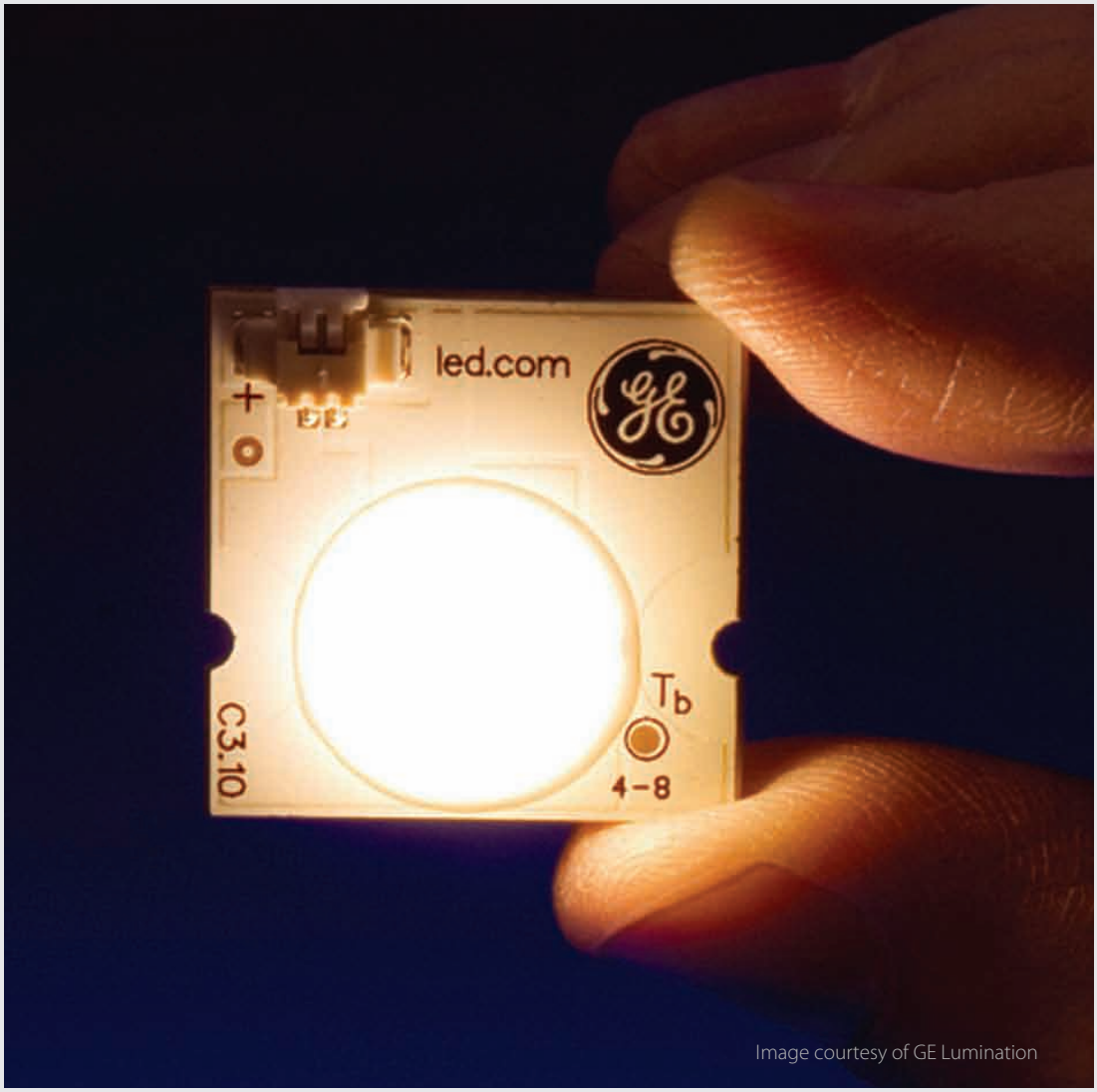
Locomotive Fuel Injection Advances into the 21st Century—With NETL support, General Electric (GE) has developed and demonstrated an advanced fuel injection system for locomotives that consumes 2–3 percent less fuel and meets EPA 2010 emissions targets. To achieve these improvements, GE successfully scaled up the common rail injection system, which is used in today's top-of-the-line automotive diesel engines. With its breakthrough technology, GE achieved system pressures reaching more than 1,800 bars, increased process control, and attained faster injection rates, all leading to a cleaner, more efficient burn than traditional production unit pump systems can produce. Results were confirmed at GE's Global Research Center using the center's locomotive single-cylinder test engine. The test engine permits real-time measurement of particulate emissions and is equipped with a visualization system that allows researchers to see spray and flame characteristics first hand. In future work, GE will seek to increase fuel savings even further by optimizing the system's multiple injection strategy.

Clean Cities Coalitions Displace Gallons of Gasoline by the Millions—In June 2007, Clean Cities Coalitions around the nation reported they had displaced the equivalent of 375 million gallons of gasoline in 2006, a 50 percent increase from their 2005 displacement of 250 million gallons. The coalitions are on track to displace 3.2 billion gallons of gasoline per year starting in 2020, exceeding their established goal by 700 million gallons. The results, which are typically published in June of the calendar year following the reporting period, indicate the impact of the Office of Energy Efficiency and Renewable Energy's Clean Cities program. Through almost 90 locally based coalitions, the program works with government and industry partners to reduce petroleum consumption in the

transportation sector. Clean Cities Coalitions are composed of local, state, and federal agencies; public health and transportation departments; transit agencies and other government offices; and auto manufacturers, car dealers, fuel suppliers, public utilities, public and private fleets, community business groups, and professional associations. NETL provides guidance and support to the Clean Cities Coalition programs.

Weatherization Assistance Program Grants Total $242 Million in Federal Funds—On average, low-income families spend 15 percent of their income on energy, compared to the 3 percent average nationwide. Through DOE's Energy Efficiency and Renewable Energy's (EERE) Weatherization Assistance program, NETL and EERE's Golden Field Office collaborate with state and local agencies to help these families make their homes more energy efficient, thus reducing energy bills by an average of $403 per year. Weatherization programs operate in all 50 states, the District of Columbia, and among Native American tribes. Approximately 900 local agencies deliver weatherization services to eligible residents in every county in the nation. In the 2006 program year, which ended September 2007, $242 million in federal funds were used to help weatherize 104,125 homes. On average, participant heating bills were reduced by 32 percent, and each dollar invested returned $2.69 in energy- and non-energy-related benefits. Across the nation, the Weatherization Assistance program generates 8,000 direct jobs and thousands more through indirect employment. It also decreases overall U.S. energy use by the equivalent of 18 million barrels of oil annually.

State Energy Program Promotes Clean Energy, Creates Jobs—Co-managed by NETL and the Golden Field Office—the primary field agent for EERE—the State Energy program distributed $45.5 million in fiscal year 2007 across all 50 U.S. states, plus its territories, the Commonwealth of Puerto Rico, and the District of Columbia. By adding an additional $150 million in cost share and leveraged funds, recipients developed and expanded state energy programs aimed at increasing energy efficiency, reducing energy use and costs, pursuing alternative and renewable energy sources, promoting environmental quality, stimulating economic development, and reducing U.S. reliance on imported oil. In one example of the program's success, Pennsylvania awarded a total of $5.4 million to 28 participants in its Energy Harvest program, which seeks to develop innovative environmental and energy solutions. The grants will leverage almost $14 million in private investment and create or retain more than 100 jobs throughout the state. Individual projects are expected to generate 18.5 million kilowatt hours of clean electricity, replace 3.1 billion Btu of natural gas and 225,000 gallons of petroleum-based fuel, reduce CO_2 emissions by 29 million pounds, and prevent 204,000 pounds of SO_2 and 56,000 pounds of NO_x emissions.



The Vio™ high-power white LED by GE Lumination utilizes proprietary phosphors to create a warm, white light.

NETL Supports "Brightest Ideas" in Solid-State Lighting Technologies

Just as integrated circuits replaced electron tubes some 50 years ago, the traditional incandescent light bulb—and even fluorescent bulbs—are poised to be upstaged in the next few years. DOE has set a target date of 2015 to replace many of today's incandescent and fluorescent lighting systems with solid-state lighting technologies. Such a "revolution" in lighting could ultimately cut the global use of electricity for lighting in half and at the same time— dramatically reduce the amount of carbon emissions by reducing the amount of electricity generation required of fossil-fuel-based power plants.

NETL researchers believe that the new revolution in lighting is a "bright idea" and thus managed a number of projects in fiscal year 2007 to move that idea toward fruition. In cooperation with the Solid-State Lighting program, administered through EERE, NETL set its sights on the broad mission of creating energy-efficient, long-lasting lighting technologies that are cost-competitive with conventional fluorescent lighting and that emit a warm, white light comparable to incandescent lighting.

Solid-state lighting refers to a variety of light-producing semiconductor devices, including light-emitting diodes (LEDS) and organic light-emitting diodes (OLEDs). While LEDs have historically been found in devices such as digital clocks, watches, and remote controls—and more recently in exit signs, traffic signal, and vehicle brake lights—OLEDs are more typically found in commercial products such as mobile phone screens, portable digital music players, and digital cameras.

Four LED and OLED projects managed by NETL in fiscal year 2007 have helped to illuminate the breakthrough potential of solid-state lighting.

Building on research sponsored by NETL, GE Lumination, LLC, has marketed an advanced light LED, called Vio™, for use in landscaping, commercial displays, and other applications. Compared to today's cool LEDs, Vio's light is warm and white, very similar to a soft, white incandescent light. The commercial success of Vio moves this LED technology a step closer to replacing less-efficient incandescent and fluorescent light sources. NETL sponsored the research of advanced ultraviolet LED and phosphor combinations developed by the University of Georgia in collaboration with GE Global Research and GE Lumination that led to Vio.

In another project managed by NETL, researchers at Los Alamos National Laboratory developed a novel technique to grow various crystalline materials from a liquid base and applied that technique to the development of OLEDs. The liquid-based technique is used to quickly test the suitability of crystal compositions for critical use as a highly transparent, electrically conductive OLED layer. Solid-state, mercury-free OLEDs are more environmentally friendly than fluorescent tubes and can be up to 10 times more efficient than conventional incandescent light bulbs. Also, OLEDs can be arranged in aesthetically pleasing configurations, and the spectral properties of their light can be electrically controlled.

Working under an NETL-managed Small Business Innovation Research grant, researchers at the Universal Display Corporation demonstrated an all-phosphorescent white OLED, a significant achievement because it represents a milestone toward DOE's goal. The warm, white emission from this OLED renders a color that closely resembles the light of incandescent lamps, which the OLED is expected to replace.

Cree, Inc. fabricated a white multi-chip LED array prototype that delivers a luminous rate that exceeds DOE's milestone for fiscal year 2007. Cree's LED array is based on a chip called EZBright™ combined with prototype packaging technology that uses improved materials and optimized circuit design layout. The EZBright chip was developed in part by DOE funding.

The continued development and commercial use of solid-state lighting is expected to have a significant future impact. In the United States, lighting accounts for more than 8 percent of all the energy used, the equivalent of 22 percent of all the electricity produced. Consumers pay an estimated $58 billion a year for lighting.

Supply & Environment

Conserving Our Resources

Fuel Cells— Clean, Economical Electricity from Coal

NETL's vision for fuel cells is to develop the ultimate power system with essentially zero emissions, the highest efficiency, and overall lowest cost. 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. The fuel cell technologies that are being developed and demonstrated today will ensure that economical, environmentally friendly electricity will be available to America for the foreseeable future

New Processes Revitalize an Old Metallurgy, Improve SOFC Performance and Cost Efficiency— In an inter-agency collaboration, researchers at Allegheny Technology Inc. (ATI), NETL, and Pacific Northwest National Laboratory have successfully modified the metallic alloy AISI 441 to help achieve SOFC electrical interconnect requirements for lifetimes of 40,000 hours or more. AISI 441 is an inexpensive ferritic stainless steel that, with the addition of a manganese cobalt spinel coating, hinders chrome depletion and reduces oxidation. Recent experiments at Pacific Northwest National Laboratory indicated that testing on coated AISI 441 exhibited a very low and constant area-specific resistance over 1,000 hours of testing. A rare earth treatment that reduces oxidation without vacuum melt and a manufacturing process that reduces silica formation, also without vacuum melt, have been developed by NETL and ATI respectively. In addition to these breakthroughs, the cost of large-scale manufacturing and processing of AISI 441 is predicted to be 10 times lower than the cost of producing state-of-the-art, high-temperature metal alloys suitable for SOFC electrical interconnect service.

Sorbent Captures Both Sulfur and Fuel Cell System Market—Under a Phase II Small Business Innovation Research grant administered by NETL, product developers at TDA Research, Inc., in Wheat Ridge, CO, have developed a low-cost, high-capacity sorbent that can reduce the concentration of sulfur species to parts-per-billion levels in natural gas and liquefied petroleum gas. With a high capacity and removal efficiency for naturally occurring sulfur compounds and sulfur-bearing odorants, the SulfaTrap™ sorbent can be used to prevent SOFC performance degradation or catalyst poisoning in fuel processors that generate hydrogen from natural gas.

SECA Fuel Cell Development Program Surpasses Phase I Targets— The SECA program is designed to drive down the cost of solid oxide fuel cells (SOFCs) by developing new high-tech materials and processes. The program is focused on developing commercial-grade fuel cells with a market-competitive $400-per-kilowatt manufactured cost by 2010 producing fuel cell technology usable in virtually any size application that requires electricity or combined electricity and heat. Concurrently, the scale-up, aggregation, and integration of SECA's technologies are leading to the validation of prototype megawatt-class products in 2012 and 2015. SECA's coal-based fuel cell system projects are developing megawatt-class fuel cell power systems that will produce affordable, reliable, efficient, and environmentally-friendly electrical power from coal.

Six SECA industry teams have completed tests of the first SOFC prototypes that can be manufactured at costs approaching those of conventional stationary power-generation technology. Managed by NETL and led by Acumentrics, Cummins Power Generation, Delphi Automotive Systems, FuelCell Energy, General Electric, and Siemens Power Generation, respectively, each team designed and manufactured SOFC electrical power generators in the 3–10 kilowatt range. The generators then underwent a series of rigorous tests to evaluate system performance with respect to efficiency, endurance, availability, and production cost. Results were verified by independent audits, and additional validation testing was performed at the NETL fuel cell test facility. The prototypes exceeded Phase I programmatic targets by demonstrating the following:

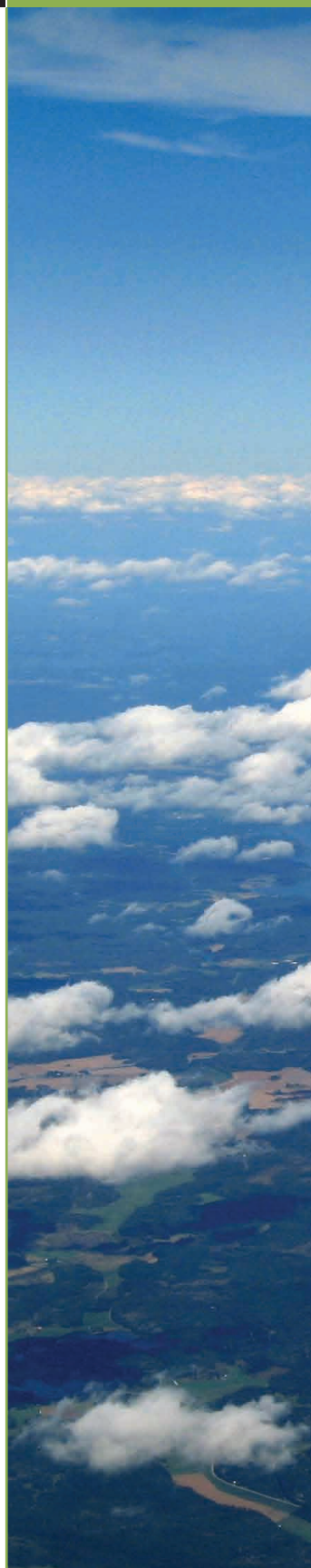
- An average efficiency of 38.5 percent, with a high of 49.6 percent; the target was 35 percent.
- Average steady-state power degradation of 2 percent per 1,000 hours during steady-state operation; the target allowed 4 percent per 1,000 hours.

- System availabilities averaging 97 percent; the target was 90 percent.

- Projected system costs ranging from $724–$775 per kilowatt, positioning the teams to meet the 2010 target of $700 per kilowatt (2007 dollars).

Efficiency Goal Exceeded in Power Electronics Technology Development—In cooperation with NETL, researchers at Virginia Polytechnic Institute and State University have developed a device that enhances the efficiency of power conversion. Employing high-performance digital control techniques and advanced high-power solid-state switches with high-efficiency switches that sense when energy losses are at a minimum, the device can boost 50 volts direct current to 400–460 volts direct current with energy efficiency greater than 97 percent. Subsequently, this advancement enabled the development of a compatible 99 percent efficient direct-current-to-alternating-current inverter to convert the 400–460 volts direct current to 120 and 240 volts alternating current suitable for multiple power applications. This energy-efficient power electronics technology reduces fuel consumption as well as the size of fuel cell systems, helping to meet the performance and cost targets of the SECA program.

Propane-Powered Fuel Cell Operates for 1,100 Hours in Remote Alaska—A 5-kilowatt SOFC system, supplying electrical power and heat to the visitor center at the Exit Glacier Nature Center at Kenai Fjords National Park, AK, operated for 1,100 hours with no notable degradation in performance. This feat was achieved by researchers at the University of Alaska Fairbanks in cooperation with NETL. The demonstration test displayed improvements resulting from SECA support in reforming both technology and stack design by the fuel cell system supplier, Acumentrics Corporation of Westwood, MA, which is one of six SECA industry teams. The National Park Service's use of fuel cell systems in a remote setting also demonstrates the remarkable versatility and fuel flexibility of SECA systems developed for coal applications.



Phipps Conservatory and Botanical Gardens, Pittsburgh, PA, is a recognized leader in green building practices and sustainable operations.

Conservatory Turns to "Green" Power

Siemens Power Generation (SPG) engineers recently installed a 5-kilowatt solid oxide fuel cell (SOFC) system in the Phipps Conservatory and Botanical Gardens in Pittsburgh, PA—the first conservatory in the world to use such a power source. The SPG-developed and manufactured SOFC system in the conservatory is a highly visible public demonstration of the high-efficiency, low-emission SOFC technology developed in cooperation with NETL. SOFCs are among the most energy-efficient and environmentally clean technologies available today.

Phipps Conservatory recently opened the Tropical Forest Conservatory, a 12,000-square-foot, 60-foot tall addition to its Victorian glasshouse that was originally built in 1893. While the Tropical Forest Conservatory boasts many green attributes—such as passive solar climate control, double-pane glass in the north sloping roof to reduce heat loss, and remotely controlled cloth energy blankets that provide summer shade and prevent heat loss in cold weather—the SOFC is the crowning "green" technology, generating electricity as well as thermal energy for the in-house hot water system from natural gas—without combustion.

The SOFC system at the Phipps Conservatory, which is located near the campuses of both Carnegie Mellon University and the University of Pittsburgh, has accumulated over 8,000 hours of operation to date, with an availability of more than 85 percent, delivering 4 kilowatts of electrical power and providing 4 kilowatts for heating water. The primary by-products of the fuel cell are heat, water, and CO_2, which are later used in adjacent production greenhouses. Phipps plans to keep the quietly operating SOFC on public display to educate visitors on the benefits of fuel cells.

The Phipps officials ultimately plan to fuel an SPG 100 kilowatt class SOFC system with gas generated from the Conservatory's decomposing biomass—such as plant cuttings, waste paper, etc. SPG, leader of one of six SECA coal-based systems industry teams managed by NETL, is assisting the program by focusing on developing of SOFC technology suitable for large fuel cell power systems (greater than 100 megawatts) that will produce affordable electrical power from coal with 45–50 percent overall efficiency.

The project was co-funded by the Department of Energy. Cost-sharing was provided by Phipps, the Pennsylvania Energy Development Authority, and SPG.

An NETL-sponsored solid-oxide fuel cell system powers the newly built Tropical Forest Conservatory at Phipps.

Phipps Conservatory is the first conservatory in the nation to install a "green" solid oxide fuel cell that provides electrical power without byproducts such as nitrous or sulfur dioxide. A second fuel cell is planned that will run on methane generated from an anaerobic waste generator, with its only emission—CO_2—pumped back into the greenhouse to be sequestered by plants.

Supply & Environment

Conserving Our Resources

Gasification—Coal Power with Near-Zero Emissions

Gasification is a method for converting carbon-based materials ("feedstocks"), such as coal, biomass, petroleum coke, etc., into synthesis gas, which can then be used to produce clean electrical energy, transportation fuels, and various useful chemicals. NETL's gasification program is developing advanced technologies that will reduce gasification's relatively high cost, improve its thermal efficiency, increase its reliability, and broaden its ability to operate economically on multiple feedstocks. Gasification-based plants of tomorrow will produce power and other products with near-zero emissions of criteria pollutants while simultaneously capturing CO_2 for safe and permanent storage in geologic formations far underground. By using coal—our country's most abundant energy resource—as the main fuel, these gasification-based plants will contribute to enhancing our nation's energy and economic security..

Supported Liquid Membrane Promising for High-Temperature Capture of CO_2—NETL researchers have successfully fabricated and tested a supported liquid membrane that remains stable at temperatures greater than 300 °C, which is far in excess of the usual 100 °C limit for such systems. The high-temperature membrane system promises to be useful for carbon capture in integrated gasification combined cycle (IGCC) power plants. The membrane consists of an advanced polymer substrate and an ionic liquid and was developed under a Cooperative Research and Development Agreement with the University of Notre Dame.

New Material Has CO_2-Separation Potential—Using a sophisticated analytical technique involving infrared spectroscopy, NETL researchers have found a new adsorbent that has a greater preference for CO_2 than hydrogen—a property that could be of use in gas separation applications. The new adsorbent is a microporous inorganic crystal similar to the industrial dye Prussian Blue. These materials are relatively easily made and quite stable. Results of this basic science study in gas adsorption were published in the highly regarded scientific publication *Journal of Physical Chemistry C* in the January 2007 issue.

Nanocatalysts Nearly Five Times More Effective in Producing Synthesis Gas—NETL researchers collaborating with University of Pittsburgh faculty have completed a detailed study of a novel catalyst that demonstrates enhanced synthesis gas-producing capabilities. Previous work has shown that with 20 times less platinum, this nanocatalyst is nearly 5 times more effective than conventional alumina-supported catalysts in producing synthesis gas from the partial oxidation of methane. The nanocatalyst consists of a barium hexa-aluminate support embedded with platinum nanoparticles.

Industrial-Size Gasification Investigated as a Means to Refuel U.S. Industries—NETL performed an analysis to evaluate the technical and economic merit of using coal-derived synthesis gas and substitute natural gas (SNG) to refuel U.S. industries that have been challenged by the volatility of and increase in domestic natural gas prices. The application of industrial-sized gasification to provide SNG, synthesis gas, steam, and/or power to energy-intensive U.S. industries was assessed to help guide further research and development. The study included an investigation of the energy-demand profile of potential U.S. industrial customers that could benefit from coal gasification, identifying more than 300 industrial facilities with energy needs that have the potential to be satisfied by industrial-sized gasification. Technical analysis indicates that the gasification technology considered, the BGL 1000, could be viable for 33–66 percent of those facilities under specific economic scenarios. Since publication of the report, Great Northern Power Development, L.P., and Allied Syngas Corporation announced the development of a $1.4 billion coal gasification project in North Dakota based on the BGL 1000 technology.

Process for Low-Cost Oxygen Production Reaches Operational Milestone—Engineers at Air Products and Chemicals, Inc. (APCI), cycled two oxygen-production modules with commercial-scale ion transport membranes (ITM) between "idle" and "full" operating conditions in the five-ton-per-day subscale prototype facility. The ability of membrane modules to cycle between these operating conditions without experiencing structural or mechanical failure or performance degradation indicates that the materials and architecture for the technology can withstand the necessary stresses of operation. The

ITM oxygen process is being developed by APCI of Allentown, PA, in cooperation with NETL. The new process will produce oxygen at a nearly 33 percent lower cost and energy requirement than conventional cryogenic processes. It can be used in advanced power generation systems, including IGCC plants and stand-alone plants.

Significant Progress Made in Gasification of Lignite Coals—Developed in cooperation with NETL and Kellogg Brown & Root, a semiworks-scale transport gasifier operated successfully during tests using both Powder River Basin (PRB) subbituminous coal and high-sodium (greater than 7 percent by weight) North Dakota lignite coal supplied by the Lignite Energy Council. During 180 hours of operation using PRB coal, carbon conversions exceeded 98 percent, a significant increase from prior tests. In the lignite test, which spanned 301 hours of operation, the addition of kaolin to the coal feed resulted in the elimination of previously observed fouling and agglomeration problems in the gasifier; consequently, a more stable operation and a significant increase over previously possible carbon conversion—reaching 90–98 percent—resulted. The success of these tests corroborates that transport gasification technology can effectively gasify the low-rank coals that account for half of the world's coal reserves but whose high moisture and ash content have made them much less economical as energy sources.

Prototype Microsensors Could Help Achieve Low Emissions and Optimum Efficiency—A prototype array of 16 independent microsensors, each uniquely responsive to one of the gases common to coal combustion and gasification systems, was tested at the Pilot Scale Development Facility in Wilsonville, AL. While exposed to clean synthesis gas, the system accurately identified carbon monoxide, CO_2, SO_2, and NO_x. Developed in cooperation with NETL at Sensor Research and Development Corporation in Orono, ME, the metal-oxide-based microsensors will be evaluated for responsiveness to ammonia and hydrogen chloride injected upstream as well as for accurate determination of individual gas concentrations. When fully developed, the sensor system will eliminate errors inherent to existing techniques by taking direct measurements from hot, corrosive combustion gas streams without sample transport or cooling. Precise determination of gas stream composition is essential to achieving optimum efficiency and low emissions from gasification processes.

New Hydrogen and Hydrogen Sulfide Sensors Developed for Next-Generation Clean Coal Technology—Researchers at Mississippi State University, working in cooperation with NETL, have developed two new chemical sensors compatible with the harsh environments of IGCC power plant processes: a cadmium-oxide-doped silica optical fiber sensor for hydrogen sulfide measurement and a tin-oxide-coated silica optical fiber for hydrogen measurement. Made by the relatively inexpensive sol-gel process for glass and ceramics, the sensors are sensitive to the parts-per-million level and resistant to temperatures of at least 600°C, even in reducing atmospheres. Accurate measurement and control of gaseous species in IGCC products is essential for achieving the highest process efficiency and lowest pollutant emission.

Sensor Outlasts Thermocouples in Gasifier—In a test that began in 2006 and concluded in 2007, the sapphire temperature sensor installed at the Tampa Electric Polk Power Station IGCC plant in Lakeland, FL, remained in continuous operation for seven months under cyclic conditions. Thermocouples located in parallel service failed after only two or three months. Developed at Virginia Polytechnic Institute and State University specifically for harsh, high-temperature service, the instrument design exploits fundamental relationships among light, material, and temperature changes. The next sensor is being installed closer to the high-temperature region of the gasifier where traditional thermocouples usually fail rapidly. Long-term, reliable temperature measurements will enable improved gasifier-control schemes that achieve higher operating temperatures and less recycle. The project is funded by the Office of Fossil Energy and being managed by NETL.

This direct sulfur recovery system test skid was integrated with a high-temperature desulfurization process unit (not shown) to convert recovered sulfur into a pure product for beneficial use.

Warm Gas Cleanup Technology Gives Boost to Gasification

DOE and Research Triangle Institute (RTI) partnered to develop technologies designed to reduce the cost of gasification and make it more thermally efficient.

Cleaning of conventional synthesis gas, the product of gasification technology, requires the energy-losing step of cooling the fuel-gas product as it leaves the gasifier and reheating the gas prior to its use in a turbine. When the gas is cooled, the heat losses that occur result in a lower efficiency for the process—less power for the same amount of coal. RTI, however, has developed two technologies that work in concert to increase efficiency: the high-temperature desulfurization system (HTDS), which operates at high temperatures to remove sulfur from the synthesis gas, and the direct sulfur recovery process (DSRP), which converts the recovered sulfur compounds into a pure sulfur product.

The HTDS, a sorbent-based technology for removing hydrogen sulfide and carbonyl sulfide from synthesis gas, was successfully field tested by RTI for over 3,000 hours on a coal gasifier slipstream at the 1,200 ton-per-day Eastman Chemical Company plant in Kingsport, TN. Testing was carried out with a General Electric quench gasifier fed with high-sulfur Eastern coals. RTI's HTDS unit consists of two integrated transport reactors (a sulfur absorber and a sorbent regenerator) that have achieved stable operation and ease of control—exceeding the most optimistic expectations. RTI used their highly reactive and attrition-resistant RTI-3 sorbent, which won an R&D 100 award in 2004. This effective sorbent reduced synthesis gas sulfur concentrations to as low as 0.5 parts per million by volume from a feed stream that typically contains about 8,000 parts per million by volume of sulfur compounds (hydrogen sulfide and carbonyl sulfide), without requiring a separate carbonyl sulfide hydrolysis step. Test conditions ranged from 700–900 °F and from 300–600 psig.

RTI developed the direct sulfur recovery process to operate in concert with the HTDS in order to treat the SO_2 in the regeneration of tail gas at similar temperatures and pressures. In the DSRP, SO_2 is partially reduced (using a small slipstream of synthesis gas) to elemental sulfur. In over 100 hours of integrated operation, the DSRP successfully converted over 90 percent of the SO_2 into elemental sulfur.

RTI's detailed technical gasifier-based and economic evaluation that compared the HTDS and DSRP technologies to a General Electric reference plant using Selexol, another sulfur-removing system, showed that—for a 600 megawatt (nominal) IGCC plant—the HTDS with DSRP could increase the overall thermal efficiency by a 3.6 efficiency point over conventional technologies. It could also reduce the overall capital cost of the entire IGCC system by $269 per kilowatt over current technology and reduce the cost of electricity by 9.6 percent.

The next development step is to build a 50-megawatt electric facility for demonstrating this appealing technology to bring it to the marketplace.

Supply & Environment

Conserving Our Resources

Hydrogen—The Fuel of the Future

Hydrogen, which burns so cleanly that water is its only by-product, is the ultimate clean energy source for producing power, both for electricity production and as a replacement for liquid fuels. Making hydrogen from coal—via gasification technology with carbon capture and sequestration—is one route for using America's fossil fuels without contributing more CO_2 to the atmosphere. NETL is exploring ways in which to centrally produce great volumes of ultra-pure hydrogen primarily through advanced separation techniques from coal-derived gases. Additionally, NETL is driving to reduce costs and improve process efficiency to allow hydrogen production to be economically competitive in today's markets. Technically and economically viable coal-to-hydrogen production would ultimately enable transition to a hydrogen-energy economy based on abundant domestic coal

Hydrogen-Selective Membrane Nearly Doubles Equilibrium Value of Water-Gas Shift Reaction—NETL researchers conducted a study of the first water-gas shift reaction performed without added catalyst particles in the presence of a hydrogen-selective membrane. The membrane reactors, consisting of an external shell and an internal tube bundle, were composed of palladium and a palladium-based alloy. By facilitating removal of hydrogen as it formed from reacting water and carbon monoxide at high temperature, the materials and configuration of the reactors allowed a shift in reaction equilibrium, causing more hydrogen to be produced. The study showed that the modest catalytic activity of the membrane surface, combined with the high rate of hydrogen extracted through the membranes, resulted in a dramatic shift in the conversion of carbon monoxide (up to 93 percent)—well above the equilibrium value of 54 percent associated with a conventional, non-membrane reactor. Results from the approach, which could enhance the production of both hydrogen and sequestration-ready CO_2 from coal, appeared in the July 2007 issue of the *Journal of Membrane Science*.

NETL Completes Study on the Hydrogen Permeability of Palladium Sulfide—NETL and Carnegie Mellon University researchers collaborated to study the rate of hydrogen diffusion through the palladium sulfide (Pd_4S) corrosion often observed on palladium-based membranes. Membrane durability is essential to successful gasification, and this is the first time that the growth of Pd_4S and its transport properties have been measured. Though the amount of hydrogen penetrating the Pd_4S layer varies according to layer thickness, the hydrogen permeability of the Pd_4S itself is approximately 10 times less than that of pure palladium. In addition to providing guidance for ongoing membrane development, the computational and experimental results obtained are instrumental in quantifying the corrosion that can develop on membranes, particularly when used in sour synthesis gas streams. Research results were presented in a paper for the August 2007 issue of the American Chemical Society journal *Industrial & Engineering Chemistry Research*.

NETL-Developed Metal Organic Frameworks Ideal for Adsorption of Gases—Basic research at NETL has developed metal organic frameworks that appear to be ideal agents for adsorbing gases, such as hydrogen or CO_2. Making hydrogen with coal is one route for using this abundant fossil fuel without contributing to the burden of CO_2 in the atmosphere. However, storage and transport of hydrogen have been a problem. In order to improve hydrogen storage material, it is necessary to explore the chemical and physical means by which the gas is adsorbed on the surface of microporous materials. A surprising discovery from new experimental data is that quantum effects play a major role in the adsorption of hydrogen at low temperatures. These data compare favorably with theoretical simulations conducted as part of the study, which were completed in collaboration with the University of Pittsburgh, Advanced Materials Corporation, and the University of Trento, Italy. An article published in the highly regarded *Journal of Physical Chemistry C* in July 2007 describes this as a better means for both synthesizing and activating metal organic frameworks for maximum gas storage capacity.

Large-Volume Fuel Samples Isolate and Identify Nitrogen Species in Jet and Diesel Fuels—NETL has developed a novel method for separating polar nitrogen-containing species from jet and diesel fuels. Unlike limiting methods of analysis that use only microliters of fuel, the NETL method uses milliliter quantities of fuel samples and thus can detect species that would normally remain undetected, producing a matrix that can be analyzed directly using gas chromatography. Analysis of nitrogen compounds is important for understanding fuel properties, such as lubricity and thermal stability, as well as emissions from diesel-powered engines. A paper outlining the improved method appeared in the June 2007 issue of the American Chemical Society publication *Energy & Fuels*.

Major Milestone Reached in Coal-to-Hydrogen Process—NETL, in partnership with engineers at Eltron Research, Inc., of Boulder, CO, completed initial experiments utilizing a process demonstration unit (PDU) designed to produce hydrogen at practical rates from coal-derived synthesis gas. A significant milestone in developing a technically and economically viable coal-to-hydrogen process, the achievement is seen as a step toward transition to a coal-based hydrogen energy economy. The PDU is the first scale-up of novel hydrogen separation materials that in bench-scale tests has met or exceeded target values for sulfur tolerance, economic life, hydrogen production rate, product purity, and cost. PDU experiments show that the robust membrane materials attain production flux goals at the engineering research and development scale.

Supply & Environment

Conserving Our Resources

One-Step Process Maximizes Hydrogen Production—Western Research Institute, in cooperation with NETL, designed and fabricated a device that removes hydrogen while simultaneously converting synthesis gas through a water-gas shift reaction. With a total of 60 square centimeters of membrane surface area, the device will be used to design a full-scale modular unit with 1,000 square centimeters or more of membrane area. Completing the water-gas shift reaction and product gas removal in one step will maximize hydrogen production and reduce associated capital and operating costs.

Simulations Show Feasibility of Novel Coal-to-Hydrogen Concept—A simulation conducted at Lehigh University in cooperation with NETL shows that high-purity hydrogen and CO_2 can be simultaneously produced from clean synthesis gas in a single unit operation. In the conceptual Thermal Swing Sorption Enhanced Reaction process, desulfurized synthesis gas is introduced to a reactor packed with a mixture of water-gas shift catalyst and a special adsorbent that primarily captures CO_2 in the presence of excess steam. Continuous removal of CO_2 from the reaction zone will produce fuel cell-grade hydrogen while delivering a pure CO_2 stream. The single unit process will also eliminate elaborate separation equipment needed in other coal-to-hydrogen approaches, reducing the plant's environmental footprint and lowering costs. A paper describing the concept and its successful simulation was published in the November 2007 issue of the *AIChE Journal,* an official publication of the American Institute of Chemical Engineers.

Modeling Studies Suggest Improved Hydrogen Transport Materials—Using a combination of scientific models (e.g., atomistic and thermodynamic), investigators at the United Technologies Research Center in East Hartford, CT, have identified alloying agents needed to maintain the hydrogen permeation of sulfur-tolerant membranes despite repeated heating and cooling. The studies, performed in a cooperative agreement with NETL, show the potential of several alloys to remain stable while separating hydrogen in the presence of typical gasified coal emissions. The team has filed an invention disclosure on its palladium-based alloy, which consists of three different metals. Investigators have also applied a similar modeling approach to increase the stability of water-gas shift catalysts in sulfur and chlorine environments. Sulfur-, chlorine-, and carbon monoxide-tolerant materials for a membrane reactor with compatible catalyst compositions would enable researchers to combine water-gas shift reaction and hydrogen separation into a significantly simpler process. If the process is successful, high-purity hydrogen would be produced in a smaller, single-stage reactor with less catalyst.

Unique System Exhibits Excellent Hydrogen Storage Capacity—Working under an NETL-administered University Coal Research grant, investigators at Alfred University in Alfred, NY, have demonstrated that hydrogen can be stored and delivered with superior efficiency using hollow microspheres made of glass doped with iron, nickel, or cobalt oxide. The tiny structures can contain hydrogen at pressures up to 10,000 pounds per square inch until it is released upon exposure to intense light of appropriate wavelength. Demonstration of photo-induced diffusion in sample microspheres made with conventional technology provides the first proof-of-concept for their use as a safe, large-scale, high-capacity, low-cost storage medium in a hydrogen-economy infrastructure.

New Metal-Organic Frameworks Are Inexpensive, Recyclable, and Environmentally Safe—Working in cooperation with NETL, researchers at Advanced Materials Corporation have developed a new class of inexpensive, recyclable, and environmentally safe microporous metal-organic framework materials. Preliminary lab-scale testing on the composition is promising, with the materials exhibiting hydrogen storage capacities as high as 4.5 percent by weight in early trials. As DOE has targeted a hydrogen storage capacity of 6 percent by weight for 2010, these low-cost, high-capacity storage materials will help enable a coal-based hydrogen economy.

NETL's "Single Battlefield Fuel" Research Supports National Long-Range Initiative—A "single battlefield fuel" could help the nation's armed services meet the goal of significantly reducing battlefield fuel consumption of petroleum-derived fuel by 2020. A new microreactor designed to accelerate the effects of thermal stress observed in fuel systems of advanced military aircraft was commissioned by NETL researchers. The microreactor is being used to determine how prospective seal-swelling additives would affect the thermal stability of synthetic jet fuels. The research supports a Department of Defense long-range initiative to develop a single, fully synthetic, hydrogen-rich fuel, capable not only of powering fuel cells but ground vehicles, aircraft, and ships as well.

Supply & Environment

Photo courtesy of the University of North Dakota's Energy & Environmental Research Center

Powered by hydrogen fuel cells, the eP-ICEBEAR ice resurfacer is safe to use in an enclosed ice rink because it emits no dangerous exhaust fumes.

Fuel Cell–Powered Ice Resurfacer Smoothes the Way to a Hydrogen Economy

In 2006 and 2007, thanks in part to NETL, skaters at select ice rinks in North America could take a break, sip their hot chocolate, and watch the ice being resurfaced without any of the noise and fumes associated with the usual propane-powered ice resurfacers. At these rinks, the machine restoring the ice to a shine was the eP-ICEBEAR, the world's first fuel cell–powered ice resurfacer.

The eP-ICEBEAR sprang to life when commercial partners ePower Synergies Inc. and Resurfice Corporation teamed with the National Center for Hydrogen Technology at the University of North Dakota's Energy and Environmental Research Center. NETL helped fund the ice resurfacer's development—and its tour of ice rinks across the United States and Canada—through its financial support for the National Center for Hydrogen Technology.

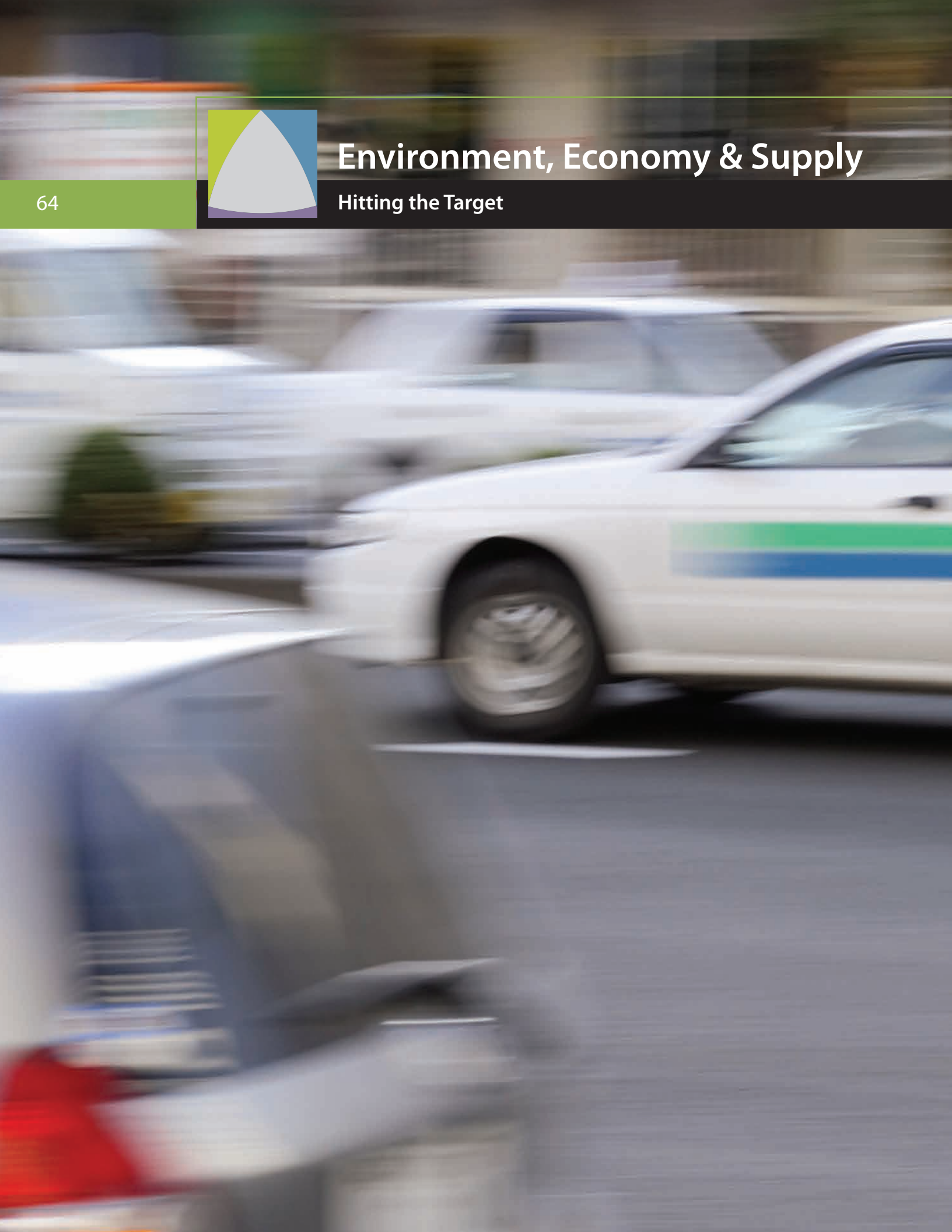
Hydrogen is envisioned to be the primary energy carrier of the future, driving the energy security of the United States. Secretary of Energy Samuel Bodman has said, "Hydrogen fuel cells are one of the technologies that, if we are successful, could totally transform the way we use energy. . . . [W]e believe hydrogen fuel cell technology remains a viable long-term solution to end petroleum dependency and minimize carbon emissions."

The crowded, enclosed space of an ice arena made a perfect venue for the introduction of hydrogen-powered vehicles. While on exhibition, the eP-ICEBEAR proved much quieter and safer than other ice resurfacers, which have sometimes caused dangerous carbon monoxide buildups on the ice while resurfacing. With its fuel cells running on pure hydrogen, the eP-ICEBEAR has no harmful exhaust at all—plain water is the only emission.

Supporting the eP-ICEBEAR project is just one of many NETL activities to advance fuel cell development and promote a future hydrogen economy. Working with private industry and other research partners, NETL is a leader in the development and demonstration of high efficiency solid oxide fuel cells and fuel cell/turbine hybrid power-generation systems.

Environment, Economy & Supply

Hitting the Target



NETL provides the advanced scientific and technological tools to ensure an abundant supply of clean, affordable, and abundant energy. The goals—providing environmentally friendly energy, affordable energy, and abundant, secure energy—are often at odds with one another. For instance, the most efficient and economic ways of producing energy are not generally the most environmentally acceptable. NETL, however, consistently targets the area where these three goals intersect—affordable technologies that protect our air, water, and land while providing an abundant, secure energy supply for the nation. The carbon capture and storage technologies being developed under NETL management are hitting the bull's eye.

Environment, Economy & Supply

Hitting the Target

Carbon Capture & Storage—Curbing CO_2 Emissions

Because CO_2 is closely linked with global climate change, solutions must be found to stabilize atmospheric CO_2. One way to do this is to capture anthropogenic CO_2 at its source—such as coal-fired power plants—and permanently store it in deep geologic formations and terrestrial sinks. Current technologies used for CO_2 need to be improved. Since 1997, NETL has been exploring 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 storage; and breakthrough concepts for reducing the cost of capture.

NETL also manages DOE's seven Regional Carbon Sequestration Partnerships, a collaboration of regional, state, and local governments, universities, and private companies that determine the best approaches for capturing and permanently storing greenhouse gases in each region of the country. These partnerships pull together the efforts of nearly 350 organizations spanning 41 States, 3 Indian nations, and 4 Canadian provinces to advance the understanding and infrastructure development of carbon capture and storage. Collectively, the seven partnerships represent regions encompassing 97 percent of U.S. coal-fired emissions, 96 percent of our nation's total land mass, and essentially all of the geologic storage formations available in the United States for carbon storage.

NETL Invents Novel Method for Measuring Sequestration Rates—NETL researchers have invent-ed and tested a method for measuring isotherms and diffusion rates for CO_2 sequestered in coal seams. Such data are needed for engineering computations of reservoir sequestration capacities and field-project design. Sorption isotherms are conventionally measured on powdered coal by a pressure-drop method, but diffusion rates obtained from powdered samples may give unrealistic sorption capacities. In the NETL technique, a pre-weighed sample of centimeter-sized pieces of coal is exposed in a high-pressure cell to CO_2 (or other gas) at a specified pressure and temperature. Following the desired period of exposure, the sample is removed, and the change in sample weight is automatically recorded on a conventional laboratory balance over the next hour.

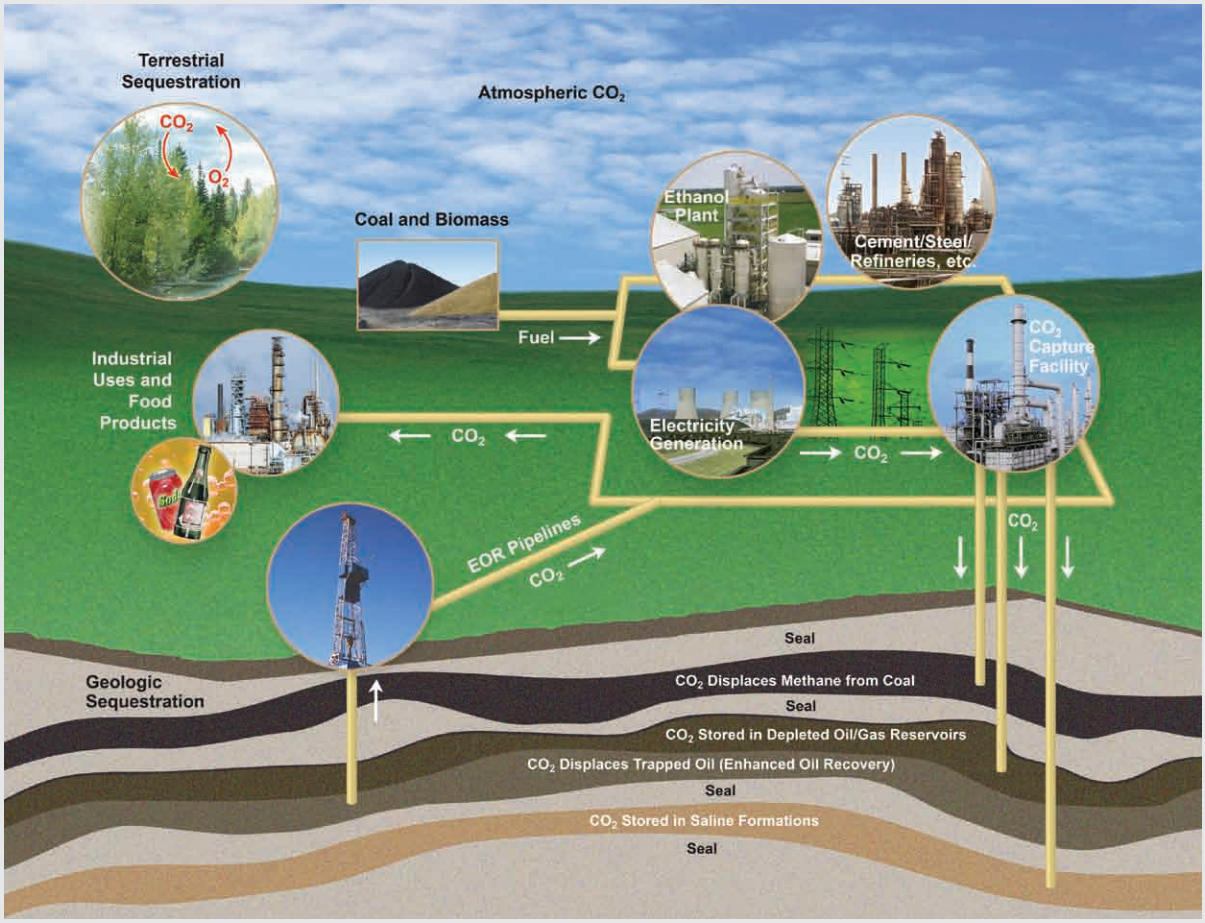
Computational Experiments at NETL Validate Sequestration Predictions—Using the NETL-developed computer code NETfLow™, NETL scientists have shown that equations describing CO_2 flow when CO_2 is injected into brine-saturated geologic formations are also valid under laboratory conditions for a large range of fluid parameters and porous materials. This "cross-over" behavior had been predicted in the theoretical literature and could serve to accelerate the development of carbon sequestration methods and practices. A paper describing the results was published in the October 2007 issue of the peer-reviewed American Physical Society publication *Physical Review E*.

NETL Develops New Approach for Modeling CO_2 Sequestration in Coalbeds—NETL has developed a framework for improving conventional geomechanical approaches to modeling carbon sequestration in coalbeds. By considering coal properties at the macromolecular level, this approach is a major improvement over the mechanical engineering models that have been used in simulating CO_2 sequestration in coal seams. The cross-scale theory, published in the American Chemical Society's 2007 May issue of *Energy & Fuels*, describes the structural rearrangement of coal after injection of high pressure gaseous or supercritical CO_2, which was previously ignored or incorrectly accounted for by the mechanistic models. Improved modeling could avoid costly and unexpected problems, such as coal swelling around injectors and reduced injection efficiency that can stall or even terminate site development.

NETL Model Helps Predict Sequestration Behavior for CO_2 Injected into Coal Seams—An advanced model developed at NETL to describe the shrinkage and swelling of coal caused by methane and CO_2 has been used to fit field data from the Allison Field in northern New Mexico. Carbon dioxide was injected for more than 10 years in the field to enhance

coalbed natural gas production, and the data are being used to help predict the behavior of CO_2 when sequestered in coal seams. NETL research has shown that the effect of CO_2 sorption on coal properties can vary depending on an interplay of factors not fully realized. In some cases, sorption causes the coal to swell, reducing its permeability and making injection difficult; in other cases, CO_2 sorption causes fractures to develop in the coal, making injection easier. Results from simulations using the NETL model, which appeared in both the *Journal of Petroleum Technology and SPE Reservoir Evaluation & Engineering,* were comparable to or better than other simulators and swelling models.

New NETL Adsorbent Exhibits Exciting Possibilities for CO_2 Capture—NETL researchers have engineered an absorbent material with an unusually flexible structure that offers exciting possibilities for separating CO_2 from other gases. The material is composed of sheets of an ionic nickel complex that is interlayered with pillars of a specially selected organic compound to form galleries of open chan-nels into which gas molecules can fit. In the presence of CO_2 at a certain threshold of pressure, the structure flexes open to accommodate more gas molecules. Despite depressurization, once full the opened structure retains the CO_2 until a very low pressure is reached. At that point, the structure collapses again and the CO_2 exits. Achieving such a degree of control over the properties of a family of porous materials represents a real advance in adsorption science.



Captured CO_2 may be stored safely and permanently in underground formations (geologic sequestration); stored in trees, vegetation, and soil (terrestrial sequestration); or put to use in manufacturing or enhanced oil and natural gas production.

NETL Releases Groundbreaking Carbon Sequestration Atlas

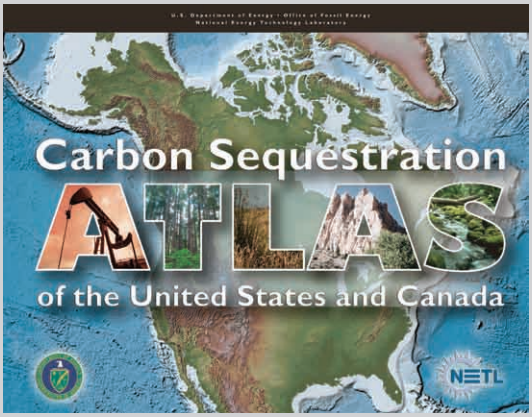
In March 2007, NETL released the first-ever *Carbon Sequestration Atlas of the United States and Canada.* Developed jointly by NETL, DOE's Regional Carbon Sequestration Partnerships, and the National Carbon Sequestration Database and Geographical Information System (NATCARB), the atlas is proving to be a critical tool in the research and development of carbon sequestration technologies.

Emissions of the greenhouse gas carbon dioxide (CO_2) have increased from an insignificant level two centuries ago to more than 30 billion tons worldwide today. If no effort is made to reduce CO_2 emissions, yearly release from the United States could increase by one third from 2005 to 2030. Carbon capture and sequestration could slow or even reverse this growth by capturing CO_2 before it is emitted into the atmosphere and safely storing it in geologic formations, soils and vegetation, or in other environmentally safe forms. Sequestration is a key component of U.S. efforts to combat global climate change.

DOE's Office of Fossil Energy and NETL support a number of carbon sequestration initiatives, including the Regional Carbon Sequestration Partnership program. The program was started in 2003 in response to geographic differences in fossil fuel use and sequestration potential. The seven regional partnerships include members from more than 350 government agencies, universities, and private companies spanning 41 states, 4 Canadian provinces, and 3 Indian nations.

The atlas, which will be updated annually, aids carbon sequestration research and technology development by providing maps and information at both the national and regional levels. It has three main purposes:

- Present an overview of the lifecycle of CO_2 through the capture and sequestration processes.
- Summarize DOE's and NETL's sequestration research and development efforts.
- Present information about the Regional Carbon Sequestration Partnerships' activities.



The 2007 atlas documented U.S. and Canadian stationary sources—such as power plants, refineries, and other fossil-fuel–consuming industries—that release 3.8 billion tons of CO_2 each year. It also identified potential storage sites across the United States and Canada for more than 3,500 billion tons of CO_2.

The atlas is available in both online and print versions. The online version, an interactive and frequently updated resource, is located at the NATCARB website. The print version can be downloaded from the NETL website.

Environment, Economy & Supply

Hitting the Target

NETL Work on Metal Organic Frameworks Yields New Way to Evaluate Adsorbent Materials—NETL research on metal organic frameworks, a new type of porous material useful as an adsorbent, has yielded a novel method for evaluating the way in which vapors desorb from any type of porous adsorbent. The NETL method will help evaluate the performance of metal organic frameworks, which are expected to be of value in many applications, including the separation of CO_2 from other gases. Potentially, the new materials will be useful for capturing CO_2 in power plants and similar facilities prior to sequestration or for purifying other gases or liquids.

NETL-Developed Power Plant Cost-and-Performance Data Made Available to the Public—A 500-page NETL report, *Cost and Performance Baseline of Fossil Energy Plants*, contains the most comprehensive set of publicly available data to date for comparing the types of technology that are available for future power plants and for estimating the cost and performance of pulverized coal, natural gas combined cycle, and integrated gasification combined cycle power plants, both with and without carbon capture and sequestration. Plant efficiencies, busbar cost of electricity, and the cost of carbon mitigation were estimated using computer-based models developed from information from published reports, vendor quotes, technology-user comments, and data from recent utility projects. The report was peer-reviewed by industry experts, academia, and government research and regulatory agencies and is proving valuable to decision-makers as they evaluate the trade-offs of various power options. This study has been highlighted at several international conferences and published in *Gas Turbine World*.

NETL and Argonne National Laboratory Identify an Energy Security Pathway Based on Clean Coal Fuels and Efficient Vehicles—The Hydrogen Economy Scenario Modeling project, jointly undertaken by NETL and Argonne National Laboratory, has concluded that petroleum consumption can be reduced by 11 million barrels per day and carbon emissions by 500 million metric tons per year by 2040—energy and climate security goals announced by President Bush in 2003. These results can be accomplished by dovetailing supply-side initiatives based on clean coal technologies with demand-side vehicle efficiency improvements. Critical technologies include transportation fuel substitution from coal-based liquids, the sequestration of CO_2 by 10–20 percent of new coal power plants, and the proliferation of high-efficiency vehicles powered by hybrid engines or hydrogen fuel cells.

NETL Evaluates Impacts of Capturing CO_2 from Existing Coal-Fired Power Plants—NETL analysts evaluated the technical and economic impacts of removing CO_2 from an existing U.S. coal-fueled power plant using an advanced amine-based postcombustion CO_2 capture system. The study is unique as it investigates the performance and economic impact of retrofitting an existing plant for various levels of CO_2 capture, ranging 30–90 percent. The results establish performance benchmarks for reducing greenhouse gas emissions and will serve as a foundation for exploring the impact of widespread CO_2 capture across the entire U.S. fleet of coal-fueled power plants.

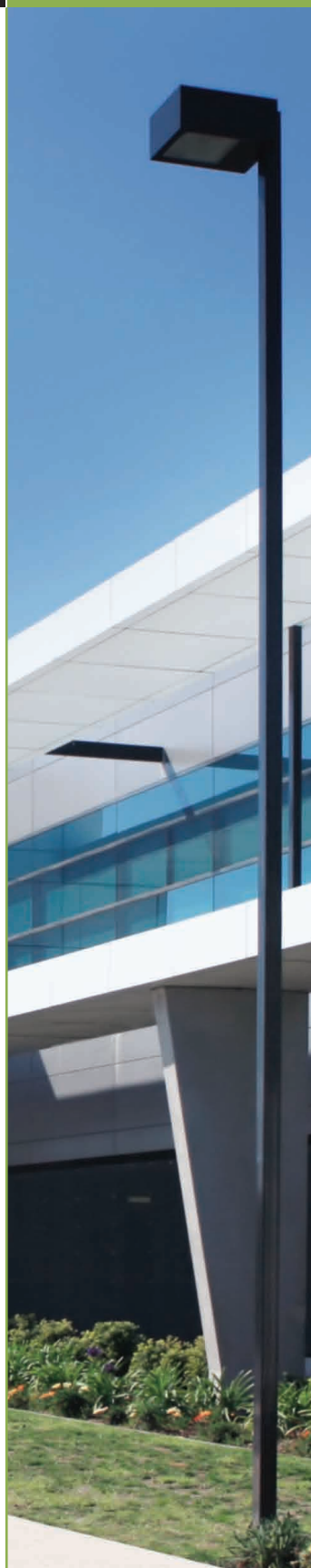
NETL Identifies Critical Study Areas for CO_2 Capture at Pulverized Coal Plants— NETL has established a baseline for the cost and performance of new pulverized coal-fired power plants and next-generation ultra-supercritical power plant designs that capture CO_2 using either oxy-fuel combustion or one of a variety of postcombustion capture technologies. Study results establish a point of reference to which research and development progress in the areas of oxy-fuel combustion and postcombustion can be compared. Improved oxygen production, advanced boiler materials, advanced boiler designs, and improved CO_2 compression were identified as critical areas of study necessary to decrease CO_2 mitigation costs from new pulverized coal plants.

NETL Develops Capability to Model Market Penetration of Capture Technologies Using CO_2 Supply-and-Demand Curves—NETL's new version of its CarBen desktop model includes CO_2 supply curves that constrain the potential contribution of capture technologies based on capacity estimates. CarBen was originally developed to evaluate the environmental benefits derived from carbon capture generation technology development. Now, the model can also translate the opportunities for CO_2 enhanced oil recovery (EOR) into the number of power plants that capture carbon and supply it to the EOR industry. This step is accomplished by aligning CO_2 demand from state-of-the-art CO_2-EOR applications with CO_2 supply from power plants. The research effort determines what is economically feasible by considering demand constraints based on economically recoverable resources and supply constraints based on power-plant deployment economics. As a result of this research and model enhancement, NETL now has the capability to model the market penetration of capture technologies based on economic incentives and constraints.

Deep-Well Drilling Completed for Geologic Sequestration Pilot Test at FirstEnergy Power Plant—An 8,500-foot well in Shadyside, OH, is one of the first wells drilled into a U.S. basin by the seven NETL-managed Carbon Sequestration Partnerships. As part of a demonstration conducted by the Midwest Regional Carbon Sequestration Partnership led by Battelle Columbus Laboratories, technicians began deep-well testing into the formations underlying FirstEnergy Corporation's R. E. Burger electric gen-erating facility. After the well was drilled, cored, and logged, results of the pilot-scale test were reviewed to determine if the core samples showed sufficient permeability and porosity for geologic sequestration. Once approval for injection is received, an amount of CO_2 equivalent to two days of plant emissions (3,000–10,000 tons) will be injected into the test well over a period of several months. Results from the injection will help determine the suitability of regional geologic formations for perma-nently storing CO_2

Marsh Restoration Shows Carbon Sequestration Potential—Researchers at the University of Maryland are helping to mitigate the effects of anthropogenic greenhouse gases by restoring carbon-capturing marshes in the Blackwater National Wildlife Refuge on the eastern shore of the Chesapeake Bay. So far, 27 acres have been restored with clean dredge that is annually removed to keep Port of Baltimore channels clear. Revegetation of the dredge represents part of a terrestrial sequestration project being conducted in cooperation with NETL by the Midwest Regional Carbon Sequestration Partnership.

New Process Produces Oxygen Without Cryogenics—In a sub-pilot-scale test, a Ceramic Autothermal Recovery (CAR) unit produced seven-tenths of a ton of oxygen per day at Western Research Institute in Laramie, WY. Expected to require less energy and capital than cryogenic approaches, the CAR process adsorbs oxygen from air in a fixed bed containing calcium titanium oxide. The bed then releases the oxygen into a sweep gas, such as recycled flue gas or steam. Dual beds are cycled between these two modes of operation to provide a semicontinuous process. The mixture of oxygen and recycled flue gas could replace air in combustion processes, producing a CO_2-rich flue gas that can be readily conditioned for sequestration or enhanced oil recovery (EOR) operations. BOC Gases—part of the Linde Group that is now the largest industrial gas company in the world—is partnering with Western Research Institute, Alstom Power, Inc., and NETL to assess the technical and economic merits of CAR technology for supplying oxygen instead of air to coal-fired boilers.



Technology Transfer

Innovation, Invention & Commercialization

Technology transfer is central to NETL's mission. NETL's inventions and innovations cannot effect a positive change until they are brought into the public realm to aid in the discovery, recovery, and use of America's energy resources economically and with proper environmental stewardship. NETL dedicates significant efforts to transferring information and technologies to private-sector companies, colleges and universities, and other government entities to accelerate the advancement and commercialization of valuable technologies and maximize returns to the American people. Some of the primary vehicles that are used to move NETL's new technologies into the private sector are Cooperative Agreements (CAs), Cooperative Research and Development Agreements (CRADAs), patents and licensing, and publications.

Technology Transfer

Innovation, Invention & Commercialization

Commercialization—Moving Innovation to the Marketplace

Through CAs and CRADAs, NETL partners with private companies, colleges, universities, and state and local governments to develop and advance new energy and environmental technologies. By providing partners with a portion of the funding for development of new technologies, NETL decreases the time it takes for the partners to advance the new products toward commercialization.

NETL Licenses Mercury-Capture Technology That Preserves Thermal Efficiency at IGCC Power Plants—NETL has licensed a high-temperature palladium metal sorbent to Johnson Matthey, a world leader in catalyst manufacture, for commercial development. The sorbent captures larger quantities of mercury from simulated synthesis gas than sorbents made from platinum. The palladium-based technology was invented by NETL researchers for use in IGCC power systems to capture mercury, arsenic, and selenium. Capturing these trace elements at high temperature will help preserve the high thermal efficiency of IGCC plants more effectively than the low-temperature activated carbons used to capture mercury in many of today's power systems. The sorbents are described in the June 21, 2006, edition of *Industrial & Engineering Chemistry Research*, as well as in the September 2007 Elsevier journal *Fuel*.

NETL Refractory Material Prolongs Service Life of Coal Gasifiers, Now Licensed for Production—Harbison and Walker Refractories Company of Pittsburgh, PA, is producing an NETL-developed refractory material for coal gasifiers under the marketing name Aurex® 95P. Field trials show that the refractory liner, which is composed of a phosphate-modified high-chromia-and-alumina matrix, either reduced or eliminated wear caused by fragmenting and flaking, thus extending the refractory service life an estimated 50 percent beyond that normally achieved by conventional materials. The refractory also was found to have equivalent or better resistance to chemical deposition, the other primary wear mechanism that impacts refractory service life. Refractory brick with greater longevity will help gasification become a more reliable and economic technology for coal-based power and hydrogen production.

Oil and Gas Exploration Software Commercialized—New modeling software developed at Houston-based Rock Solid Images (RSI) in cooperation with NETL confirms or disproves the presence of oil or gas better than conventional seismic attribute analysis. The new software can significantly reduce the risk of drilling a dry hole and causing financial losses of millions of dollars. Now available commercially from RSI as part of the company's iMOSS software package, the technology has been adopted by several major oil companies and successfully applied offshore in West Africa and Norway as well as in the deep Gulf of Mexico of the United States.

"Super-Cements" Now Available for Reducing Deep Well Maintenance Costs—Two supercement formulations with patents pending—one epoxy-based, the other Portland-cement-based—are now commercially available for improving long-term sealing integrity in high-pressure, high-temperature wells. Developed and field-tested in cooperation with NETL by Houston-based CSI Technologies, LLC, these formulations will significantly reduce maintenance costs for highly productive wells in deep, hot environments where cement failures are expensive to repair and result in costly well closings that average $200,000 onshore and $1,000,000 offshore. This project outcome is another significant success for NETL's Deep Trek program, the goal of which is the development of advanced technologies to tap the nation's large deposit of technically recoverable gas trapped in reservoirs below 15,000 feet.

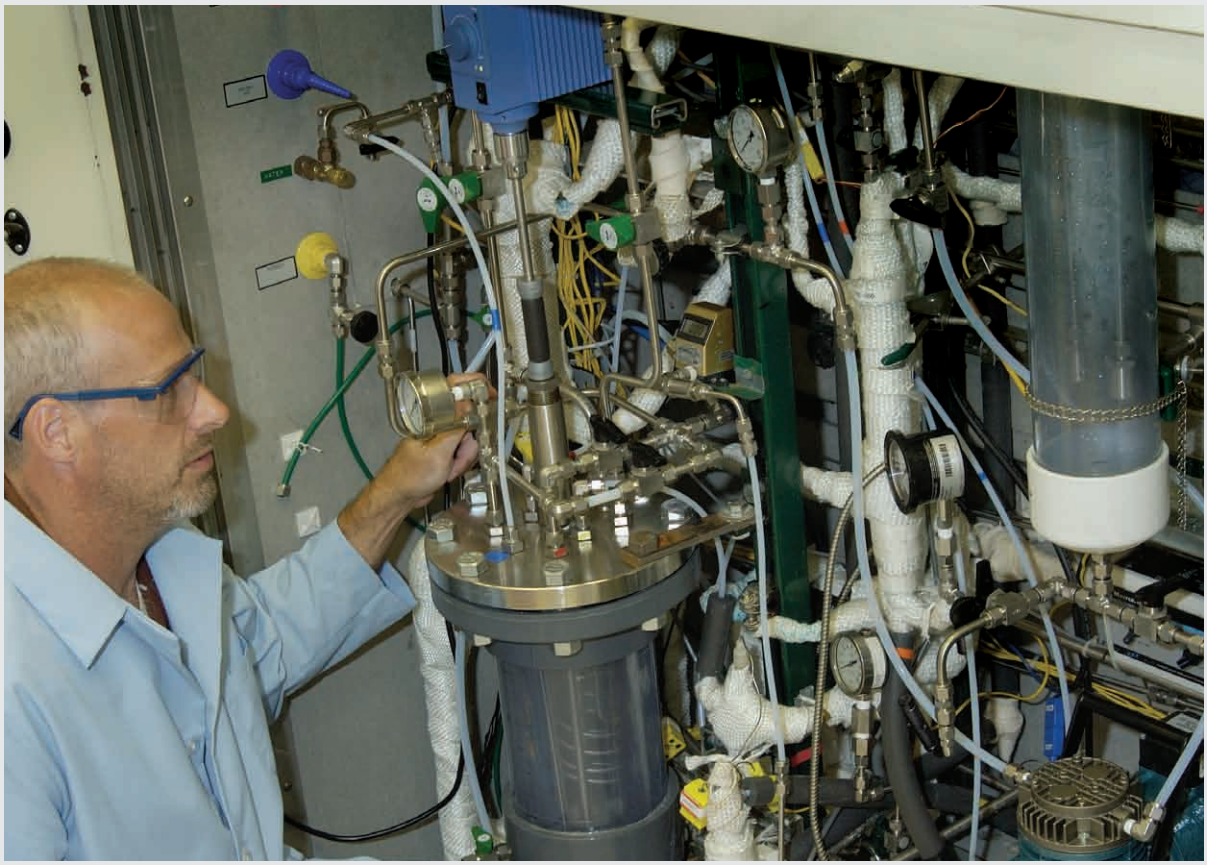
Capstone Microturbine Meets Stringent Regulations of the 2007 California Air Resources Board—Capstone Turbine Corporation has put into commercial production a 65-kilowatt microturbine that meets the stringent emission requirements established by the California Air Resources Board (CARB). "CARB 2007" regulations set emissions standards for NO_x, carbon monoxide, and volatile

organic compounds and are part of California's regulations governing the certification of distributed generation resources. Capstone's new microturbine is sold as part of the company's integrated combined heat and power package, which achieves a minimum 60 percent efficiency. The system combines ultra-low-emission lean-premix combustion technology with a catalyst that requires no scheduled maintenance for the life of the system. Capstone developed the package through an Advanced Microturbine Systems project aimed at developing a 200-kilowatt advanced microturbine. NETL manages this project for the Office of Electricity Delivery and Energy Reliability (OE).

Breakthrough NO_x Management Technology Commercialized—Fossil Energy Research Corporation of Laguna Hills, CA, is now offering a non-intrusive monitoring system that provides a real-time view of catalyst deactivation within selective catalytic reduction (SCR) units used to control nitrogen oxides (NO_x) in coal-fired power plants. Developed by Fossil Energy Research in collaboration with NETL, Southern Company, and the Electric Power Research Institute, the Knoxcheck Online Catalyst Activity Test system predicts remaining catalyst life and evaluates catalyst replacement options without requiring a unit outage to obtain and analyze catalyst samples. Such in situ monitoring permits the SCR to remain in operation the year around, significantly reducing maintenance costs. The system proved successful in field tests conducted during the 2005 and 2006 ozone seasons at Alabama Power Company's Plant Gorgas near Parrish, AL.

Results of Advanced Microturbine Project Adopted Commercially—United Technology Corporation's UTC Power unit has introduced PureCycle™ to the marketplace. PureCycle is a closed-cycle system that uses hot water from underground to generate electrical power with no emissions. The newly commercialized system is a result of work performed by engineers at the United Technology Corporation Research Laboratory in cooperation with NETL for OE. The research boosted microturbine system efficiency more than 5 percentage points using an Organic Rankine Cycle, a closed system that uses a working fluid to convert waste heat into electricity without producing pollutants. PureCycle garnered a 2007 R&D 100 Award for recovering geothermal energy at Chena Hot Springs Resort near Fairbanks, AK—site of the lowest-temperature geothermal resource (165 °F) ever used for commercial power generation.

Technology Transfer



NETL has patented three inventions that have been recently licensed to industry to remove mercury from power plant gas streams.

Techniques for Mercury Capture Extend Success by Transferring Technology

Energy security means having reliable and affordable energy now and in the future. Because NETL's research portfolio is aligned to address both immediate and anticipated needs of the U.S. energy sector, technology transfer is an important component of all of our research.

Our research and technology innovations in mercury capture are evidence of NETL's success in its important national mission. Mercury is a neurotoxin, and can accumulate in the food chain. The United States Environmental Protection Agency issued the Clean Air Mercury Rule, which is in the process of being revised, regulating the mercury emissions from coal-utilizing facilities such as coal-burning power plants. In addition, at least 26 states have legislation or pending legislation requiring the removal of mercury from coal-derived flue gases.

NETL's trace metal capture efforts focus on developing low-cost and effective mercury removal solutions to meet the goal of capturing more than 90 percent of mercury emissions from U.S. coal-fired plants by 2010.

Researchers Evan Granite and Henry Pennline have been active in developing techniques for mercury capture. Three of those techniques are in the early stages of commercial development, with three commercial license agreements, and a cooperative research and development agreement.

Their inventions are known as the PCO Process, the Thief Process, and the PG Trace Metal Sorbents.

The Thief Process, licensed to Nalco-Mobotec in May 2005, is being demonstrated at coal-burning power plants, and holds great potential as an economic way to reduce mercury emissions from coal-burning electric utilities. It is a cost-effective alternative to activated carbon injection (ACI) for mercury removal from flue gas. Activated carbons are expensive, ranging from $500 to $3,000/ton compared to $90-to-$200/ton for Thief carbon sorbents. Laboratory, bench, pilot-scale, and field tests demonstrate that carbon sorbents are comparable to activated carbons for mercury capture.

The PG sorbents, licensed to Johnson Matthey in March 2007, are being successfully demonstrated for the removal of mercury and arsenic from fuel gases at independent bench-scale facilities, and are scheduled for pilot-scale demonstration at two facilities in June of 2008. The sorbents work on fuel gas at elevated temperatures. Unlike conventional sorbents such as activated carbon, which operate at ambient temperature, these high-temperature sorbents remove mercury and arsenic at temperatures above 500°F, and have more than twice the capacity of previously existing sorbents, resulting in a major improvement in overall energy efficiency of the power combustion process.

The Photochemical Oxidation (PCO) process introduces a 254-nm ultraviolet light into the flue gas, leading to oxidation of mercury and facilitated mercury removal in a downstream SO_2 scrubber, wet electrostatic precipitator, or baghouse. In field tests, the process demonstrated greater than 90 percent oxidation and capture of elemental mercury in simulated flue gas streams. The PCO process was licensed to Powerspan Corp.

During a visit to NETL, Jeffrey Jarrett, then DOE Assistant Secretary for Fossil Energy, said, "Development of advanced coal technology at NETL is a keystone of the President's Advanced Energy Initiative. Advanced technology and coal can deliver new increments of electric power to our nation in the near- and mid-term in the volumes we will require it, at the times we will need it, on the terms we want it–abundant, always available, low cost and clean."

NETL inventions such as the mercury removal technologies are the types of innovative advances that prompted Jarrett's remarks.

Technology Transfer

Innovation, Invention & Commercialization

Patents—Safeguarding Invention

NETL makes government-owned inventions available to private sector companies in the energy marketplace through patent licensing. Inventions created through Cooperative Research and Development Agreements (CRADAs) collaborations are available for exclusive licensing to the CRADA partner. Inventions made through Cooperative Agreements (CAs)are often owned by the CA partner who is responsible for commercialization.

Novel Regenerable Sorbent a First for Removing CO_2 at Warm Gas Temperature—NETL researchers have received a patent for a first-of-its-kind process that creates a sodium-based sorbent capable of removing CO_2 at warm gas temperatures (200–400 °C). Unlike CO_2 removal processes available on the market today, this sorbent does not require the contacting gas stream to be cooled. This makes it particularly suitable for high-temperature coal gasification processes. The innovative sorbent also exhibits a very high capacity for adsorbing CO_2 (greater than 4 moles per kilogram), with a greater than 99 percent CO_2 removal efficiency at 315 °C; further, it can be regenerated at 700 °C. The sorbent is described in the July 2007 issue of the peer-reviewed American Chemical Society publication *Energy & Fuels*.

NETL Sensor for Gas Turbines Receives Patent—A U.S. patent has been issued to NETL inventors for a sensor that detects incipient lean blowout (LBO)—a power-robbing condition that can damage gas turbines. By providing real-time monitoring of conditions in the combustor, the sensor would allow modern turbines, particularly those utilizing a more LBO-susceptible dry low-NO_x combustion technology, to safely operate closer to the LBO limit where emissions are lowest. NETL is partnering with Woodward Governor Company to commercialize the novel sensing technology.

NETL Patents Device for Flow Control in Fuel Cells—NETL engineers have been granted a U.S. patent on a microvalve that can control small amounts of flow. The device improves the flow of fuel and oxidizers within fuel cells and is powered by a pressure-induced electricity source called piezoelectricity. Other applications of the device are also possible, including flow control in combustion systems for NO_x control. NETL shares the patent with two faculty members from the University of Pittsburgh. The team is continuing its collaboration through the NETL University Research Initiative to develop other sensor and control technologies for energy applications.

NETL Patents Aqua Ammonia-Based Technique to Remove CO_2 from Flue Gas—NETL researchers have invented and patented a wet-scrubbing technique that uses an ammonia-based solution to capture acid gases, including CO_2, from flue gas at coal-burning power plants. During the process, a salable fertilizer is produced and the spent ammonia solution is regenerated and recycled back to the scrubbing unit. At the same time, a stream of CO_2 is produced that can be captured for either sequestration or industrial use. The technique has been licensed to Powerspan Corp., New Durham, NH. Company officials plan to construct a one-megawatt demonstration unit.

Noteworthy Publications—Sharing Our Expertise

NETL shares its expertise and technological progress in fossil energy research and development in several ways: through project reports, topical reports, technology roadmaps, newsletters, and brochures; through DOE's Office of Scientific and Technical Information; and through publishing the latest ideas, innovations, and discoveries in books and various scientific journals and periodicals.

NETL Staff Co-Edit Publication for World's Largest University Press—Oxford University Press has published Ultraclean Transportation Fuels, a book edited by Olayinka I. Ogunsola and Isaac K. Gamwo describing recent advances in the research and development of ultra-clean transportation fuels. Derived from a variety of hydrocarbon feedstocks, such as coal, biomass, and waste oils, the ultra-clean fuels were evaluated during production, processing, upgrading, and utilization phases. In addition to his editing duties, Dr. Gamwo and several other NETL researchers authored multiple chapters for the book. Dr. Ogunsola, a former NETL employee, is now a program manager in the Office of Fossil Energy's Office of Oil and Natural Gas at Department of Energy headquarters.

NETL Researchers Prepare Article for New Wiley Publication—NETL researchers have been invited to contribute an article describing the use of dense metal membranes for separating hydrogen and CO_2 from coal-gasifier gas. The article will appear in the inaugural edition of the Encyclopedia of Energy, to be published by Wiley Interscience® in 2010. Wiley extended the invitation after learning of NETL's membrane research during a presentation at the March 2007 meeting of the American Chemical Society. The new publication will cover every conceivable source of energy, from wind to nuclear power; all energy uses, such as transportation and electricity; and unique case studies for energy utilization around the world. NETL's article will be among approximately 1,500 contributions in 18 categories to be published in 5 volumes of approximately 1,000 pages each.

NETL Researchers Contribute to Singular Issue of Scientific Journal—In March 2007, Dr. Charles Taylor, Director of NETL's Chemistry and Surface Science Division, was guest editor for a special issue of Elsevier's *Journal of Petroleum Science & Engineering* dedicated to the field of gas hydrates and clathrates (a group of one type of molecule trapped within the lattice of another). The special volume includes 21 refereed papers authored in government research laboratories, academia, and industry and represents the best presentations offered at a related symposium during the 229th National Meeting of the American Chemical Society. NETL researchers are primary authors of three articles contained in the special volume. The first and second articles detail gas hydrate research on the macro- and micro-scale respectively, and the third article presents an overview of advances in hydrate research made between 2001 and 2005. In a fourth article, NETL and Lawrence Berkeley National Laboratory researchers discuss the groundbreaking use of computerized tomography to monitor the formation and dissociation of methane hydrate in sediment.

***Power Engineering* Highlights NETL NO_x-Control Accomplishments**—An overview of NO_x-control advances made under the Office of Fossil Energy's Innovations for Existing Plants program, managed by NETL, is included in the November 2006 issue of the prominent industry publication Power Engineering. The article details such NOx-control technologies as neural control systems, oxygen-enhanced combustion, burner improvements, and specialized reagent injection. Not only do these cost-effective technologies equal state-of-the-art selective catalytic reduction (SCR) systems in achieving NOx reductions, they are better suited to the smaller, older facilities that make up the 66 percent of the domestic fleet that are not easily retrofitted with SCR units due to economic considerations and space constraints.

Awards & Recognition

Acknowledgements of Success

Striving for excellence in energy research and development through innovation, publication, and technology transfer won NETL special recognition throughout 2007. NETL has been acknowledged for major contributions in many different areas and by many different organizations, proving that our contributions are both significant and on target.

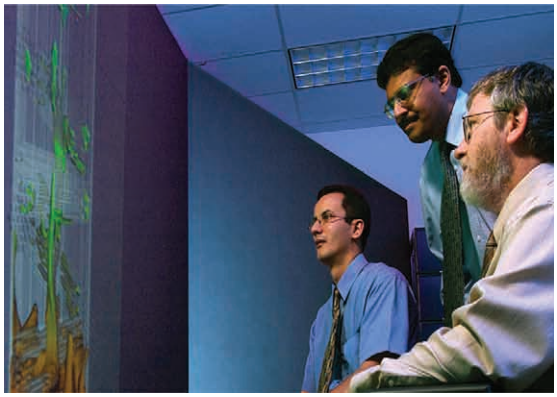
Awards & Recognition

Acknowledgements of Success

NETL Garners Seven R&D 100 Awards for 2007

NETL researchers stepped forward this year to receive three prestigious R&D 100 Awards for energy technology innovations. Another four awards went to NETL-sponsored technologies. Dubbed the "Oscars of Invention" by the *Chicago Tribune,* the R&D 100 awards stamp winning products, processes, materials, and software packages with "a mark of excellence known to industry, government, and academia as proof that the product is one of the most innovative ideas" recently introduced into the marketplace, according to *R&D Magazine.*

SEQURE™ Well-Finding Technology is a major breakthrough in carbon sequestration efforts, offering a method for quickly locating potential sites for permanently storing CO_2 emissions. Oil and gas reservoirs have trapped hydrocarbons for millions of years, a feature that makes them primary targets for trapping and storing CO_2. However, thanks to oil and gas production ongoing since 1859, millions of wells now perforate the caprock that once trapped the hydrocarbons in these reservoirs. Improperly plugged wells can provide an escape route for CO_2—threatening the potential success of geologic CO_2 sequestration.



Multiphase Flow with Interphase eXchanges (MFIX) is a much-needed software developed at NETL with support from Oak Ridge National Laboratory, Aeolus Research Inc., of Dunbar, PA, and Parsons, Inc., of Morgantown, WV.

Developing the technologies needed to use coal cleanly, efficiently, and with lower carbon emissions is essential. It is also a complex and costly process. Researchers develop designs that use solid fuels and repeatedly build and test these designs at several different scales. However, the high cost of these demonstrations limits the opportunities engineers have to test innovative designs of coal processing reactions and prevents the exploration of the radical and innovative ideas needed to develop novel designs for near-zero-emissions future power plants. MFIX brings these ideas back to the table by replacing build-and-test steps with accurate and less-costly simulations.

The Armstrong Process is a continuous process that is low temperature, low pressure, and low cost. It also lends itself to a variety of applications, particularly NETL's work with the U.S. Army Tank and Automotive Command and Army Research Laboratory in developing armorplate. Titanium armorplate is valued for its light weight, high corrosion resistance, and superior ballistic properties. The reduced cost of the Armstrong Process makes titanium a practical choice as well. Work is currently ongoing to develop titanium body armor.

The Armstrong Process was developed jointly by NETL, International Titanium Powder, Rockport, IL; BAE Systems, Rockville, MD; AMETEK, Paoli, PA; Red Devil Brakes, Mount Pleasant, PA; and Oak Ridge National Laboratory.

Low-Swirl Combustion for Fuel Flexible Near-Zero Emissions Gas Turbines enables gas turbines from 70 kilowatts to 250+ megawatts to run on almost any gaseous hydrocarbon, including those derived from landfills, biomass, refineries, and pure hydrogen. In addition to being affordable, low-swirl combustion is also one of the only gas turbine technologies to demonstrate significant reduction of NOx and other greenhouse gas emissions. The technology was developed by Lawrence Berkeley National Laboratory and Solar Turbine with support from NETL through DOE's Office of Electricity Delivery and Energy Reliability.

NO_xTrac™ detects NO_x in the parts-per-billion range, making possible quick adjustments to fossil-fuel-burning power stations and other applications to reduce or eliminate NO_x in exhaust gases. NOxTrac displays no cross-sensitivity to carbon monoxide, CO_2, or hydrocarbons. The technology was developed by researchers at Ohio State University's Department of Chemical Engineering in cooperation with NETL.

PureCycle™, a power cycle developed by UTC Power, uses a moderate-temperature heat source to generate electricity. As part of work performed in cooperation with NETL for the Office of Electricity Delivery and Energy Reliability, UTC engineers demonstrated that an organic Rankine cycle—a closed system that uses a working fluid to convert waste heat energy into electrical energy—can boost microturbine system efficiency more than 5 percentage points. This helped confirm the viability of PureCycle technology, which is now recovering geothermal energy at Chena Hot Springs Resort near Fairbanks, AK—site of the lowest-temperature geothermal resource ever used for commercial power generation.

A long-life, semi-active plate valve for reciprocating compressors was developed by Southwest Research Institute under the Advanced Reciprocating Compression Technology program managed by NETL. The semi-active plate valve replaces current passive compressor valves, which are prone to fatigue failure and require frequent replacement. The technology will cut valve replacement costs up to 90 percent over conventional valves typically used in the gas compression industry.

Awards & Recognition

Acknowledgements of Success

Salt Scar Remediation Earns NETL Chairman's Stewardship Award—NETL received a Chairman's Stewardship Award from the Interstate Oil and Gas Compact Commission (IOGCC) for work completed in partnership with Kansas Corporation Commission and ALL Consulting in the remediation of "salt scars"—soil contaminated by saltwater during historic oil and natural gas production. The team designed the online Site Specific Remediation Planner to give oil and gas operators and landowners economic recommendations for repairing salt scars through soil manipulation, chemical amendments, and revegetation. The award is the highest IOGCC honor conferred for exemplary achievement in environmental stewardship. It was presented to NETL Director Carl Bauer by Chairman Dave Freudenthal, Governor of Wyoming, at the IOGCC Annual Meeting held October 15–17, 2006, in Austin, TX.

NETL Honored for Excellence in Technology Transfer—NETL merited two highly esteemed awards from the Federal Laboratory Consortium (FLC) in 2007. The awards were presented on May 17 at the FLC National Meeting in Arlington, TX.

- Carl Bauer, Director of NETL, accepted one of FLC's three 2007 Laboratory Director of the Year awards. The highly competitive and prestigious award recognizes leadership excellence in both the direction and achievement of a facility's technology transfer program. Director Bauer's award honors his work in facilitating the transfer of technology from NETL through CRADAs and other cooperative agreements, promoting early licensing of commercially relevant innovation through the NETL patent process, personally informing and updating interested stakeholders through presentations on promising NETL technologies, and encouraging information exchange among NETL researchers and stakeholders.

- Dr. Stephen Zitney of NETL accepted a 2007 FLC Excellence in Technology Transfer Award for innovative effort in transferring the Advanced Process Engineering Co-Simulator (APECS) to the private sector. Developed at NETL in collaboration with private industry and the university community, APECS is an integrated software suite that combines the power of process simulation with high-fidelity computational fluid dynamics, advanced visualization, and high-performance computing for improved design, analysis, and optimization of process engineering systems. NETL engineers are applying this technology to reduce the time, cost, and technical risk of developing high-efficiency, near-zero-emissions power plants.

NETL Accepts Prestigious Award for Environmental Stewardship—NETL was honored by the American Association of Petroleum Geologists for supporting and funding the Regional Carbon Sequestration Partnerships, which seek to reduce greenhouse gas intensity in North America. The regional partnerships have identified potential storage capacity for more than 3.5 trillion tons of CO_2 in geologic formations throughout the United States and Canada. The partnerships have designed 25 field trials to prove the capacity and suitability of these formations for safe and permanent CO2 storage. In addition, the partnerships are beginning to examine the technologies, regulations, and infrastructure components needed to manage CO_2 sequestration. John Litynski, NETL program coordinator for the regional partnerships, accepted the association's 2007 Corporate Award for Excellence in Environmental Stewardship during its annual convention April 1–4, 2007, in Long Beach, CA.

NETL Employee Recognized for Contributions to Federal Workforce—Project Manager Paula Flenory accepted the Pittsburgh Federal Executive Board's Professional Employee Non-supervisory award on August 23 at the board's 2007 Federal Women of the Year awards luncheon, an Equal Employment Opportunity and Diversity event. Ms. Flenory has been an NETL project manager since 1993 and for the past 10 years has managed the University Coal Research program, which has provided internships to more than 600 students—many of them women—as they pursue degrees in science and engineering.

Ms. Flenory is also a founding member of NETL's Minority Mentoring and Internship program. The program provides long-term, on-the-job training and mentoring opportunities for minorities at NETL while supporting their development as highly trained candidates for permanent employment. Federal Executive Boards across the nation promote communication and collaboration among federal agencies outside of Washington, D.C.; the Pittsburgh Federal Executive Board comprises more than 100 area federal agencies and over 20,000 federal employees.

NETL Research Paper Named "Best" at American Chemical Society Conference—Authors from NETL and the University of Pittsburgh, who worked together to evaluate various preparation techniques for the oxygen carrier of chemical-looping combustion processes, received the American Chemical Society's prestigious Glenn Award for the quality, innovation, and presentation of their research. Oxygen carriers transfer oxygen from air to fossil fuel without involving other constituents of air during combustion. The empirical study, which considered both conventional techniques and a technique involving nanocomposites, was completed under the NETL University Research Initiative. The research findings show that the nanoscale composites adsorb oxygen up to 100 times faster than conventional carriers. As a result, the new carriers hold great potential for clean energy applications. Each author received a monetary award and a plaque at the 234th American Chemical Society National Meeting and Exhibition held in Boston, MA, August 19–23, 2007.

NETL Partnership Receives Award for Novel Energy Solution—Officials of the Energy Solutions Center presented the organization's 2006 Partnership Award to representatives of NETL, Blue Mountain Energy, Inc., Oak Ridge National Laboratory, and Southwest Gas Corporation for combined support and develop-ment of gas-engine-driven air conditioner (GEDAC) technology. The Energy Solutions Center is a nonprofit organization of energy utilities and equip-ment manufacturers focused on the introduction of new energy solutions to residential, commercial, and industrial energy users. A family of residential and commercial GEDAC units and related products is being developed for operation in high-temperature regions, such as the desert climate of the southwest-ern United States. NETL manages the project for the Office of Electricity Delivery and Energy Reliability. The award was presented February 1, 2007, in Las Vegas, NV

Awards & Recognition

Acknowledgements of Success

Project Performers Receive Two Engineering Achievement Awards —Officials from Great River Energy and Barr Engineering Company were presented with two separate awards: the Minnesota Society of Professional Engineers Award and the 2007 Engineering Excellence Award conferred by the American Council of Engineering Companies of Minnesota. Officials received both awards in recognition of their outstanding achievement in the design, construction, and operation of a prototype lignite coal dryer that could offer significant benefits to the U.S. power industry with regard to efficiency improvements and emissions reduction. The technology, which uses waste heat to reduce the moisture in lignite so that more power can be produced from the fuel, is being demonstrated at the Great River Energy Coal Creek Station in Underwood, ND, under NETL's Clean Coal Power Initiative.

Multi-Pollutant Control Project Garners Conservation Award—We Energies, a subsidiary of Wisconsin Energy Corporation, received the 2006 Corporate Conservation Award from the Superior Watershed Partnership, a nonprofit organization dedicated to protecting and restor-ing Upper Peninsula rivers and watersheds. The honor was bestowed at the partnership's annual meeting on January 25, 2007, to recognize the environmental benefits offered by the mercury-removal technology TOXECON™. TOXECON is a patented technology developed in cooperation with NETL by the Electric Power Research Institute as a low-cost retrofit option that achieves up to 90 percent mercury control at coal-fired power plants. It is being tested at full scale at the We Energies Presque Isle Power Plant, Marquette, MI, under NETL's Clean Coal Power Initiative.

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Two Technologies Selected for Prestigious Meritorious Engineering Awards—Since 1971, annual awards have been presented by Hart Energy Publishing's monthly *E&P* magazine to recognize the world's best new tools and techniques for finding, drilling, and producing oil and gas wells. The follow-ing technologies, developed in cooperative agreements with NETL, received 2007 awards:

- The super cement field-tested by investigators at CSI Technologies, LLC, was selected for a 2007 Special Meritorious Award for Engineering Innovation. Outperforming widely used Portland-based cements, the epoxy resin-based Ultra Seal®-R wellbore sealant solves difficult downhole problems and lowers the overall maintenance costs of high-temperature, high-pressure well completions.

- Cutting-edge seismic imaging technology developed at 3DGeo Development, Inc., was also selected for an award. By unpacking more of the information available in a three-dimensional seismic wave than was possible with previous technologies, the 3DGeo technology offers a way to obtain images of deep and complex gas-bearing structures with higher precision and resolution than the current industry standard offers—improving pre-drill evaluation of a deep prospect's location, size, and hydrocarbon charge.

Methane Hydrate Study Is Best Paper in *The Leading Edge*—The Society of Exploration Geophysicists (SEG) bestowed its 2006 Best Paper in *The Leading Edge* award on a team of scientists from the University of Texas, Bureau of Economic Geology. The team's paper was chosen from among the hundreds of technical papers published by SEG in *The Leading Edge* in 2006. It describes work conducted in cooperation with NETL on the use of multi-component seismic data for mapping gas hydrate accumulations in the Gulf of Mexico. The new mapping technique combines ocean-bottom cable, chirp-sonar, and new rock-physics models to estimate the concentration of hydrate in near-seafloor sediments. It will ultimately assess future hydrate resource potential. The award was presented during the 77th Annual Meeting of the SEG, held September 2007 in San Antonio, TX.

» About NETL

The National Energy Technology Laboratory is owned and operated by the U.S. Department of Energy (DOE). NETL's research 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 research activities in the United States and in more than 40 foreign countries.

NETL is a single organization comprised of three research facilities located in Albany, OR; Morgantown, WV; and Pittsburgh, PA. NETL also has offices in Tulsa, OK, and Fairbanks, AK. 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.

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